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ACCEPTANCE OF WILDLIFE CROSSING STRUCTURES

ON US HIGHWAY 93 MISSOULA, MONTANA

By

Jeremiah Pate Purdum

Bachelor of Science, Virginia Tech, Blacksburg, Virginia, 2006

Thesis

presented in partial fulfillment of the requirements

for the degree of

Master of Science
in Major, Environmental Studies

The University of Montana
Missoula, MT

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Purdum, Jeremiah P.   M.S. February 2013   Environmental Studies

Acceptance of wildlife crossing structures on US Highway 93 Missoula, Montana

Chairperson: Len Broberg

Wildlife and humans have always interacted on the landscape. However, growing transportation infrastructure and its associated use are causing a large increase in direct and indirect effects on wildlife populations. Humans can also directly be affected, for example, through wildlife-vehicle collisions that impact human safety and lead to economic costs for individuals and society. In some cases transportation and wildlife agencies have implemented substantial mitigation measures along roadways in an attempt to reduce wildlife-vehicle collisions and to provide for safe crossing opportunities for wildlife. Wildlife-specific crossing structures are now increasingly considered in road construction. Reconstruction projects and a range of studies have reported on the effect of structural attributes on wildlife use to help guide crossing structure design and improved effectiveness. However, measuring wildlife use of structures does not account for the effect of varying population sizes or the willingness of wildlife to come close to the highways and the crossing structures. Passage success (number of successful passage attempts/number of total approach events) may be a more biologically meaningful measure of crossing structure effectiveness. I investigated the acceptance of wildlife crossing structures by wildlife species using 17 wildlife crossing structures associated with US Highway 93 on the Flathead Indian Reservation north of Missoula, Montana. Overall acceptance was high among most species including 80% or higher for black bear (*Ursus americanus*), bobcat (*Lynx rufus*), coyote (*Canis latrans)*, and white-tailed deer (*Odocoileus virginianus*) while mule deer (*Odocoileus hemionus*) exhibited a lower acceptance rate of 67%. I used logistic regression to predict the probability of acceptance given the immediate structural attributes of the crossing structures. Species showed varying relations to crossing structure attributes. White-tailed deer acceptance was most positively associated with the height of a structure. Mule deer acceptance of crossing structures was associated with their ability to see past the exit of a crossing structure and the absence of a water channel in a structure. Acceptance by a group of carnivores (black bear, coyote, and bobcat combined) showed a positive association with the height of a structure as well as the ability to see past the exit of the crossing structure. I recommend that decision makers use acceptance of structures as a parameter rather than use alone when choosing the appropriate type and dimensions of crossing structures given certain target species.

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1. Introduction

Transportation infrastructure, including highways, are an integral part of human society and are directly linked to the impact we have on the landscape and wildlife. As human population size in the United States increased, so did the transportation network and the use of this network to transport people and goods (Federal Highway Administration, 2011). Roadways change the landscape they pass through and have direct and indirect effects on wildlife (Bennet, 1991). Roads impact wildlife through direct mortality, habitat loss, and habitat fragmentation by creating a barrier to movements and through reducing habitat quality in a zone adjacent to the road (Forman et al., 2003; Forman and Alexander, 1998; Trombulak & Frissell, 2001). Although research in the United States and abroad have increased our understanding of the wide range of effects of highways on wildlife, most transportation agencies in the US focus on mitigating wildlife-vehicle collisions because of the impact on human safety and the economic costs of those collisions. This is contrasted by efforts in other countries in Europe, South America, Asia and others where more emphasis is placed on mitigating the impacts of roads and traffic on wildlife.

The impact of wildlife-vehicle collisions on human safety and the associated costs are substantial. In 1995, wildlife-vehicle collisions were estimated to cause 29,000 human injuries, 211 human fatalities, and $1 billion in property damage annually in the U.S. (Conover et al., 1995). Huijser et al. (2009) estimated ungulate-vehicle collisions alone caused $6 – $12 billion of damage annually based on estimates of one to two million vehicle collisions with larger mammals per year (Huijser et al., 2007) There has been a demand for accident, resulting in an increase in wildlife mitigation measures implemented on US highway construction and reconstruction projects including; variable message signs, detection and warning systems, wildlife fencing and crossing structures (Huijser et al., 2009). There are dozens of mitigation measures that aim to reduce the number of wildlife-vehicle collisions, but only wildlife fencing with associated crossing opportunities has been shown to be both effective and robust (Huijser et. al, 2009). Transportation agencies have begun to incorporate the use of large mammal crossing structures to maintain wildlife population connectivity for those species that cause major damage and injury in a wildlife-vehicle collision.

In summarizing current research on the effectiveness of wildlife crossing structures, Clevenger and Wierzchowski (2006) explain that many studies have described the number of species and their frequency using crossing structures (Foster and Humphrey, 1995; Goldingay, 2003; Ng et al., 2004; Taylor et al., 2003), associating use, or passage events, with effectiveness. This measure does not take into account the population levels in the surrounding landscape nor the willingness of those species to approach the roadway or crossing structure. More recently, researchers have been using passage rate data as the dependent variable in identifying attributes that lead to effective crossings structures (Clevenger and Waltho, 2005, 2000; Rodrıguez et al., 1996; Yanes et al., 1995). Some have included expected passage rates in their analysis, taking into account the population levels in the surrounding landscapes, in analyzing effective crossing structures and their attributes (Clevenger and Waltho 2005, 2000). Researchers are beginning to monitor the approaches to crossing structures to detect acceptance rates of species in response to certain crossing structure attributes (Donaldson, 2005; Gagnon et al., 2011 Gordon & Anderson, 2003). Acceptance rates are the percentage of successful crossing events out of the total number of approach events captured. By understanding acceptance rates and associated crossing structure characteristics, wildlife managers and highway planners will be better able to choose and install crossing structures that facilitate greater movement of wildlife species through the surrounding landscape. Acceptance rates provide an additional dimension for use in the process of designing and implementing specific crossing structure projects.

Previous studies of crossing structure use have found varying effects of crossing structure attributes and landscape variables on wildlife use of crossing structures. Some species will traverse crossing structures of various sizes, while some species exhibit preference for crossing structures of specific dimensions. In Alberta, Canada, along the Trans-Canada Highway, crossing structures that were high, wide and short showed increased performance indices for wolves, elk, and deer (Clevenger and Waltho, 2005). Other studies have combined species into guilds that show or are expected to show similar responses to crossing structure use (Clevenger and Waltho, 2000; Ng et al., 2003). Until recently, there has been little research on the effects of structural attributes on acceptance rates of different wildlife species. Studies using acceptance rates have been somewhat limited, using a limited number (< 6) (Dodd et al., 2010; Gagnon et al., 2011; Gordon and Anderson, 2003); limited monitoring periods (4 days per month) (Ng et al., 2004); or limited range of crossing structure dimensions (Dodd et al., 2010; Gagnon et al., 2011) The reconstruction and monitoring project on US Highway 93 in northwestern Montana provided an opportunity to observe wildlife approach and use of 17 wildlife crossing structures in a human dominated landscape. My objectives included: 1) measuring acceptance rates of wildlife species at crossing structure entrances and 2) identifying the physical characteristics of structures that are associated with higher acceptance rates. My research provides additional information to our understanding of crossing structure use by wildlife species by incorporating increased sample sizes of crossing structures monitored and more diverse crossing structure types, while focusing on site specific characteristics that facilitate acceptance; thus improving the overall understanding of crossing structure effectiveness.

2. Methods

2.1 Study area

The study area involves 90.6km of US Highway 93 from Evaro, Montana, USA (47.035189, -114.159321) north to Polson, Montana (47.694409, -114.159321). This road section located in Lake and Missoula Counties, is fully contained in the Flathead Indian Reservation with various private, tribal, state and federal lands adjacent to the road. From October 2004 to November 2010 the Montana Department of Transportation (MDT) reconstructed 8 portions of US 93 to accommodate higher traffic volumes. In the process they added 41 wildlife crossing structures on these sections of highway. Mitigation measures installed along the entire portion of the reconstructed US 93 include 41 fish and wildlife crossing structures (including 1 wildlife overpass), 13.4 km of road with wildlife exclusion fencing with wildlife guards and jump-outs bordering both sides of the roadway. The post-construction state of US 93 includes sections of; 4 lane divided and undivided highway, 3 lanes (middle lane a turn lane) and two lane undivided highway. In 2011, MDT Annual Traffic Report shows an Annual Average Daily Traffic volume (AADT) of 6,892 vehicles for monitoring station A-08 located 800m south of Ravalli, Montana (Montana Department of Transportation, 2011). This station reported a monthly low average daily number of vehicles of 4,915 for January and a high of 9,452 vehicles during July. Speed limits vary from 112 km per hour on the highway portions to 40 to 47km per hour in towns. The reservation is bounded to the east by the Mission Mountain Range with elevations up to 2,993 m, Flathead Lake to the north at an elevation of 882 m, a valley bottom transitioning to mountain foothills to the east, and the Rattlesnake Divide Mountain Range to the south. The regional climate is dominated by Pacific maritime systems, with 305mm of precipitation in the west to over 2.54m in the mountainous east. Average minimum monthly temperatures ranged from -8.2 ° C in winter to 9.7° C in summer, and average maximum monthly temperatures ranged from -0.7° C in winter to 29.1° C in summer; average annual precipitation was 403.4mm for a weather station located in St. Ignatius, Montana (WRCC, 2006). Vegetation communities on the Flathead Indian Reservation include: shrubs, grasslands, wetlands, riparian areas, and subalpine communities. A notable complex of wetlands and glacial "pothole" lakes (Ninepipe area) also occurs on the section of roadway south of Ronan, Montana. Land uses include agriculture, urban development, and residential use. Mammals present in the area include; white-tailed deer (*Odocoileus virginianus*), mule deer (*Odocoileus hemionus*), elk (*Cervus elaphus*), moose (*Alces alces*), coyote (*Canis latrans*), black bear (*Ursus americanus*), grizzly bear (*Ursus arctos*), bobcat (*Lynx rufus*), raccoon (*Procyon* lotor), rabbit (*Leporidae spp*), striped skunk (*Mephitis mephitis*), mountain lion (*Puma concolor*), red fox (*Vulpes vulpes*), badger (*taxidea taxus*) and long-tailed weasel (*Mustela frenata*).

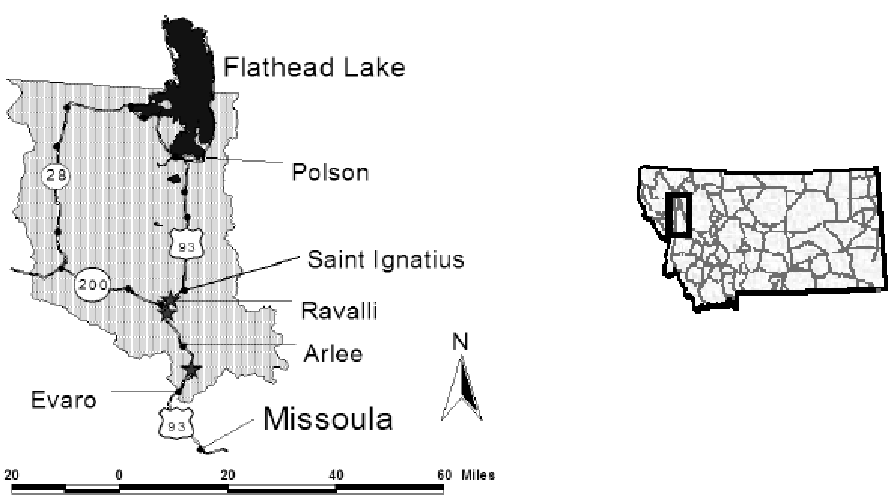

Figure 1. The Flathead Indian Reservation in western Montana, showing major highways.

2.2 Methods

To observe wildlife acceptance rates of crossing structures, infrared remote sensing cameras (HyperFire PC900 [Reconyx™, Holmen, WI]) were placed at one entrance of 17 of the 42 crossing structures available on this study area to obtain data on approaches of wildlife species. Fourteen monitored crossing structures were located in two road sections with continuous fencing in the south end of the study area and 3 isolated crossing structures not associated with continuous fencing (Figure 2). The Evaro fenced section included 4 corrugated metal arch culverts; 1 multi span bridge; and 1 wildlife overpass. The structures in the fenced Ravalli Curves include 3 corrugated metal arch culverts; 2 open span bridges; 1 corrugated plastic culvert; and 2 concrete box culverts. Isolated structures with no associated wildlife fencing consisted of 1 large concrete arch culvert and two arch culverts. Crossing structure construction was completed in 2006 (9 structures) and 2009 (8 structures) and data were collected September 2010 through May 2012. Crossing structures were evaluated for 7 physical characteristics (Table 1). Cameras were deployed from February 2010 to the end of December 2011. Each camera was set so that its field of view included the entrance of the crossing structure and a 40 degree field of view of the approach (approximately 3.4m). Cameras were set to an approximate height of 76cm to capture all movements of midsized carnivores (i.e. bobcat and coyote) and all ungulate and bear species expected in the study area. Cameras were set to take 10 photos in rapid succession (<10 sec for all photos) per event and the lag time was set to zero allowing cameras to be triggered immediately after the previous event is captured. This zero lag time allowed for better capture of groups of individuals and behavior for those animals remaining in front of the camera. Four gigabyte SD cards combined with lithium batteries enabled the cameras to operate for at least 1 month at a time. Cameras were checked monthly for memory card and battery status. Cameras were in continuous operation during the study with camera malfunctions, battery failures or memory cards becoming full creating the only down times, equaling only 2% of the available camera days.

Without a camera at both the entrance and exit of a crossing structure, I adopted a decision protocol to evaluate the outcome of an approach event, my sample unit. An approach event was any approach of the crossing structure entrance, captured by the camera(s) that was more than 5 minutes removed from a previous approach event. An approach event was defined as an acceptance if an animal entered into a crossing structure without evidence of an immediate return to the entrance area within 5 minutes of the individual or last individual in a group entering the crossing structure. Individuals or groups entering a crossing structure but returning to the entrance area were categorized as a successful crossing attempt if they did not leave the field of view of the camera before reentering the crossing structure in the original direction of travel. Rejected crossing attempts were those events where an individual was observed approaching or entering the crossing structure then immediately observed exiting the crossing structure or leaving the crossing structure entrance from the direction from which it came. Species traveling in groups (deer, raccoon, coyotes, adults with juveniles) were considered a group if they approached the crossing structure from the same direction within 5 minutes. Groups were assigned one of three outcomes: full passage, mixed passage, rejected passage. If at least one individual in a group aborted a crossing event and at least one animal crossed successfully, the group was considered split and the numbers making a successful cross were noted as well as numbers who aborted the crossing attempt. For my analysis, any group that split was considered to have an unsuccessful passage attempt as the total group did not make passage and the crossing structure served as a barrier for part of the group. Split groups were less than

5% for all species except moose (33%; 1 out of 3 approaches). This approach was more conservative than previous studies that considered passages of ≥ 50% of a group as a successful passage attempt (Dodd et al., 2010; Gagnon et al., 2011). The following parameters were recorded for each crossing event based on the images: species, number of individuals in a group, direction of travel (East or West), date, time, and outcome (acceptance/rejection). Species identifications were given a grade of possible, probable, or definite. Only those events where the species identification was definite were used for analysis.

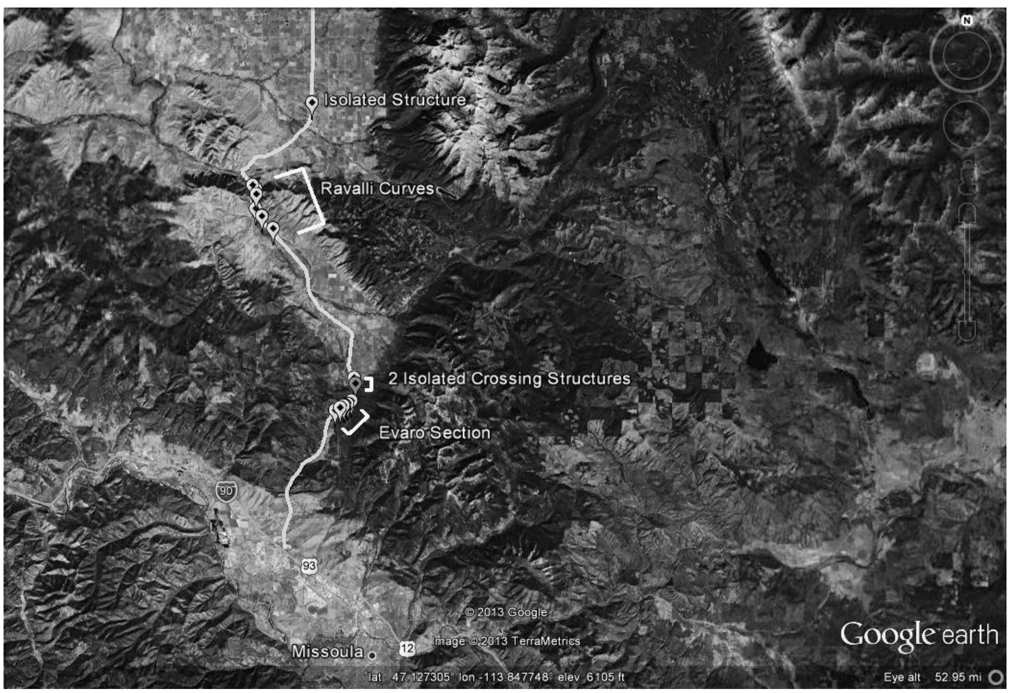

Figure 2. Study area showing locations of wildlife crossing structures on US 93, Montana, USA.

2.3 Analysis

Individual or group approach event outcomes were used to estimate acceptance and rejection rates of species for various crossing structures. Univariate logistic regression was conducted to evaluate the relationship between crossing structure attributes and acceptance rates of wildlife species that met a minimum threshold of 300 approach events. Acceptance data (passage, no passage) for each group served as the binomial response variable in logistic regression analysis (Hosmer and Lemeshow, 2000). Explanatory variables included structural attributes: height, length, width and environmental attributes: presence of water channel in structure (water; levels = yes, no), vegetative cover in the crossing structure (Floor; levels = dirt, vegetated) (Table 1). A crossing structure with a mix of vegetation and dirt or rock was considered vegetated if the vegetation covered 50% or more of the area under the crossing structure. An additional structural attribute used as an explanatory variable was the sight distance from the exit (hereafter exit view distance). This was a measure of the visible distance, as seen standing in the entrance, from the exit of the crossing structure to the nearest vegetation or slope that obstructed view at a height of 1.25meters. Exit view distance may have implications for species that prefer greater sight distances or are associated with more open or closed landscapes.

Table1. Crossing structure attributes.

Type	Height(m)	Width(m)	Length(m)	Water channel	Exit View[a] Distance	Floor	Year Completed
railroad bridge	7.5	104.2	14.9	yes	10.0	vegetated	2009
arch	4.0	9.4	31.9	yes	17.1	dirt	2009
arch	3.9	7.6	24.6	yes	15.6	dirt	2009
overpass	15.1	55.4	18.6	no	0.0	vegetated	2009
arch	3.3	7.5	25.0	yes	11.0	dirt	2009
arch	4.1	7.6	24.8	yes	26.4	dirt	2009
arch	3.7	7.5	29.9	yes	18.3	dirt	2009
arch	3.4	7.6	24.9	yes	15.2	dirt	2009
bridge	3.4	26.8	13.2	yes	39.1	vegetated	2006
arch	3.4	6.6	22.2	yes	14.6	dirt	2006
arch	3.2	6.4	26.7	no	10.4	dirt	2006
bridge	3.8	30.0	13.6	yes	16.5	vegetated	2006
small culvert	1.5	1.2	21.4	no	5.5	dirt	2006
small culvert	1.5	1.9	21.8	no	7.4	dirt	2006

small culvert	1.1	1.8	25.2	no	1.0	dirt	2006
arch	3.2	7.5	18.3	yes	8.4	dirt	2006
arch	3.4	7.4	19.3	yes	12.0	dirt	2006

a. Exit view distance = the distance from the exit of a crossing structure to the furthest visible distance

Logistic regression of the univariate effects of structural attributes was used to evaluate acceptance rates per species and investigate influence of individual factors on acceptance (Hosmer and Lemeshow, 2000). Prior to multivariate logistic regression, attributes were checked for multicollinearity through correlation analyses. Due to the high correlation of width with length and exit view (r=-0.627 and r=0.671 respectively), width was chosen to be removed from multivariate logistic regression (See Appendix- Table A). To reduce the influence of pseudoreplication and variability at individual crossing structures, generalized linear mixed models were used, accounting for a random effect of individual crossing structures (Bolker et al. 2009). Backwards stepwise regression was then used to reduce the full model, including all crossing structure attributes, for each species or species group to develop a model of predicted crossing success. Variables were dropped one-by-one from the saturated model until all remaining variables were significant at $\alpha = 0.05$ (Hosmer and Lemeshow, 2000). Logistic regression reference levels for categorical variables were set to the most basic crossing structure installation; no water channel present and a dirt floor. To measure the performance of the final model the proportion of correct predictions, or overall predictive success, and specificity were measured via a resubstition confusion matrix output (Fielding and Bell, 1997). As an additional comparison the $R^2_{GLMM(c)}$ coefficient of determination, using the 'MuMIn' package (Barton, 2013) in R version 2.15.0 (R Core Team 2012), was given to describe the variance explained by the entire model (Nakagawa and Schielzeth, 2013). All other statistical analyses were conducted using R (R Core Team 2012, v2.15.0).

3. Results

Remote cameras were operational for a total of 9,935 days accounting for 98% of the possible 10,132 days. Events such as battery or camera failure, SD cards becoming full and vandalism caused cameras to stop sampling. I observed the approach behavior for 6,515 approach events by wildlife species at the crossing structure entrances. White-tailed deer accounted for a majority of approaches (5,399 approaches; 81.0%) followed by mule deer (492 approach events; 7.1%). Coyote comprised 3.1% of approach events with 204 events, followed by black bear (181 events; 2.8%), and bobcat (98 events; 1.5%). Other wildlife species with observed approach events included: 196 raccoon, 42 rabbits, 31 striped skunk, 13 mountain lion13 elk, 2 red fox, 3 moose, and 1 long-tailed weasel. Eight events were unidentified species and were not used in analysis. Domestic species (cats and dogs) were observed approaching 570 and 298 times respectively. Domestic dog approaches included 83 events with associated human activity, while humans accounted for an additional 179 events (including 3 on horseback, 2 with motor-vehicles, and 3 on all-terrain vehicles); excluding research personnel events. Overall crossing structure acceptance by all species was 83%, influenced largely by white-tailed deer with 85% acceptance over all crossing structures (See Appendix – Table B).

Hierarchical cluster analysis showed domestic species used similar structures as raccoon and white-tailed deer while mule deer used similar structures as striped skunk, mountain lions and rabbits (Figure 3). Coyote, bobcats, and black bear were observed using similar structures as well. Combined sample sizes for this group (hereafter carnivore group) met the minimum sample size of n>300 for continued analysis (204 coyote, 181 black bear, 98 bobcat events, total= 483 events).

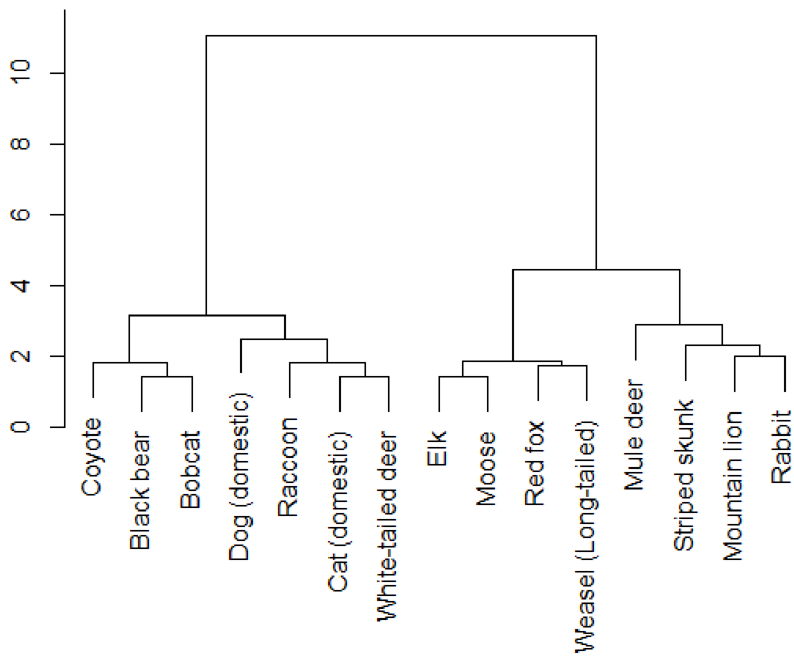

Figure 3. Dendrogram from agglomerative hierarchical cluster analysis using Ward's minimum variance with Euclidean distances illustrating co-occurrence of wild and domestic species at crossing structures along US 93, Montana, USA.

Univariate analysis provided initial information for crossing structure variables and their effect on success of white-tailed deer, mule deer and the carnivore group (Table 2). Though results of univariate logistic regressions may be confounded by other variables, it does provide a starting point for examining the data. Univariate results provide a comparison to coefficients from multivariate analysis; looking for large changes in coefficient estimates, including sign changes (indicating possible confounding variables); as well as for relationship between variable removed from backwards stepwise linear regression and acceptance. For white-tailed deer (n=5,470) all the variables considered were significant at $\alpha = 0.05$. White-tailed deer showed higher success at short, wide, and tall crossing structures, with larger exit view distances that had a water channel and vegetated floor. Mule deer (n=496) showed no significant variables, with the positive influence of exit view distance being marginally significant (p-value = 0.068). The carnivore group showed significant p-values for all measured variables except length and a marginally significant estimate for vegetated floor (p-value = 0.067), showing increased acceptance given wide, tall crossings structures with a water channel present. White-tailed deer seem to show some interaction with all of the variables that were measured, while mule deer acceptance of the structures does not seem to be associated with the variables included in the analyses.

Table 2. Results from univariate logistic regression for crossing structure attributes associated with successful use of wildlife crossing structures by white-tailed deer, mule deer, and 3 carnivores at wildlife crossing structures on US 93 Montana, USA. Estimates of coefficients, standard error, Z value, P-value and odds of successful crossing.

		Estimate	Std. Error	Z value	Pr(>|z|)	odds
White-tailed Deer	(Intercept)	1.86	0.051	36.14	<0.001	
	Length Intercept	3.61	0.231	15.645	<0.001	
	Length	-0.08	0.010	-8.058	<0.001	0.92
	Width Intercept	1.45	0.089	16.184	<0.001	
	Width	0.04	0.008	5.126	<0.001	1.04
	Height Intercept	0.24	0.626	0.387	0.699	
	Height	0.47	0.181	2.579	0.010	1.60
	Exit View Intercept	1.31	0.114	11.426	<0.001	
	Exit View Distance	0.03	0.006	5.064	<0.001	1.03
	Water intercept	-0.47	0.329	-1.428	0.153	
	Water channel (present)	2.38	0.333	7.128	<0.001	10.76
	Floor intercept	1.73	0.055	31.134	<0.001	
	Floor (vegetated)	0.73	0.150	4.868	<0.001	2.07
Mule Deer	(Intercept)	0.74	0.098	7.585	<0.001	
	Length intercept	0.40	0.337	1.181	0.238	
	Length	0.02	0.017	1.057	0.291	1.02
	Width intercept	0.74	0.180	4.118	<0.001	
	Width	0.00	0.008	-0.012	0.990	0.999
	Height Intercept	0.11	1.010	0.113	0.910	
	Height	0.18	0.286	0.622	0.534	1.19
	Exit View Intercept	0.12	0.348	0.351	0.725	
	Exit View Distance	0.04	0.024	1.825	0.068	1.04
	Water intercept	1.00	0.195	5.139	<0.001	
	Water channel (present)	-0.36	0.225	-1.578	0.115	0.70
	Floor intercept	0.74	0.139	5.323	<0.001	
	Floor (vegetated)	0.01	0.195	0.028	0.977	1.01

Carnivore	(Intercept)	1.66	0.124	13.380	<0.001	
Group	Length intercept	1.61	0.666	2.413	0.016	
	Length	0.00	0.031	0.084	0.933	1.00
	Width intercept	1.48	0.153	9.728	<0.001	
	Width	0.01	0.008	1.765	0.078	1.01
	Height intercept	1.20	0.210	5.712	<0.001	
	Height	0.13	0.052	2.423	0.015	1.14
	Exit view intercept	1.00	0.213	4.683	<0.001	
	Exit view distance	0.07	0.020	3.446	0.001	1.07
	Water intercept	1.14	0.162	7.046	<0.001	
	water channel present	1.08	0.260	4.150	<0.001	2.94
	Floor intercept	1.54	0.136	11.384	<0.001	
	Floor (vegetated)	0.63	0.346	1.831	0.067	1.88

Backward stepwise regression for white-tailed deer produced a generalized logistic mixed-effects model with one variable, height (Table 3). The large estimated coefficient and associated increase in odds for the height variable shows this relationship to be very strong. Overall predictive success was 87% (n=3245), but was dominated by true positive predictions (n=2,805) whereas specificity, or the proportion of true negatives, was only 5% (n=439). More specifically, this model accurately predicted successful crossing attempts while not accurately predicting unsuccessful crossing attempts as unsuccessful. Additionally, $R^2_{GLMM(c)}$ coefficient of determination, showing variance explained by the entire model, was moderate ($R^2_{GLMM(c)}$ = 0.306) (Nakagawa and Schielzeth, 2013).

Table 3. Backwards stepwise logistic regression output and multiplicative change in success per one unit change in the variable given all others held constant odds of successful crossing of crossing structure.

Variable	Estimate	Std. Error	z value	Pr(>|z|)	Odds
White-tailed deer (*Odocoileus virginianus*)					
Constant	-4.44	1.628	-2.729	0.006	
Height	1.58	0.475	3.327	0.001	4.86

random effect for crossing structure Variance = 1.29 SD= 1.14					
Mule deer (*Odocoileus hemionus*)					
Constant	-0.43	0.504	-0.86	0.39	
Exit view distance	0.14	0.046	3.085	0.002	1.15
Water Channel present	-1.16	0.336	-3.445	<0.001	0.31
random effect for crossing structure Variance < 0.005 SD< 0.005					
Carnivore group (*Canis latrans, Ursus americanus, Lynx* rufus)					
Constant	0.38	0.386	0.992	0.321	
Height	0.12	0.048	2.534	0.011	1.13
Exit view distance	0.09	0.028	3.25	0.001	1.10
random effect for crossing structure Variance = 0.122 SD= 0.349					

Backwards stepwise regression for mule deer produced a model with two variables, exit view distance and the presence of a water channel (Table 3). Mule deer acceptance showed a negative relationship with the presence of a water channel and a positive relationship to exit view distance. Overall predictive success was moderate, with predictive success 68% and a specificity of 8%. The conditional coefficient of determination showed the variance explained by the model was low with $R^2_{GLMM(c)} = 0.09$.

Finally, backwards stepwise regression for the carnivore group produced a model with two variables, height and exit view (Table 3). The carnivore group showed increasing acceptance for increasing height and exit view distance. Predictive success was high with 84% proportion correct, however this was due to 100% of outcomes predicted as successful and no true rejections being classified as rejections of the crossing structure, meaning specificity was equal to 0. The conditional coefficient of determination, $R^2_{GLMM(c)}$, was low at 0.161.

4. Discussion

Overall crossing structure acceptance rates were high for most species, with elk and moose being the only species with crossing acceptance below 50%, with some approaching 85-90% (black bear, bobcat and white-tailed deer). For the larger ungulates, elk and moose, I found not only low acceptance rates, but low approach rates (See Appendix – Table B). Low approach rates may be due to the presence of 4-strand livestock fencing (1 smooth wire on top, 2 barbed wires in middle, 1 smooth wire on bottom) that ties in with the continuous wildlife fencing in the forested areas where one would expect to see elk and moose approach crossing structures. In fact, cameras captured several instances of moose or elk that appear to be hindered by the livestock fence from entering the crossing structure. Structures in Arizona had much higher approach rates for elk with passage rates above 60%, possibly due to the presence of polyvinyl chloride pipes fitted on the top two strands to create elk jumps (Dodd et al., 2010; Gagnon et al., 2011). Changes in approach area designs may allow an increased number of elk and moose to approach crossing structures, though not necessarily increasing the acceptance rates for those species either.

Acceptance rates for a given species vary across studies for various reasons. Landscape differences, human activity and influence, and migratory patterns all affect wildlife acceptance rates at crossing structures. My results show higher acceptance rates for some species compared to acceptance rates of other studies. One study in Arizona State Route 260, Gagnon et al. (2011), found much lower acceptance rates for white-tailed deer than my study (39% to 85%), mule deer (55% to 67%), and coyotes (46% to 80%). The project on SR-260 had longer and higher structures (mean length (m): $90_{\text{SR-260}}$, $22_{\text{US/MT-93;}}$ mean height (m) $8.8_{\text{SR-260}}$, $3.1_{\text{US/MT-93}}$) which would suggest that length and height may be driving acceptance rates for these species across landscapes. Additionally, human activity is likely higher on the US-93 study area here. It is most likely that variation in calculating approach and acceptance rates via remote camera methods are introducing some of the variation in acceptance rates across different projects. Gagnon et al.

(2011) and Dodd et al. (2010) both observed approaches of up to 50m from the mouth of crossing structure entrances, while my study and others (Donaldson, 2011; Ng et al., 2009) have cameras set up at crossing structure entrances, observing the physical mouth and portion (20-40degrees) of view from that location. This is an important difference due to the continuous decision making process that an approach and eventual success or failure of passage entails. One may expect that the closer that an individual animal is to the mouth of a crossing structure, the higher the probability of successful passage for that individual. Approach studies either need to have a standardized approach measure or explicitly describe the approach areas observed. Due to the variety in approach fencing, topography and structure design, I recommend placing cameras immediately adjacent to the structure opening, thus reducing variation across monitoring studies.

It is notable that mule deer, often characterized as a more skittish species than white-tailed deer, had a lower acceptance rate than white-tailed, 68% to 85% respectively. Additionally, generalized linear mixed models showed low variance between crossing structures for mule deer (variance < 0.005) while white-tailed deer and carnivores showed variation among crossing structures (see appendix - Table D). It is evident that crossing structure acceptance differs between species and different attributes interact differently with species behaviors than others. By observing the approaches of each crossing structure, I was able to identify those attributes that facilitate acceptance for various species while reducing the influence of population sizes and willingness to approach crossing structures of those species in the surrounding landscape. Mule deer, who utilize dry upland grassy areas in the study area, had higher acceptance rates in structures without a water channel and with a greater exit view distance, and this appeared very consistent across all crossing structures as indicated by the low variance in the random effect. White-tailed deer, who utilize riparian corridors more often in the study area, had higher acceptance rates using taller structures. Additionally, there may be an influence of predators on the landscape that influence prey species use and acceptance of crossing structures, though evidence of crossing structures as prey-traps is weak (Little et al., 2002), there is evidence that sympatric mule deer and white-tailed deer will exhibit habitat segregation due to coyote predation during winter (Lingle 2002). My results show very dissimilar use of crossing structures by white-tailed deer and mule deer may be influenced by coyote presence on the landscape. Mule deer may actively avoid structures where they might encounter coyotes, possibly due to a greater likelihood of coyotes pursuing and attacking mule deer compared to white-tailed deer (Lingle and Pellis, 2002).

The inclusion of the exit view in multivariate logistic regression for mule deer and the carnivore group indicates the need for inclusion of visual properties of the crossing structures (Jacobson 2007). Their relative importance in the white-tailed deer and mule deer models reveal the necessity to involve sight distances for prey species and the possible importance of other presently unconsidered crossing structure site characteristics that may interact with the predator-prey dynamics. The finding that mountain lion, elk, moose and mule deer seem to use similar crossing structures in this study area may warrant further investigation of the predator-prey dynamic in the study area. This result differs from conclusions of Little et al. (2002) who found, through literature review, that predators and prey use different passages. Little et al. (2002) work in a largely protected area while my research was conducted in a human dominated landscape may show that human activity may differentially separate entire parts of the mammalian food web from each other. Similar to my results, though, Little et al. (2002) found that research must separate the influence of habitat and structural attributes before assigning differences in use solely to predator-prey dynamics.

Backwards stepwise regression produced models showing the importance of key structural attributes in increasing species acceptance of wildlife crossing structures. Specifically, the importance of height and exit view distance for multiple species and species groups. The models showed decent overall classification success and modest $R^2_{GLMM(c)}$ coefficients of determination. Classification statistics and R^2 measures inform the ability of selected models to accurately predict outcomes. This study concentrated on the physical attributes at the mouth of the crossing structure that might affect behavior of those wildlife species approaching the crossing structures. There are likely latent and unmeasured variables, possibly broader scale landscape attributes that are impacting the acceptance rates for the various species I observed. Future research will need to investigate what aspects of the surrounding landscape that are interacting with crossing structure attributes to increase or decrease acceptance rates.

It is important to realize, as Clevenger and Waltho (2005) discussed, factors facilitating movement of wildlife through crossing structures may vary across landscapes and regional variation in behavior of wildlife species may change the relationship of acceptance rates to structural attributes. Furthermore, no one structure will provide equal suitability to every species present in a specific landscape. Transportation planners and ecologists involved in highway planning and mitigation projects need tools to help them make decisions on the best types of structures to implement. Acceptance rates, the number of successful crossing events divided by total approach events, provide managers a metric to use in the decision making process that is less arbitrary and less influenced by population levels in the surrounding landscapes. By selecting a target species or multiple species, managers can select a minimum acceptance rate for the given species and then select crossing structure types and dimensions that are likely to meet those given acceptance levels. With increasing fragmentation and traffic volume, roadway mitigation measures, including wildlife crossing structures, will need to be designed and implemented with the highest possible success rates if wildlife populations are to remain even somewhat connected.

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Appendix

Table A. Correlation matrix output with Pearson correlation coefficient below the diagonal and the associated p-value for the coefficients for structural attributes of crossing structures above the diagonal.

	Height	Width	Length	Exit View
Height	-	0.070	0.805	0.013
Width	0.480	-	0.012	0.006
Length	0.070	-0.627	-	0.336
Exit.View	0.625	0.671	-0.267	-

Table B. Approach and outcome for all observed wildlife species.

	Passage			
Species	No	Yes	Total Approaches	Success
Black bear	25	161	186	86.6%
Bobcat	13	86	99	86.9%
Coyote	41	166	207	80.2%
Mule deer	162	334	496	67.3%
White-tailed deer	829	4641	5470	84.8%
Elk	9	4	13	30.8%
Red fox	1	1	2	50.0%
Moose	2	1	3	33.3%
Mountain lion	0	13	13	100.0%
Rabbit	9	29	38	76.3%
Raccoon	20	176	196	89.8%
Striped skunk	5	25	30	83.3%
Long-tailed weasel	0	1	1	100.0%
Grand Total	1116	5638	6754	83.5%

Table C. Percent acceptance and number of approaches for the different species for each crossing structure type along US 93 North, Montana, USA.

	Arch		Bridge		Overpass		Small Culvert (<2m tall)		Species Totals	
Bear black	97.0%	100	87.0%	23	71.4%	14	68.2%	44	86.7%	181
Bobcat	89.7%	39	88.9%	18	100.0%	6	82.9%	35	87.8%	98
Coyote	85.6%	104	95.0%	20	96.3%	27	54.7%	53	79.9%	204
Deer mule	68.7%	233	67.8%	242		0	20.0%	5	67.7%	492
Deer white-tail	85.5%	2517	86.6%	1929	80.1%	946	5.3%	19	84.7%	5399

Elk	100.0%	1		0	27.3%	11	0.0%	1	30.8%	13
Moose		0		0	0.0%	2		0	0.0%	2
Mountain lion	100.0%	3	100.0%	9		0	100.0%	1	100.0%	13
Grand Total	84.7%	2997	84.7%	2241	79.8%	1006	57.6%	158	83.3%	6402

Table D. Random effects intercepts for acceptance rates for crossing structures for white-tailed deer and carnivore group.

White-tailed deer		Carnivore Group	
	Intercept		Intercept
EastFrkFinley	-6.12	Finley1	0.51
Finley1	-4.87	Finley2	0.54
Finley2	-4.77	Finley3	0.38
Finley3	-5.01	Finley4	0.19
Finley4	-5.79	Overpass	0.35
PstCr1	-2.47	PstCr1	0.25
RC381	-2.72	Railroad bridge	0.27
RC396	-3.81	RC381	0.39
RC406	-4.28	RC396	0.45
RC422	-5.19	RC406	0.66
RC426	-4.92	RC422	0.36
RC427	-4.75	RC426	0.43
RC431	-4.23	RC427	-0.14
RC432	-3.63	RC431	0.42
Schley	-3.97	RC432	0.56
		Schley	0.41