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STRUCTURES ON US HIGHWAY 93  
MISSOULA, MONTANA

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**ACCEPTANCE OF WILDLIFE CROSSING STRUCTURES  
ON US HIGHWAY 93 MISSOULA, MONTANA**

By

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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  
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## **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 **1. Introduction**

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

16 The impact of wildlife-vehicle collisions on human safety and the associated costs are  
17 substantial. In 1995, wildlife-vehicle collisions were estimated to cause 29,000 human injuries,  
18 211 human fatalities, and \$1 billion in property damage annually in the U.S. (Conover et al.,  
19 1995). Huijser et al. (2009) estimated ungulate-vehicle collisions alone caused \$6 – \$12 billion  
20 of damage annually based on estimates of one to two million vehicle collisions with larger  
21 mammals per year (Huijser et al., 2007) There has been a demand for accident, resulting in an  
22 increase in wildlife mitigation measures implemented on US highway construction and  
23 reconstruction projects including; variable message signs, detection and warning systems,

24 wildlife fencing and crossing structures (Huijser et al., 2009). There are dozens of mitigation  
25 measures that aim to reduce the number of wildlife-vehicle collisions, but only wildlife fencing  
26 with associated crossing opportunities has been shown to be both effective and robust (Huijser  
27 et. al, 2009). Transportation agencies have begun to incorporate the use of large mammal  
28 crossing structures to maintain wildlife population connectivity for those species that cause  
29 major damage and injury in a wildlife-vehicle collision.

30 In summarizing current research on the effectiveness of wildlife crossing structures,  
31 Clevenger and Wierzchowski (2006) explain that many studies have described the number of  
32 species and their frequency using crossing structures (Foster and Humphrey, 1995; Goldingay,  
33 2003; Ng et al., 2004; Taylor et al., 2003), associating use, or passage events, with effectiveness.  
34 This measure does not take into account the population levels in the surrounding landscape nor  
35 the willingness of those species to approach the roadway or crossing structure. More recently,  
36 researchers have been using passage rate data as the dependent variable in identifying attributes  
37 that lead to effective crossings structures (Clevenger and Waltho, 2005, 2000; Rodriguez et al.,  
38 1996; Yanes et al., 1995). Some have included expected passage rates in their analysis, taking  
39 into account the population levels in the surrounding landscapes, in analyzing effective crossing  
40 structures and their attributes (Clevenger and Waltho 2005, 2000). Researchers are beginning to  
41 monitor the approaches to crossing structures to detect acceptance rates of species in response to  
42 certain crossing structure attributes (Donaldson, 2005; Gagnon et al., 2011 Gordon & Anderson,  
43 2003). Acceptance rates are the percentage of successful crossing events out of the total number  
44 of approach events captured. By understanding acceptance rates and associated crossing structure  
45 characteristics, wildlife managers and highway planners will be better able to choose and install  
46 crossing structures that facilitate greater movement of wildlife species through the surrounding

47 landscape. Acceptance rates provide an additional dimension for use in the process of designing  
48 and implementing specific crossing structure projects.

49         Previous studies of crossing structure use have found varying effects of crossing structure  
50 attributes and landscape variables on wildlife use of crossing structures. Some species will  
51 traverse crossing structures of various sizes, while some species exhibit preference for crossing  
52 structures of specific dimensions. In Alberta, Canada, along the Trans-Canada Highway,  
53 crossing structures that were high, wide and short showed increased performance indices for  
54 wolves, elk, and deer (Clevenger and Waltho, 2005). Other studies have combined species into  
55 guilds that show or are expected to show similar responses to crossing structure use (Clevenger  
56 and Waltho, 2000; Ng et al., 2003). Until recently, there has been little research on the effects of  
57 structural attributes on acceptance rates of different wildlife species. Studies using acceptance  
58 rates have been somewhat limited, using a limited number (< 6) (Dodd et al., 2010; Gagnon et  
59 al., 2011; Gordon and Anderson, 2003); limited monitoring periods (4 days per month) (Ng et  
60 al., 2004); or limited range of crossing structure dimensions (Dodd et al., 2010; Gagnon et al.,  
61 2011) The reconstruction and monitoring project on US Highway 93 in northwestern Montana  
62 provided an opportunity to observe wildlife approach and use of 17 wildlife crossing structures  
63 in a human dominated landscape. My objectives included: 1) measuring acceptance rates of  
64 wildlife species at crossing structure entrances and 2) identifying the physical characteristics of  
65 structures that are associated with higher acceptance rates. My research provides additional  
66 information to our understanding of crossing structure use by wildlife species by incorporating  
67 increased sample sizes of crossing structures monitored and more diverse crossing structure  
68 types, while focusing on site specific characteristics that facilitate acceptance; thus improving the  
69 overall understanding of crossing structure effectiveness.

70

71 **2. Methods**

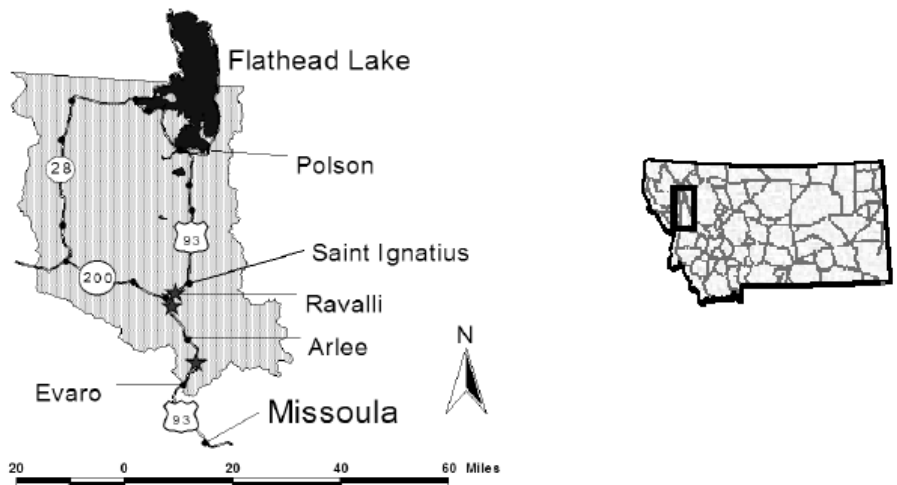
72 *2.1 Study area*

73 The study area involves 90.6km of US Highway 93 from Evaro, Montana, USA (47.035189, -  
74 114.159321) north to Polson, Montana (47.694409, -114.159321). This road section located in  
75 Lake and Missoula Counties, is fully contained in the Flathead Indian Reservation with various  
76 private, tribal, state and federal lands adjacent to the road. From October 2004 to November  
77 2010 the Montana Department of Transportation (MDT) reconstructed 8 portions of US 93 to  
78 accommodate higher traffic volumes. In the process they added 41 wildlife crossing structures on  
79 these sections of highway. Mitigation measures installed along the entire portion of the  
80 reconstructed US 93 include 41 fish and wildlife crossing structures (including 1 wildlife  
81 overpass), 13.4 km of road with wildlife exclusion fencing with wildlife guards and jump-outs  
82 bordering both sides of the roadway. The post-construction state of US 93 includes sections of;  
83 4 lane divided and undivided highway, 3 lanes (middle lane a turn lane) and two lane undivided  
84 highway. In 2011, MDT Annual Traffic Report shows an Annual Average Daily Traffic volume  
85 (AADT) of 6,892 vehicles for monitoring station A-08 located 800m south of Ravalli, Montana  
86 (Montana Department of Transportation, 2011). This station reported a monthly low average  
87 daily number of vehicles of 4,915 for January and a high of 9,452 vehicles during July. Speed  
88 limits vary from 112 km per hour on the highway portions to 40 to 47km per hour in towns. The  
89 reservation is bounded to the east by the Mission Mountain Range with elevations up to 2,993 m,  
90 Flathead Lake to the north at an elevation of 882 m, a valley bottom transitioning to mountain  
91 foothills to the east, and the Rattlesnake Divide Mountain Range to the south. The regional  
92 climate is dominated by Pacific maritime systems, with 305mm of precipitation in the west to



93 over 2.54m in the mountainous east. Average minimum monthly temperatures ranged from -8.2  
 94 ° C in winter to 9.7° C in summer, and average maximum monthly temperatures ranged from -  
 95 0.7° C in winter to 29.1° C in summer; average annual precipitation was 403.4mm for a weather  
 96 station located in St. Ignatius, Montana (WRCC, 2006). Vegetation communities on the Flathead  
 97 Indian Reservation include: shrubs, grasslands, wetlands, riparian areas, and subalpine  
 98 communities. A notable complex of wetlands and glacial “pothole” lakes (Ninepipe area) also  
 99 occurs on the section of roadway south of Ronan, Montana. Land uses include agriculture, urban  
 100 development, and residential use. Mammals present in the area include; white-tailed deer  
 101 (*Odocoileus virginianus*), mule deer (*Odocoileus hemionus*), elk (*Cervus elaphus*), moose (*Alces*  
 102 *alces*), coyote (*Canis latrans*), black bear (*Ursus americanus*), grizzly bear (*Ursus arctos*),  
 103 bobcat (*Lynx rufus*), raccoon (*Procyon lotor*), rabbit (*Leporidae spp*), striped skunk (*Mephitis*  
 104 *mephitis*), mountain lion (*Puma concolor*), red fox (*Vulpes vulpes*), badger (*taxidea taxus*) and  
 105 long-tailed weasel (*Mustela frenata*).

106



107

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

109

110 2.2 *Methods*

111 To observe wildlife acceptance rates of crossing structures, infrared remote sensing  
112 cameras (HyperFire PC900 [Reconyx<sup>TM</sup>, Holmen, WI]) were placed at one entrance of 17 of the  
113 42 crossing structures available on this study area to obtain data on approaches of wildlife  
114 species. Fourteen monitored crossing structures were located in two road sections with  
115 continuous fencing in the south end of the study area and 3 isolated crossing structures not  
116 associated with continuous fencing (Figure 2). The Evaro fenced section included 4 corrugated  
117 metal arch culverts; 1 multi span bridge; and 1 wildlife overpass. The structures in the fenced  
118 Ravalli Curves include 3 corrugated metal arch culverts; 2 open span bridges; 1 corrugated  
119 plastic culvert; and 2 concrete box culverts. Isolated structures with no associated wildlife  
120 fencing consisted of 1 large concrete arch culvert and two arch culverts. Crossing structure  
121 construction was completed in 2006 (9 structures) and 2009 (8 structures) and data were  
122 collected September 2010 through May 2012. Crossing structures were evaluated for 7 physical  
123 characteristics (Table 1). Cameras were deployed from February 2010 to the end of December  
124 2011. Each camera was set so that its field of view included the entrance of the crossing  
125 structure and a 40 degree field of view of the approach (approximately 3.4m). Cameras were set  
126 to an approximate height of 76cm to capture all movements of midsized carnivores (i.e. bobcat  
127 and coyote) and all ungulate and bear species expected in the study area. Cameras were set to  
128 take 10 photos in rapid succession (<10 sec for all photos) per event and the lag time was set to  
129 zero allowing cameras to be triggered immediately after the previous event is captured. This zero  
130 lag time allowed for better capture of groups of individuals and behavior for those animals  
131 remaining in front of the camera. Four gigabyte SD cards combined with lithium batteries  
132 enabled the cameras to operate for at least 1 month at a time. Cameras were checked monthly for

133 memory card and battery status. Cameras were in continuous operation during the study with  
134 camera malfunctions, battery failures or memory cards becoming full creating the only down  
135 times, equaling only 2% of the available camera days.

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

156 5% for all species except moose (33%; 1 out of 3 approaches). This approach was more  
157 conservative than previous studies that considered passages of  $\geq 50\%$  of a group as a successful  
158 passage attempt (Dodd et al., 2010; Gagnon et al., 2011). The following parameters were  
159 recorded for each crossing event based on the images: species, number of individuals in a group,  
160 direction of travel (East or West), date, time, and outcome (acceptance/rejection). Species  
161 identifications were given a grade of possible, probable, or definite. Only those events where the  
162 species identification was definite were used for analysis.

163

164



165

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

167

168

### 169 2.3 Analysis

170

171

Individual or group approach event outcomes were used to estimate acceptance and rejection rates of species for various crossing structures. Univariate logistic regression was

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

185 Table 1. Crossing structure attributes.

Type	Height(m)	Width(m)	Length(m)	Water channel	Exit View <sup>a</sup> 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

186 a. Exit view distance = the distance from the exit of a crossing structure to the furthest visible distance  
187

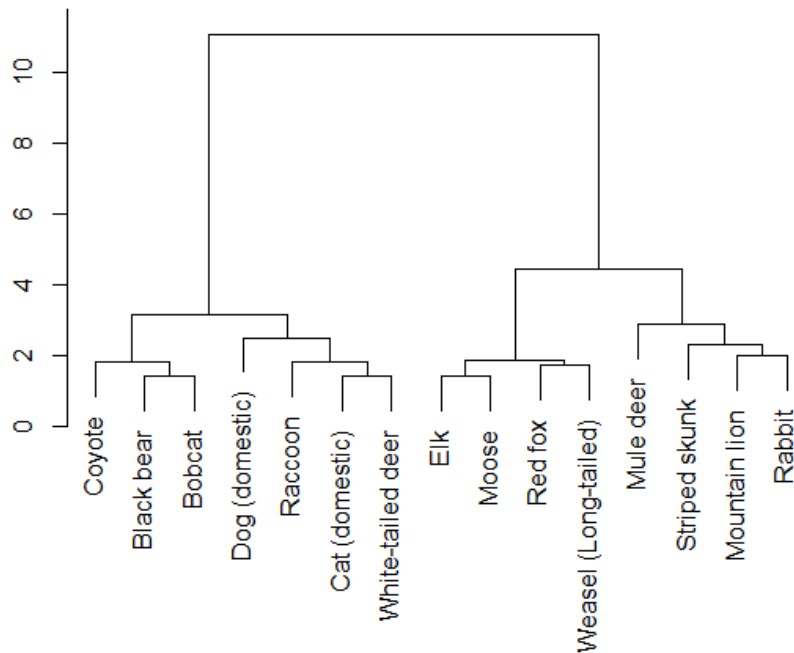
188 Logistic regression of the univariate effects of structural attributes was used to evaluate  
189 acceptance rates per species and investigate influence of individual factors on acceptance  
190 (Hosmer and Lemeshow, 2000). Prior to multivariate logistic regression, attributes were checked  
191 for multicollinearity through correlation analyses. Due to the high correlation of width with  
192 length and exit view ( $r=-0.627$  and  $r=0.671$  respectively), width was chosen to be removed from  
193 multivariate logistic regression (See Appendix- Table A). To reduce the influence of  
194 pseudoreplication and variability at individual crossing structures, generalized linear mixed  
195 models were used, accounting for a random effect of individual crossing structures (Bolker et al.  
196 2009). Backwards stepwise regression was then used to reduce the full model, including all  
197 crossing structure attributes, for each species or species group to develop a model of predicted  
198 crossing success. Variables were dropped one-by-one from the saturated model until all  
199 remaining variables were significant at  $\alpha = 0.05$  (Hosmer and Lemeshow, 2000). Logistic  
200 regression reference levels for categorical variables were set to the most basic crossing structure  
201 installation; no water channel present and a dirt floor. To measure the performance of the final  
202 model the proportion of correct predictions, or overall predictive success, and specificity were  
203 measured via a resubstitution confusion matrix output (Fielding and Bell, 1997). As an additional  
204 comparison the  $R^2_{GLMM(c)}$  coefficient of determination, using the ‘MuMIn’ package (Barton,  
205 2013) in R version 2.15.0 (R Core Team 2012), was given to describe the variance explained by  
206 the entire model (Nakagawa and Schielzeth, 2013). All other statistical analyses were  
207 conducted using R (R Core Team 2012, v2.15.0).

208

209 **3. Results**

210 Remote cameras were operational for a total of 9,935 days accounting for 98% of the possible  
211 10,132 days. Events such as battery or camera failure, SD cards becoming full and vandalism  
212 caused cameras to stop sampling. I observed the approach behavior for 6,515 approach events by  
213 wildlife species at the crossing structure entrances. White-tailed deer accounted for a majority of  
214 approaches (5,399 approaches; 81.0%) followed by mule deer (492 approach events; 7.1%).  
215 Coyote comprised 3.1% of approach events with 204 events, followed by black bear (181 events;  
216 2.8%), and bobcat (98 events; 1.5%). Other wildlife species with observed approach events  
217 included: 196 raccoon, 42 rabbits, 31 striped skunk, 13 mountain lion 13 elk, 2 red fox, 3 moose,  
218 and 1 long-tailed weasel. Eight events were unidentified species and were not used in analysis.  
219 Domestic species (cats and dogs) were observed approaching 570 and 298 times respectively.  
220 Domestic dog approaches included 83 events with associated human activity, while humans  
221 accounted for an additional 179 events (including 3 on horseback, 2 with motor-vehicles, and 3  
222 on all-terrain vehicles); excluding research personnel events. Overall crossing structure  
223 acceptance by all species was 83%, influenced largely by white-tailed deer with 85% acceptance  
224 over all crossing structures (See Appendix – Table B).

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



231  
 232 Figure 3. Dendrogram from agglomerative hierarchical cluster analysis using Ward's minimum  
 233 variance with Euclidean distances illustrating co-occurrence of wild and domestic species at  
 234 crossing structures along US 93, Montana, USA.  
 235

236 Univariate analysis provided initial information for crossing structure variables and their  
 237 effect on success of white-tailed deer, mule deer and the carnivore group (Table 2). Though  
 238 results of univariate logistic regressions may be confounded by other variables, it does provide a  
 239 starting point for examining the data. Univariate results provide a comparison to coefficients  
 240 from multivariate analysis; looking for large changes in coefficient estimates, including sign  
 241 changes (indicating possible confounding variables); as well as for relationship between variable  
 242 removed from backwards stepwise linear regression and acceptance. For white-tailed deer  
 243 (n=5,470) all the variables considered were significant at  $\alpha = 0.05$ . White-tailed deer showed  
 244 higher success at short, wide, and tall crossing structures, with larger exit view distances that had  
 245 a water channel and vegetated floor. Mule deer (n=496) showed no significant variables, with the  
 246 positive influence of exit view distance being marginally significant (p-value = 0.068). The  
 247 carnivore group showed significant p-values for all measured variables except length and a



248 marginally significant estimate for vegetated floor (p-value = 0.067), showing increased  
 249 acceptance given wide, tall crossings structures with a water channel present. White-tailed deer  
 250 seem to show some interaction with all of the variables that were measured, while mule deer  
 251 acceptance of the structures does not seem to be associated with the variables included in the  
 252 analyses.

253 Table 2. Results from univariate logistic regression for crossing structure attributes  
 254 associated with successful use of wildlife crossing structures by white-tailed deer, mule deer, and  
 255 3 carnivores at wildlife crossing structures on US 93 Montana, USA. Estimates of coefficients,  
 256 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

257

258 Backward stepwise regression for white-tailed deer produced a generalized logistic  
 259 mixed-effects model with one variable, height (Table 3). The large estimated coefficient and  
 260 associated increase in odds for the height variable shows this relationship to be very strong.  
 261 Overall predictive success was 87% (n=3245), but was dominated by true positive predictions  
 262 (n=2,805) whereas specificity, or the proportion of true negatives, was only 5% (n=439). More  
 263 specifically, this model accurately predicted successful crossing attempts while not accurately  
 264 predicting unsuccessful crossing attempts as unsuccessful. Additionally,  $R^2_{GLMM(c)}$  coefficient of  
 265 determination, showing variance explained by the entire model, was moderate ( $R^2_{GLMM(c)} =$   
 266 0.306) (Nakagawa and Schielzeth, 2013).

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

270

Variable	Estimate	Std. Error	z value	Pr(> z )	Odds
White-tailed deer ( <i>Odocoileus virginianus</i> )					
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

271

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

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

284

#### 285 4. Discussion

286 Overall crossing structure acceptance rates were high for most species, with elk and moose being  
287 the only species with crossing acceptance below 50%, with some approaching 85-90% (black

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

300           Acceptance rates for a given species vary across studies for various reasons. Landscape  
301 differences, human activity and influence, and migratory patterns all affect wildlife acceptance  
302 rates at crossing structures. My results show higher acceptance rates for some species compared  
303 to acceptance rates of other studies. One study in Arizona State Route 260, Gagnon et al. (2011),  
304 found much lower acceptance rates for white-tailed deer than my study (39% to 85%), mule deer  
305 (55% to 67%), and coyotes (46% to 80%). The project on SR-260 had longer and higher  
306 structures (mean length (m): 90<sub>SR-260</sub>, 22<sub>US/MT-93</sub>; mean height (m) 8.8<sub>SR-260</sub>, 3.1<sub>US/MT-93</sub> ) which  
307 would suggest that length and height may be driving acceptance rates for these species across  
308 landscapes. Additionally, human activity is likely higher on the US-93 study area here. It is most  
309 likely that variation in calculating approach and acceptance rates via remote camera methods are  
310 introducing some of the variation in acceptance rates across different projects. Gagnon et al.

311 (2011) and Dodd et al. (2010) both observed approaches of up to 50m from the mouth of  
312 crossing structure entrances, while my study and others (Donaldson, 2011; Ng et al., 2009) have  
313 cameras set up at crossing structure entrances, observing the physical mouth and portion (20-  
314 40degrees) of view from that location. This is an important difference due to the continuous  
315 decision making process that an approach and eventual success or failure of passage entails. One  
316 may expect that the closer that an individual animal is to the mouth of a crossing structure, the  
317 higher the probability of successful passage for that individual. Approach studies either need to  
318 have a standardized approach measure or explicitly describe the approach areas observed. Due to  
319 the variety in approach fencing, topography and structure design, I recommend placing cameras  
320 immediately adjacent to the structure opening, thus reducing variation across monitoring studies.

321         It is notable that mule deer, often characterized as a more skittish species than white-  
322 tailed deer, had a lower acceptance rate than white-tailed, 68% to 85% respectively.  
323 Additionally, generalized linear mixed models showed low variance between crossing structures  
324 for mule deer (variance < 0.005) while white-tailed deer and carnivores showed variation among  
325 crossing structures (see appendix - Table D). It is evident that crossing structure acceptance  
326 differs between species and different attributes interact differently with species behaviors than  
327 others. By observing the approaches of each crossing structure, I was able to identify those  
328 attributes that facilitate acceptance for various species while reducing the influence of population  
329 sizes and willingness to approach crossing structures of those species in the surrounding  
330 landscape. Mule deer, who utilize dry upland grassy areas in the study area, had higher  
331 acceptance rates in structures without a water channel and with a greater exit view distance, and  
332 this appeared very consistent across all crossing structures as indicated by the low variance in the  
333 random effect. White-tailed deer, who utilize riparian corridors more often in the study area, had

334 higher acceptance rates using taller structures. Additionally, there may be an influence of  
335 predators on the landscape that influence prey species use and acceptance of crossing structures,  
336 though evidence of crossing structures as prey-traps is weak (Little et al., 2002), there is  
337 evidence that sympatric mule deer and white-tailed deer will exhibit habitat segregation due to  
338 coyote predation during winter (Lingle 2002). My results show very dissimilar use of crossing  
339 structures by white-tailed deer and mule deer may be influenced by coyote presence on the  
340 landscape. Mule deer may actively avoid structures where they might encounter coyotes,  
341 possibly due to a greater likelihood of coyotes pursuing and attacking mule deer compared to  
342 white-tailed deer (Lingle and Pellis, 2002).

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

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

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

380 mitigation measures, including wildlife crossing structures, will need to be designed and  
381 implemented with the highest possible success rates if wildlife populations are to remain even  
382 somewhat connected.

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471 **Appendix**

472 Table A. Correlation matrix output with Pearson correlation coefficient below the diagonal and  
 473 the associated p-value for the coefficients for structural attributes of crossing structures above the  
 474 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	-

475  
 476  
 477 Table B. Approach and outcome for all observed wildlife species.  
 478

Species	Passage		Total Approaches	Success
	No	Yes		
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%

479  
 480  
 481 Table C. Percent acceptance and number of approaches for the different species for each crossing  
 482 structure type along US 93 North, Montana, USA.

	Arch		Bridge		Overpass		Small Culvert (<2m tall)		Species Totals	
	%	No.	%	No.	%	No.	%	No.	%	No.
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

483

484

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

<u>White-tailed deer</u>		<u>Carnivore Group</u>	
	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

487