THE USE OF WILDLIFE UNDERPASSES AND THE BARRIER EFFECT OF WILDLIFE GUARDS FOR DEER AND BLACK BEAR

by

Tiffany Doré Holland Allen

A thesis submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Biological Sciences

MONTANA STATE UNIVERSITY
Bozeman, Montana

April 2011

APPROVAL

of a thesis submitted by

Tiffany Doré Holland Allen

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citation, bibliographic style, and consistency and is ready for submission to The Graduate School.

Dr. Scott Creel
Dr. Marcel P. Huijser

Approved for the Department of Ecology

Dr. David Roberts

Approved for The Graduate School

Dr. Carl A. Fox

STATEMENT OF PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirements for a master's degree at Montana State University, I agree that the Library shall make it available to borrowers under rules of the Library.

If I have indicated my intention to copyright this thesis by including a copyright notice page, copying is allowable only for scholarly purposes, consistent with "fair use" as prescribed in the U.S. Copyright Law. Requests for permission for extended quotation from or reproduction of this thesis in whole or in parts may be granted only by the copyright holder.

Tiffany Doré Holland Allen

April 2011

ACKNOWLEDGEMENTS

I would like to thank the Research and Innovative Technologies Administration, U.S. Department of Transportation and S&K Electronics for funding this research. I would also like to thank the Western Transportation Institute (WTI) for supporting me with a graduate transportation award. I appreciate the help of many people at WTI, as well, including Jerry Stephens, Rob Ament, Marcel Huijser and Susan Gallagher, who made this research possible.

I appreciate the cooperation of the Confederated Salish and Kootenai Tribes and the many landowners in my study area and their willingness to let me conduct research on the reservation and on their land. In particular, I would like to thank Whisper Camel, Dale Becker, Nancy Martin and Dave Martin.

I owe many thanks to the Montana Department of Transportation, especially Pat Basting, Tim Callahan and Dude.

I sincerely appreciate all those who helped with fieldwork: Marcel Huijser, Jeremiah Purdum, MaryClare Rollins, Chris Allen and Steve Holland. And I greatly appreciate Megan O'Reilly's help with GIS and editing.

I would like to thank my committee members, Marcel Huijser, Dave Willey and Scott Creel for all their advice, input and support.

Finally, I am grateful to Chris Allen, Gretchen Holland, Steve Holland, MaryClare Rollins, Megan O'Reilly, Marcel Huijser and Bethanie Walder for all their support over the last three years.

TABLE OF CONTENTS

TABLE OF CONTENTS-CONTINUED

LIST OF TABLES

Table Page

LIST OF TABLES-CONTINUED

LIST OF FIGURES

ABSTRACT

Roads and traffic affect wildlife on multiple organizational scales (e.g. from individuals to populations) and different spatial scales (e.g. local patch to landscapes). Roads not only affect the natural environment, but people are also at risk when animals are on the road. As transportation agencies are incorporating mitigation measures into roadway design, more opportunities are arising to study their effectiveness.

One such opportunity is along U.S. Highway 93 on the Flathead Indian Reservation in Montana, where eight reconstruction projects over 90.6 km were completed in 2010. The mitigation measures include 2.4-m fencing, crossing structures, and wildlife guards. These measures are aimed at reducing wildlife–vehicle collisions and increasing human safety, while allowing unimpeded wildlife movement and traffic flow.

Within the 90.6-km reconstruction zone, two sections were completed in2006. For this study, we focused on these two sections to answer two questions: 1) To what extent are the wildlife guards a barrier to wildlife, especially deer (*Odocoileus* sp.)?; and 2) How do characteristics of the underpasses, landscape characteristics, and human disturbance influence use by mule deer (*O. hemionus*), white-tailed deer (*O. virginianus*), and black bear (*Ursus americanus*)?

To answer the first question, we monitored wildlife movements with cameras at two guards and in one culvert adjacent to a guard. To answer the second question, we used both sand tracking beds and cameras to monitor 11 underpasses for over two years. We also analyzed data on structural characteristics, landscape characteristics, and human disturbance from field measurements and a geographic information system.

The guards were ≥85% effective as a barrier to deer, and 93.5% of deer used the crossing structure instead of the adjacent guard. Though the guards were not an absolute barrier, the results indicate deer were substantially discouraged from crossing, and the vast majority crossed the road using the crossing structure rather than the guard, indicating the guards are an effective means of mitigation.

We found that increasing distance to cover may increase mule and white-tailed deer use of underpasses. However, we were unable to determine factors related to black bear crossings. We recommend further study for all three species.

CHAPTER 1

INTRODUCTION

Roads and associated vehicles can affect wildlife on multiple organizational scales, biologically from individuals to populations, temporally, and spatially from microsites to landscapes. There are currently more than 8.4 million lane miles of highway in the United States, with over 6.1 million lane miles in rural areas (Federal Highway Administration 2007). The potential ecological effects of vehicles and roads, especially in rural areas, are diverse and include: 1. Loss of habitat as a result of pavement or other unnatural substrate, 2. Direct mortality as a result of collisions with vehicles, 3. Habitat fragmentation as a result of barriers that affect animal movements, and 4. Reduced habitat quality adjacent to roads, for example as a result of chemical or noise pollution (Forman and Alexander 1998).

Roads not only affect wildlife, but people are also at risk when large mammals enter the roadway. Between one and two million collisions with large animals occur in the United States each year, with 26,000 human injuries and 200 human deaths (Forman and Alexander 1998, Huijser et al. 2008). It is estimated that total costs exceed eight billion dollars annually, including medical expenses, vehicle repair, towing, law enforcement, the ecological and social value of the animal, and the cost of carcass removal and disposal (Huijser et al. 2008). Furthermore, at least 42 mitigation measures or combinations of mitigation measures are available to mitigate impacts, most of which have not been thoroughly studied. These alternatives range from public information to wildlife fencing, roadside animal detection systems to culling wildlife (Huijser et al. 2008). As transportation agencies integrate mitigation measures and roadway design, opportunities become available for research that examines their effectiveness in a real world setting.

From October 2004 through November 2010, there were eight reconstruction projects along 90.6 kilometers of the U.S. Highway 93 corridor from Evaro to Polson, Montana located on the Flathead Indian Reservation. (Figure 1). The project corridor is now the site of one of the most extensive wildlife crossing mitigation projects in North America, both in terms of road length and the number of fish and wildlife crossing structures, 41 total (excluding likely future mitigation measures in the Ninepipes area). The reconstruction included mitigation measures to reduce wildlife–vehicle collisions by preventing wildlife from using the road (wildlife fencing) (Figure 2), and it included measures that allow animals to cross under or over the road safely (wildlife underpasses and one wildlife overpass) (Figure 3). In the fenced road sections, gaps for side roads are mitigated by wildlife guards. The purpose of these guards is to allow vehicle access to and from the road corridor, while preventing wildlife from gaining road access. However, in the event that animals are not deterred, wildlife jump-outs, structures that allow animals to escape the road corridor, were installed directly across the road from the wildlife guards (Figure 4). The jump-outs were designed to be low enough that animals can readily jump-out but high enough to discourage animals from jumping in (Figure 5).

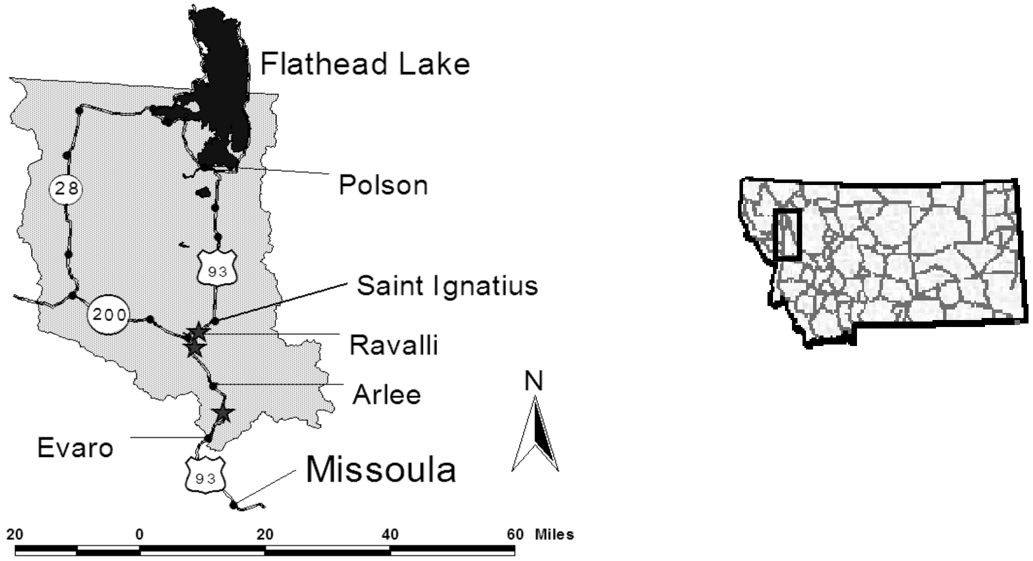

Figure 1. The Flathead Indian Reservation in Montana including major highways.

Figure 2. 2.4-m wildlife exclusion fencing.

Figure 3. Wildlife crossing structures, including a medium culvert, large culvert, bridge and wildlife overpass.

Figure 4. Wildlife guard with a jump-out directly across the road.

Figure 5. A jump-out as seen from the road corridor.

The Confederated Salish and Kootenai Tribes (CSKT), Montana Department of Transportation (MDT), and Federal Highway Administration (FHWA) were involved in the design and implementation of the reconstruction and monitoring efforts. The Memorandum of Agreement among the three governments reflected design discussions that included concerns and potential solutions to human safety issues and habitat connectivity for wildlife. From late 2002 through 2005, the Western Transportation Institute at Montana State University (WTI-MSU) conducted pre-construction monitoring of wildlife–vehicle collisions and habitat connectivity for deer (*Odocoileus* sp.) and black bear (*Ursus americanus*) along US Highway 93.

Within the 90.6-km reconstruction project, two sections were completed (2006) before fieldwork for this thesis began in April 2008. The monitoring of wildlife use of underpasses focused on these two road sections: Ravalli Curves (about 5.8 km, just south of Ravalli) and Ravalli Hill (about 1.9 km, just north of Ravalli). There are 11 wildlife underpasses in these two road sections that vary in type and size. There are four medium mammal culverts (about 1.2–2.8 m wide, 1.2–2.2 m high), five large mammal culverts (about 6.8–7.7 m wide, 3.4–4.3 m high), and two bridges (about 28.4 and 28.6 m wide, 3.9 and 3.5 m high).

My research was designed to be consistent with the design criterion detailed in a US 93 pre-construction research report (Hardy et al. 2007), and the proposal for the main post-construction research (Huijser et al. 2010) that began in 2010. This thesis addresses the following questions:

1. To what extent are wildlife guards a barrier to wildlife, especially deer?
2. How do the characteristics of the underpasses, landscape characteristics, and human disturbance influence use by mule deer (*O. hemionus*), white-tailed deer (*O. virginianus*), and black bear?

In addition, my research design will allow a future comparison between pre-construction crossing data and post-construction wildlife use, to evaluate whether the road reconstruction and the mitigation measures resulted in improved, similar, or reduced connectivity for these species (Hardy et al. 2007).

Literature Cited

Federal Highway Administration. 2007. Highway Statistics 2007. Lane miles by functional system. http://www.fhwa.dot.gov/policyinformation/statistics/hm60_summary.cfm (accessed on 14 October 2010)

Forman, R.T.T. and L.E. Alexander. 1998. Roads and their major ecological effects. Annual Review of Ecological Systems, Vol. 29, pp. 207–231.

Hardy, A.R., J.Fuller, M. P. Huijser, A. Kociolek 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-06-008/1744-1. Western Transportation Institute, College of Engineering, Montana State University, Bozeman, MT, USA. Available from the internet: http://www.mdt.mt.gov/research/projects/env/wildlife_crossing.shtml

Huijser, M.P., R. Ament, W. Camel and D. Becker. 2010. US 93 Post-construction wildlife–vehicle collision and wildlife crossing monitoring and research proposal. Western Transportation Institute and Department of Ecology at Montana State University – Bozeman, Montana, USA.

Huijser, M.P., P. McGowen, A.P. Clevenger and R. Ament. 2008. Best Practices Manual. Report to congress. U.S. Department of Transportation, Federal Highway Administration, Washington D.C., USA.

Huijser, M.P., P. McGowen, J. Fuller, A. Hardy, A. Kociolek, A.P. Clevenger, D. Smith and R. Ament. 2008. Wildlife–vehicle collision reduction study. Report to congress. U.S. Department of Transportation, Federal Highway Administration, Washington D.C., USA. Available from the internet: http://www.tfhrc.gov/safety/pubs/08034/index.htm

CHAPTER 2

EVALUATION OF WILDLIFE GUARDS AT ACCESS ROADS

Contribution of Authors and Co-Authors

Manuscript in Chapter 2:

Co-author: Tiffany D.H. Allen
Contributions: Design, executed study, analysis and interpretation of data, writing and revising of article

Co-author: Marcel P. Huijser
Contributions: Conception and design, executed study, analysis and interpretation of data, revising of article

Co-author: David W. Willey
Contributions: Analysis and interpretation of data, revising of article

Manuscript Information Page

Tiffany D.H. Allen; Marcel P. Huijser; David W. Willey

- Journal Name: Wildlife Society Bulletin
- Status of manuscript (check one)
  _x_Prepared for submission to a peer-reviewed journal
  ___Officially submitted to a peer-reviewed journal
  ___Accepted by a peer-reviewed journal
  ___Published in a peer-reviewed journal

EVALUATION OF WILDLIFE GUARDS AT ACCESS ROADS

TIFFANY D.H. ALLEN,[1] *Western Transportation Institute, Montana State University, PO Box 174250, Bozeman MT 59717, USA*
MARCEL P. HUIJSER, *Western Transportation Institute, Montana State University, PO Box 174250, Bozeman MT 59717, USA*
DAVID W. WILLEY, *Department of Ecology, Montana State University, PO Box 173460, Bozeman MT 59717, USA*
[1]*E-mail: tiffany.allen@coe.montana.edu*

Abstract

The reconstruction of 90.6 km of U.S. Highway 93 from Evaro to Polson, MT on the Flathead Indian Reservation includes 41 fish and wildlife crossing structures and 13.4 km of road with wildlife fencing. These measures are aimed at reducing wildlife–vehicle collisions and increasing human safety, while allowing wildlife to traverse the landscape. In the fenced road sections, gaps for side roads are mitigated by wildlife guards (similar to cattle guards). We focused on a 1-km fenced section where animals can either cross the road using 5 crossing structures (4 culverts and 1 bridge), or they can access the road through two guards on the east side of the road. Wildlife movements were monitored with cameras at the two guards and in one large crossing structure adjacent to one of the guards. We investigated how effective these guards were as a barrier to deer (*Odocoileus* sp.). We also compared movements across the guards to those through the crossing structures. The guards were 85% or more effective in keeping deer from accessing the road, and 93.5% of deer used the crossing structure instead of an adjacent guard when crossing the road. Though the guards were not an absolute barrier to deer, the results indicate deer were substantially discouraged from crossing the guards, and the vast majority crossed the road using the crossing structure rather than the guard, indicating the guards are an effective means of mitigation.

Introduction

Fencing can significantly reduce ungulate access to the road corridor (Falk et al. 1978) and has been shown to reduce wildlife–vehicle collisions by ≥79% (Reed et al. 1982, Clevenger et al. 2001, Dodd et al. 2007). However, in developed areas, gaps in fences are necessary to allow vehicles access to and from main roadways. Without additional measures, gaps can allow wildlife to enter the fenced road corridor. While gates (locked or unlocked) have been used at low use side roads, they are sometimes left open and are not suitable for higher traffic volumes. In contrast, wildlife guards appear to be a strong barrier and also address higher traffic volumes.

Traditional cattle guards have been used and reported effective for white-tailed deer (*Odocoileus virginianus*) under some circumstances (Bashore and Bellis 1982, Belant et al. 1998). However, to be suitable for public roads and effectively exclude wildlife from the fenced road corridor, several factors must be considered. Standard cattle guards may not be safe for pedestrians, cyclists, and heavy vehicles, so alternative designs may be required (Peterson et al. 2003). In addition, side panels (fencing) should be extended the full length of the guard to prevent diagonal (shorter) crossing by wildlife (Sebesta et al. 2003). Guards should also be placed over a pit with walls (e.g. concrete) or raised in another manner to prevent wildlife from crossing by placing their feet on the ground between the grates (Sebesta et al. 2003).

In this field study, our objective was to investigate how effective a particular type of wildlife guard design was as a barrier to mule deer (*O. hemionus*) and white-tailed deer movement and, therefore, how effective it was in keeping deer from accessing the right-of-way along a fenced section of U.S. Highway 93.

Study Area

From October 2004 through November 2010, there were eight reconstruction projects along 90.6 kilometers of U.S. Highway 93 from Evaro to Polson, Montana located on the Flathead Indian Reservation. The project corridor is now the site of one of the most extensive wildlife crossing mitigation projects in North America, both in terms of road length and the number of fish and wildlife crossing structures, 41 total (excluding likely future mitigation measures in the Ninepipes area). In addition to crossing structures that allow animals to cross under or over the road safely, the reconstruction included 2.4-m high wildlife exclusion fencing along some road sections intended to restrict access of wildlife to the road corridor.

The Flathead Indian Reservation is home to the Confederated Salish and Kootenai Tribes, which includes Bitterroot Salish, Pend d'Oreille and Kootenai tribes. U.S. Highway 93 runs north-south through the reservation and is in the process of being reconstructed to improve safety and allow for higher traffic volume. This study was conducted in a road section where the road reconstruction was completed in 2006. This section is referred to as "Ravalli Curves" and is located just south of Ravalli and the junction with MT Highway 200. Along with the reconstruction of the actual road, wildlife fencing, wildlife underpasses, jump-outs, and wildlife guards were built along a 1.0-km section just south of Ravalli, MT (Figure 6). The wildlife underpasses varied in type and size. There were three medium mammal culverts (about 1.2–2.8 m wide, 1.2–1.6 m high), one large mammal underpass (about 7.7 m wide, 3.5 m high), and one bridge (about 28.4 m wide, 3.9 m high) (Table 1.). There were also two wildlife guards and 9 jump-outs in the study area. Jump-outs are earthen ramps that allow animals that may have entered the fenced road corridor to jump down to safety. Jump-outs should be low enough so that animals will readily jump out of the fenced road corridor but high enough to discourage animals from jumping in. The two wildlife guards had a jump-out on the other side of the road. If an animal crossed the wildlife guard into the fenced road corridor, the jump-out on the other side allowed it to cross the road and escape to safety.

The landscape adjacent to this 1.0-km section of mitigation measures was rather homogeneous, with a railroad and the Jocko River running parallel to the road on the west side, an old oxbow of the Jocko River to the east, and steep hills to both the east and west. The surrounding vegetation was primarily coniferous forest, with some grassland, as well as riparian habitat along the river and old oxbow.

Average minimum temperatures ranged from -8.2^{0} C in winter to 9.8^{0} C in summer, and average maximum temperatures ranged from 0.7^{0} C in winter to 29.1^{0} C in summer. Temperatures ranged from well below -18^{0} C to over 38^{0} C. Average annual precipitation was 403.4 mm, with precipitation mostly in the form of snow in the fall, winter, and spring and mostly rain in the summer. (NRCS 2005)

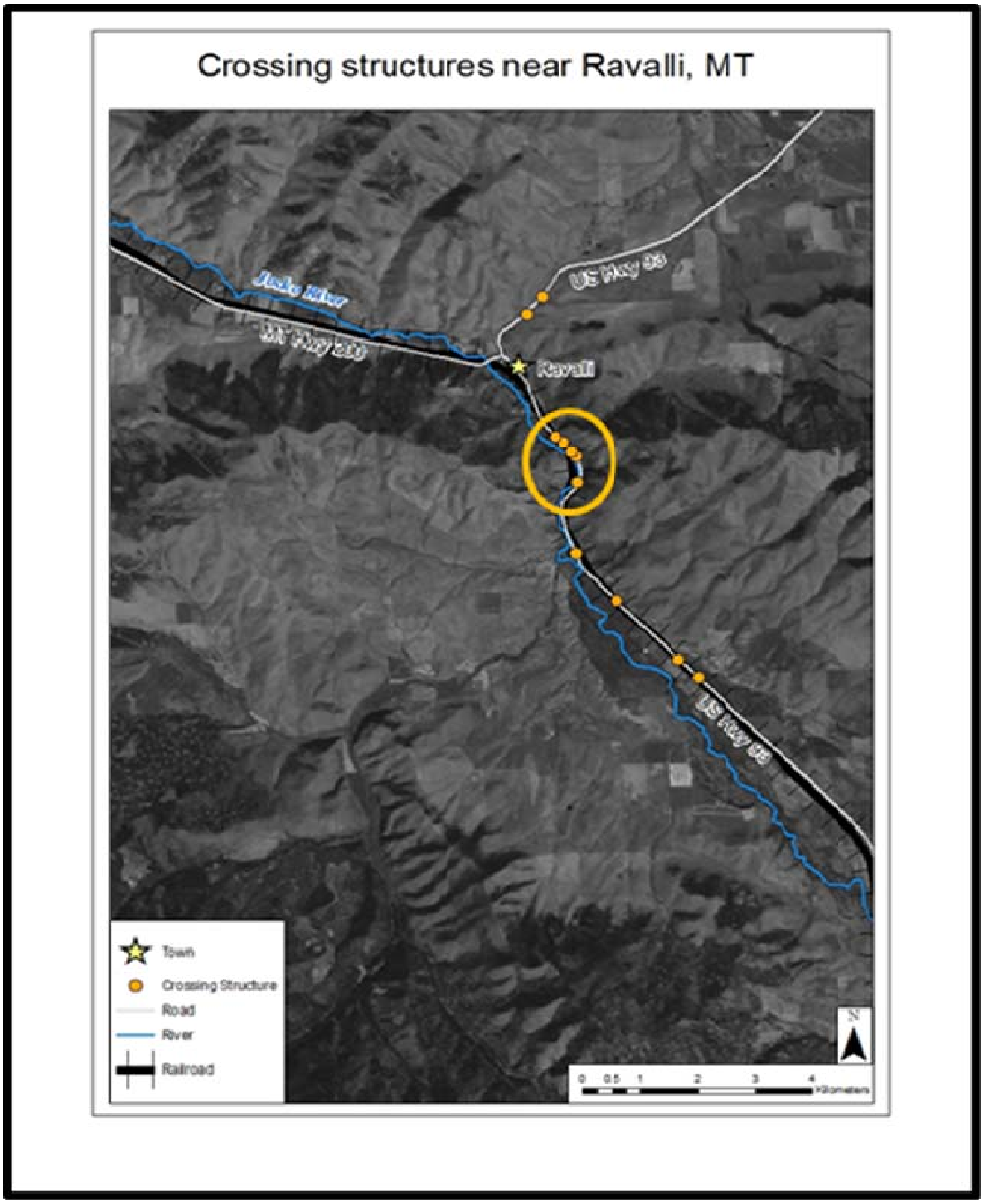

Figure 6. Location of the crossing structures within the 7.7-km study area, with the Ravalli Hill study section to the north of the town of Ravalli, and Ravalli Curves study section to the south of the town of Ravalli.

Methods

Wildlife Guards

Both wildlife guards are located on the east side of the road and have 2.4 m-high fencing on each side parallel to traffic. Each guard consists of a steel grate placed over a backfilled depression supported by concrete foundation walls. The grates are 6.8 m in the direction perpendicular to traffic by 6.6 m in the direction parallel to traffic. Each grate is formed by smaller 8 cm by 10 cm rectangles, made of a combination of 6 mm and 130 mm steel. The depressions are approximately 76 cm deep and are filled with approximately 46 cm of backfill, effectively leaving about a 45-cm deep pit after the steel grate is placed on top. This pit serves to discourage animals from placing their feet on the ground between the grates. Foundation walls of the depression are 20 cm wide, surround the metal grate on all sides, and both were manufactured by L.B. Foster Company (Figure 7).

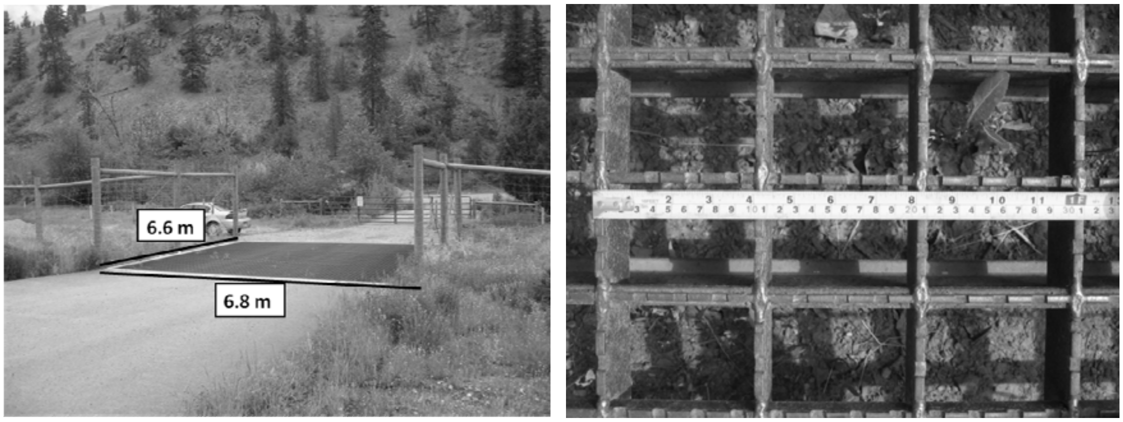

Figure 7. Wildlife guard and grate dimension.

Study Design

We evaluated the effectiveness of the guards as a barrier to wildlife movements by addressing three research questions. First, how effective are the guards as a barrier to animals that come close to the guard or that show intent to cross? To answer this question, we calculated the percentage of animal movements that crossed the guards out of the number of animal movements that approached the guards traveling towards the fenced road corridor. Second, are guards a greater barrier to animals than the road and traffic alone? To answer this question, we compared pre-construction crossing rates at the road to crossing rates at the guard, post-construction. Third, we asked, if presented with an option, will animals choose to use a wildlife guard or a crossing structure to cross the road? To answer this question, we compared animal movements across one of the guards to those through the large crossing structure (about 7.7 m wide, 3.5 m high) that was closely paired with the guard, 61 m south of the guard.

Wildlife movements were monitored for 2 years (mid-July 2008 through mid-July 2010) with wildlife cameras (RECONYX Silent Image^{TM} – Professional, Model PM35), one at each of the wildlife guards, and one in the culvert. In our analyses, we included all wildlife species (i.e. not domestic animals) for which the sample size was greater than 10. Only east to west movements were included in the analyses because east to west movements at the wildlife guards were likely motivated by intent to cross the road rather than to escape the fenced road corridor. We selected east to west movements not only for the two wildlife guards but also for the culvert. In addition, for all movements at the two guards and the culvert, we counted animals of the same species that were traveling together as one animal movement, as their movements were likely dependent.

We calculated the barrier effect of the wildlife guards in two different ways depending on whether an animal movement fit one or both of the following definitions: 1. The animal came within 2 m of the wildlife guard; 2. The animal displayed behavior indicating it intended to cross the guard. For the second definition, qualifying behavior included, but was not limited to, stalling at the guard, placing its nose on the guard, and pawing at or stepping onto the guard.

We used data obtained in earlier years (2003–2005) along the same road section to calculate and compare "turn around" and successful crossing rates to those at the guards. Previous data were gathered before the road section was upgraded and before mitigation measures were implemented. Before these measures were installed, animals could approach the road anywhere, as there was no wildlife fencing. During the previous study, the 1-km road section in Ravalli Curves had eight sand tracking beds installed at random locations immediately adjacent and parallel to the road (Hardy et al. 2007). Each sand tracking bed was 100 m long and 2 m wide. For this analysis we only included tracks from deer and black bear (*Ursus americanus*), because the tracks of coyotes (*Canis latrans*) were not reliably detected in the exposed track bed substrate. Animal tracks were recorded as crossing, moving parallel to the road, or as present. Those recorded as crossing were assumed to have crossed the road, and the tracks recorded as parallel or present were assumed to have turned around and not crossed the road. We compared the pre-guard tracking bed data to the more recent data based on the number of individual animals (i.e. not groups) that approached the guards within 2 m. We counted individuals because there was no way of determining the number of groups from the sand beds; we could only determine the number of individuals. In addition, we think these data sets provided the best available contrast because the sand beds, located just off of the road surface, were 2 m wide. Chi-square analyses were conducted to test for a potential difference in the number of animals that turned around at the roadside tracking beds (pre-construction sample) versus the number of animals that turned around at the wildlife guard. For this study, we considered a p-value less than or equal to 0.05 to represent a significant difference.

We predicted that the guards would be a substantial barrier to deer but would not be a substantial barrier to black bear and coyotes. Other studies have shown that similar guards may be effective barriers to deer movement (Peterson et al. 2003, Sebesta et al. 2003). Due to the design of the grate and given the size of a black bear's foot, we predicted that bears would have no trouble walking over the guards. Similarly, due to the design of their feet and their agility, we predicted that coyotes would have no difficulty walking over the guards.

We compared movements across the northern-most guard to movements through an adjacent culvert. Our null hypothesis was that wildlife would use the wildlife guard and nearby crossing structure equally. Our alternative hypothesis was that wildlife would use the wildlife guard less than the crossing structure. To test these hypotheses, a chi-squared test was performed.

Results

We included deer, black bear, and coyotes in our analyses, because they each had sample sizes greater than 10, with the exception of one analysis done for black bears (Table 3). For all 3 species and all analyses, all groups of animals stayed together, either all crossing or not crossing as a group.

We observed 137 independent animal movements approaching the two guards within 2 m, and 65 (47.4%) of these resulted in a crossing of a guard. The species observed included deer, black bear, bobcats (*Lynx rufus*), coyote, domestic cat (*Felis catus*), fox (*Vulpes vulpes*), horses (*Equus ferus*) (both alone and with a human rider), mountain lion (*Puma concolor*), raccoon (*Procyon lotor*), skunk (*Mephitis mephitis*), and wolf (*Canis lupus*). Most deer were deterred from crossing the wildlife guards, and a substantial number of black bear and coyotes were also discouraged from crossing (Table 2.)

We observed 104 independent animals approaching a guard and displaying behavior indicating intent to cross. This is, by definition, a subset of the animals that approached the guards within 2 m. Sixty-five (62.5%) of this subset of approaches resulted in a crossing of a guard. The species observed included deer, black bear, bobcat, coyote, domestic cat, fox, horse (with human rider), mountain lion, raccoon, skunk, and wolf. Most deer did not cross the wildlife guards, and a large number of black bear and coyotes were also somewhat deterred from crossing (Table 3.)

During pre-construction monitoring, 15 black bear approaches were recorded in sand beds along the roadside, and 86.7% resulted in a road crossing. This is not significantly different (p=0.126, from a χ^2 test) compared to the percent of black bear approaches that resulted in a crossing of a guard post-construction (61.5%).

A total of 107 deer approaches were recorded in sand beds along the roadside, and 43.9% of these resulted in a road crossing. This is a statistically significant difference (p=<0.001, from a χ^2test) compared to the percent of deer approaches that resulted in a crossing of a guard post-construction (5.9%).

With respect to our question regarding the guard versus the crossing structure, our null hypothesis was rejected in favor of the alternative that wildlife would use the guard less than the crossing structure. We observed a total of 289 independent animal movements crossing either through the crossing structure or over the wildlife guard, and 88.2% were through the crossing structure. The species we observed both crossing the guard and going through the culvert included bobcat, coyote, deer, domestic cat, fox, and raccoon. The species we observed only going through the culvert included beaver (*Castor canadensis*), black bear, domestic dog (*Canis familiaris*) (both with and without a human present), duck, goose, otter (*Lutra canadensis*), and rabbit (*Sylvilagus nuttallii*). Horse (with human rider), mountain lion, and wolf crossed only via the guard.

We observed 48 independent black bear crossings, all of which were through the crossing structure. Most (94.7%) of the independent coyote crossings (n=57) were through the crossing structure. This was significantly (p=<0.001, from a χ^2 test) more than the number of crossings over the wildlife guard (5.3%). 93.5% of all independent deer crossings (n=46) were through the crossing structure, whereas 6.5% were across the guard. This was a statistically significant difference (p=<0.001, from a χ^2 test).

Table 1. Dimensions (m) of underpasses as seen by approaching animals.

Underpass type	Height	Width	Length
culvert	3.5	7.7	18.4
culvert	1.15	1.83	25
culvert	1.4	2.8	21.65
culvert	1.61	1.22	21.32
bridge	3.9	28.4	11.5

Table 2. Number of wildlife that crossed guards after approaching within 2 m.

Species	Approached	Crossed	% crossed	Did not cross	% effective
mule deer	32	2	6.3	30	93.8
white-tailed deer	5	2	40.0	3	60.0
deer spp.*	38	4	10.5	34	89.5
black bear	11	6	54.5	5	45.5
coyote	22	10	45.5	12	54.5

*Mule deer and white-tailed deer, combined. One deer was not identifiable to the species level.

Table 3. Number of wildlife that crossed guards after showing intent to cross.

Species	Approached	Crossed	% crossed	Did not cross	% effective
mule deer	21	2	9.5	19	90.5
white-tailed deer	4	2	50.0	2	50.0
deer spp.*	26	4	15.4	22	84.6
black bear	9	6	66.7	3	33.3
coyote	15	10	66.7	5	33.3

*Mule deer and white-tailed deer, combined. One deer was not identifiable to the species level.

Discussion

To our knowledge, there is only one other comparable study (Reed et al. 1974) that has investigated the effectiveness of wildlife guards at access roads. Though the wildlife guards we observed were not an absolute barrier to deer, they were ≥85% effective. The guards were less effective (33 to 55%) for black bear and coyotes, but these species were apparently somewhat deflected from crossing the guards. Despite some differences that existed in monitoring methods pre- versus post-construction, the road was wider post-construction, and traffic volume likely increased, we did observe that deer were strongly deterred from crossing the guards. Furthermore, deer crossed the wildlife guards less than they crossed when no guards were present during pre-construction. These results strongly suggest that the wildlife guard was functioning as a barrier, versus a response to traffic or the road itself. For black bears, this comparison did not result in a statistical difference ($\alpha=0.05$), and although our sample size was small, the data for bears supports our prediction that the wildlife guards would not be a substantial barrier to black bears.

When a crossing did occur, most animals simply walked across the guard surfaces. However, deer both walked and jumped across, landing on the guard at least once. Despite jumping on and walking across the grate, no deer or other animals appeared to be injured while crossing or attempting to cross. We did not observe any animals completely jumping across in one leap, indicating that the guards are of sufficient length. Some animals did, however, use the concrete ledges at the edges of the guards to cross.

When presented with two options, most animals crossed the road using the crossing structure rather than the guard, indicating the crossing structures are perceived as a less risky pathway to many animals.

Management Implications

Gaps in a fence, even when mitigated with guards, may reduce the barrier effect of the fence. However, in developed areas where such gaps are necessary, guards do appear to be an effective means of mitigation, particularly where deer are the main species of concern.

The concrete ledges in the design we tested slightly increased the number of wildlife that were able to cross the guard. However, this may be mitigated by adding chain link fencing or mesh at a diagonal to cover the concrete ledge (Peterson et al. 2003) or bringing the fence over the concrete ledge in its entirety. Another idea, which is currently being tested, is the placement of rubber “bumpers” that block access to the concrete ledge (Pat Basting, Montana Department of Transportation, pers. comm.). Perhaps, these or similar measures will further increase the effectiveness of the guards.

We think that wildlife guards, particularly this design, should be considered in other areas where transportation professionals and wildlife biologists are attempting to balance the need for access roads and the need for wildlife mitigation measures.

Acknowledgments

The authors would like to thank both of our funding sources: Research and Innovative Technologies Administration, U.S. Department of Transportation and S&K Electronics. We appreciate the cooperation of the Confederated Salish and Kootenai Tribes and their willingness to let us conduct research on the reservation. In particular, we would like to thank D. Becker and W. Camel. We would also like to thank the Montana Department of Transportation, especially P. Basting, T. Callahan, and C. Smith. We would also like to thank S. Creel for his help and input. In addition, we greatly appreciate the help of J. Purdum and C.R. Allen.

Literature Cited

Bashore, T.L. and E.D. Bellis. 1982. Deer on Pennsylvania airfields: problems and means of control. Wildlife Society Bulletin, Vol. 10, No. 4, pp. 386–388.

Belant, J.L., T.W. Seamans and C.P. Dwyer. 1998. Cattle guards reduce white-tailed deer crossings through fence openings. International Journal of Pest Management, Vol. 44, No. 4, pp. 247–249.

Clevenger, A.P., B. Chruszez and K.E. Gunson. 2001. Highway mitigation fencing reduces wildlife–vehicle collisions. Wildlife Society Bulletin, Vol. 29, No. 2, pp. 646–653.

Dodd, N. L., J. W. Gagnon, S. Boe, A. Manzo and R. E. Schweinsburg. 2007. Evaluation of measures to minimize wildlife–vehicle collisions and maintain permeability across highways: Arizona Route 260. Final Report 540. FHWA-AZ-07-540. Arizona Department of Transportation, Phoenix, Arizona, USA.

Falk, N.W., H.B. Graves and E.D. Bellis. 1978. Right-of-way fences as deer deterrents. The Journal of Wildlife Management, Vol. 42, No. 3, pp.646–650.

Federal Highway Administration. 2007. Highway Statistics 2007. Lane miles by functional system. http://www.fhwa.dot.gov/policyinformation/statistics/hm60_summary.cfm (accessed on 14 October 2010)

Forman, R.T.T. and L.E. Alexander. 1998. Roads and their major ecological effects. Annual Review of Ecological Systems, Vol. 29, pp. 207–231.

Forman, R.T.T. 2000. Estimate of the area affected ecologically by the road system in the United States. Conservation Biology, Vol. 14, No. 1, pp. 31–35.

Hardy, A., J. Fuller, M.P. Huijser, A. Kociolek and M. Evans. 2007. Evaluation of wildlife crossing structures and fencing on US Hwy 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 (2007) 210 pp. Available from the internet: http://www.mdt.mt.gov/research/projects/env/wildlife_crossing.shtml

Huijser, M.P., P. McGowen, A.P. Clevenger and R. Ament. 2008. Best Practices Manual. Report to congress. U.S. Department of Transportation, Federal Highway Administration, Washington D.C., USA.

Huijser, M.P., P. McGowen, J. Fuller, A. Hardy, A. Kociolek, A.P. Clevenger, D. Smith and R. Ament. 2008. Wildlife–vehicle collision reduction study. Report to congress. U.S. Department of Transportation, Federal Highway Administration, Washington D.C., USA. Available from the internet: http://www.tfhrc.gov/safety/pubs/08034/index.htm

Natural Resources Conservation Service (NRCS). 2005. Montana climate summaries: St. Ignatius. http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?mtstig (accessed on 19 October 2010)

Peterson, M.N., R.R. Lopez, N.J. Silvy, C.B. Owen, P.A. Frank and A.W. Braden. 2003. Evaluation of deer-exclusion grates in urban areas. Wildlife Society Bulletin, Vol. 31, pp. 1198–1204.

Reed, D.F., T.D.I Beck and T.N. Woodard. 1982. Methods of reducing deer–vehicle accidents: Benefit–cost analysis. Wildlife Society Bulletin, Vol. 10, pp. 349–354.

Reed, D.F., T.M. Pojar and T.N. Woodard. 1974. Mule deer responses to deer guards. Journal of Range Management, Vol. 27, No. 2, pp. 111–113.

Sebesta, J.D., S.W. Whisenant, R.R. Lopez and N.J. Silvy. 2003. Development of a deer-guard prototype for Florida Key deer. Proceedings of the Annual Conference, Southeast Fish and Wildlife Agencies, Vol. 57, pp. 337–347.

CHAPTER 3

THE EFFECT OF STRUCTURAL CHARACTERISTICS, LANDSCAPE PARAMETERS, AND HUMAN DISTURBANCE ON THE USE OF UNDERPASSES BY DEER AND BLACK BEAR

Contribution of Authors and Co-Authors

Manuscript in Chapter 3:

Co-author: Tiffany D.H. Allen
Contributions: Design, executed study, analysis and interpretation of data, writing and revising of article

Co-author: Marcel P. Huijser
Contributions: Conception and design, executed study, analysis and interpretation of data, revising of article

Co-author: David W. Willey
Contributions: Design, analysis and interpretation of data, revising of article

Co-author: Whisper Camel
Contributions: Conception, executed study, revising of article

Co-author: Pat Basting
Contributions: Conception, revising of article

Co-author: Dale Becker
Contributions: Conception, revising of article

Manuscript Information Page

Tiffany D.H. Allen; Marcel P. Huijser; David W. Willey; Whisper Camel; Pat Basting; Dale Becker

- Journal Name: Journal of Wildlife Management
- Status of manuscript (check one)
  _x_Prepared for submission to a peer-reviewed journal
  ___Officially submitted to a peer-reviewed journal
  ___Accepted by a peer-reviewed journal
  ___Published in a peer-reviewed journal

THE EFFECT OF STRUCTURAL CHARACTERISTICS, LANDSCAPE PARAMETERS, AND HUMAN DISTURBANCE ON THE USE OF UNDERPASSES BY DEER AND BLACK BEAR

TIFFANY D.H. ALLEN,[1] *Western Transportation Institute, Montana State University, PO Box 174250, Bozeman MT 59717, USA*
MARCEL P. HUIJSER, *Western Transportation Institute, Montana State University, PO Box 174250, Bozeman MT 59717, USA*
DAVID W. WILLEY, *Department of Ecology, Montana State University, PO Box 173460, Bozeman MT 59717, USA*
WHISPER CAMEL, *Tribal Natural Resources Department, The Confederated Salish and Kootenai Tribes, P.O. Box 278, Pablo, MT 59855, USA*
PAT BASTING, *Montana Department of Transportation, 2100 W. Broadway, Missoula, MT 59802, USA*
DALE BECKER, *Tribal Natural Resources Department, The Confederated Salish and Kootenai Tribes, P.O. Box 278, Pablo, MT 59855, USA*
[1] *E-mail: tiffany.allen@coe.montana.edu*

Abstract

Roads and traffic affect wildlife on multiple organizational scales (e.g. from individuals to populations), as well as on different spatial scales (e.g. local patch to landscapes). Wildlife mortality is a direct consequence of roads at the individual level. Wildlife–vehicle collisions (WVCs) not only affect wildlife, but these types of collisions are also costly and dangerous to humans. Mitigation measures, such as wildlife exclusion fencing and crossing structures, reduce WVCs while still allowing wildlife to cross the road. In this study, we investigated which underpass structural characteristics, landscape characteristics, and human disturbance factors influenced use by mule deer (*Odocoileus hemionus*), white-tailed deer (*O. virginianus*), and black bear (*Ursus americanus*) along a mitigated section of U.S. Highway 93 from Evaro to Polson, Montana, USA. Using both sand tracking beds and cameras, we monitored wildlife use of 11 underpasses for over two years. We also collected data on structural characteristics, landscape parameters, and human disturbance both in the field and using existing data in a geographic information system. Regression analyses were then conducted and *a priori* models were ranked based on Akaike's information criterion (AIC). We also conducted exploratory analyses using forward selection based on AIC. We found distance to cover to be positively correlated with both mule deer and white-tailed deer use of underpasses. We were not able to identify factors that influenced black bear crossings, and we recommend further study for all three species.

Introduction

Roads and traffic affect wildlife on multiple organizational scales (e.g. from individuals to populations), as well as spatial scales (e.g. local patch to landscapes). There are currently more than 8.4 million lane miles of highway in the United States, with over 6.1 million lane miles in rural areas (Federal Highway Administration 2007). The potential ecological effects on wildlife of vehicles and roads, especially in rural areas, are diverse and include: 1. Loss of habitat as a result of pavement or other unnatural substrate; 2. Direct mortality as a result of collisions with vehicles; 3. Habitat fragmentation as a result of barriers that affect animal movements; and 4. Changed habitat quality adjacent to roads, for example as a result of chemical or noise pollution (Forman and Alexander 1998).

Habitat fragmentation is caused is many human developments, including urbanization, suburbanization, and lands that have been cleared for agriculture. Roads are often an integral part of such developments and are particularly damaging in terms of habitat fragmentation, because they are linear and potentially divide large areas on the landscape. Fragmentation caused by roads has important impacts on wildlife and has become a conservation concern (Wilcox and Murphy 1985, Forman and Alexander 1998, Ferreras 2001). Roads may split large populations into smaller populations, thereby increasing the risk of loss of diversity through genetic drift or inbreeding (Saunders et al. 1991, Forman and Alexander 1998, Ferreras 2001, Epps et al. 2005). Genetic consequences, such as inbreeding depression, may interact with demographic and environmental stochasticity, potentially increasing the chance of population extinction (Mills and Smouse 1994). Genetic divergence provides evidence that roads are a barrier to not only small wildlife, such as the common frog (*Rana temporaria*) (Reh and Seitz 1990) and timber rattlesnake (*Crotalus horridus*) (Clark et al. 2010), but also to large mammals, such as roe deer (*Capreolus capreolus*) (Kuehn et al 2006), desert bighorn sheep (*Ovis canadensis nelson*) (Epps et al. 2005), and grizzly bear (Kendall et al. 2009).

Direct mortality, or road kill, is a consequence of roads at potentially site-specific individual spatial and temporal scales. It is estimated that an average of one million vertebrates are killed on roads in the United States each day (Forman and Alexander 1998, Huijser et al. 2008). Roads and traffic not only affect wildlife, but people are also at risk when animals, particularly large mammals, cross the road. Between one and two million collisions with large animals occur in the United States each year, with about 26,000 human injuries and 200 deaths resulting from these collisions (Huijser et al. 2008).

Fencing can substantially reduce ungulate access to the road corridor (Falk et al. 1978) and has been shown to reduce wildlife–vehicle collisions by ≥79% (Reed et al. 1982, Clevenger et al. 2001, Dodd et al. 2007). However, fencing alone increases the barrier effect of the road, and therefore, increases habitat fragmentation. Many studies have shown that crossing structures are effective in allowing animals to cross the road safely, and all of these studies found that openness (height*width/length) is an important factor for wildlife use (Reed et al. 1975, Foster and Humphrey 1995, Clevenger and Waltho 2000, Ng et al. 2004, Grilo et al. 2008).

Our objective was to identify variables that affect wildlife use of crossing structures in order to improve design and structure placement for future projects. To address this objective, we investigated how underpass structural characteristics (water and openness), landscape characteristics (distance to nearest forest, distance to nearest riparian, edge habitat, and dominant land use), and human disturbance (noise and human presence) influenced use by mule deer (*Odocoileus hemionus*), white-tailed deer (*O. virginianus*), and black bear (*Ursus americanus*) along a mitigated section of U.S. Highway 93, on the Flathead Indian Reservation, Montana, USA.

Study Area

From October 2004 through November 2010, there were eight reconstruction projects along 90.6 kilometers of U.S. Highway 93 from Evaro to Polson, Montana located on the Flathead Indian Reservation. The project corridor is now the site of one of the most extensive wildlife crossing mitigation projects in North America, both in terms of road length and the number of fish and wildlife crossing structures, 41 total (excluding likely future mitigation measures in the Ninepipes area). In addition to crossing structures that allow animals to cross under or over the road safely, the reconstruction included 2.4-m high wildlife exclusion fencing along some road sections intended to restrict access of wildlife to the road corridor.

The Flathead Indian Reservation is home to the Confederated Salish and Kootenai Tribes, which includes Bitterroot Salish, Pend d’Oreille, and Kootenai tribes. U.S. Highway 93 runs north–south through the reservation and was reconstructed to improve safety and allow for higher traffic volume. Our study took place along two road sections where the road reconstruction was completed in 2006. These sections are referred to as “Ravalli Curves” and “Ravalli Hill” and are located just south and just north, respectively, of Ravalli, MT and the junction with MT Highway 200. Along with the reconstruction of the actual road, mitigation measures, including wildlife fencing, wildlife underpasses, jump-outs, and wildlife guards (modified cattle guards) were built. Our two study sections were 7.7 km long in total (Figure 8). The wildlife underpasses varied in type and size. There were four medium mammal culverts (about 1.2–2.8 m wide, 1.2–2.2 m high), five large mammal underpasses (about 6.8–7.7 m wide, 3.4–4.3 m high), and two bridges (about 28.4 and 28.6 m wide, 3.9 and 3.5 m high) (Table 4.). Wildlife guards or gates were at access roads in the study area, and 29 jump-outs were also part of the highway design. Jump-outs are earthen ramps that allow animals that may have entered the fenced road corridor to jump down to safety. Jump-outs should be low enough so that animals will readily jump out of the fenced road corridor but high enough to discourage animals from jumping in. The wildlife guards were paired with a jump-out on the other side of the road. If an animal crossed the wildlife guard into the fenced road corridor, the jump-out on the other side allowed it to escape to safety on the opposite side of the road.

The landscape surrounding the two road sections was diverse and included Palouse prairie grasslands, comprised mainly of wheat grasses, bunch grasses, and needle grasses (McCoy 2005, Camel 2007), cropland, pasture, and forest. The forests are coniferous, including Douglas fir (*Pseudotsuga menziesii*) and ponderosa pine (*Pinus ponderosa*), though there are deciduous trees and shrubs along riparian areas. A railroad and the Jocko River run parallel to the road on the west side of Hwy 93 in the Ravalli Curves area, and the south east corner of the National Bison Range is adjacent to the highway in the Ravalli Hill area.

Average minimum temperatures ranged from -8.2^0 C in winter to 9.8^0 C in summer, and average maximum temperatures ranged from 0.7^0 C in winter to 29.1^0 C in summer. Temperatures ranged from well below -18^0 C to over 38^0 C. Average annual precipitation was 403.4 mm, with precipitation mostly in the form of snow in the fall, winter, and spring and mostly rain in the summer (NRCS 2005).

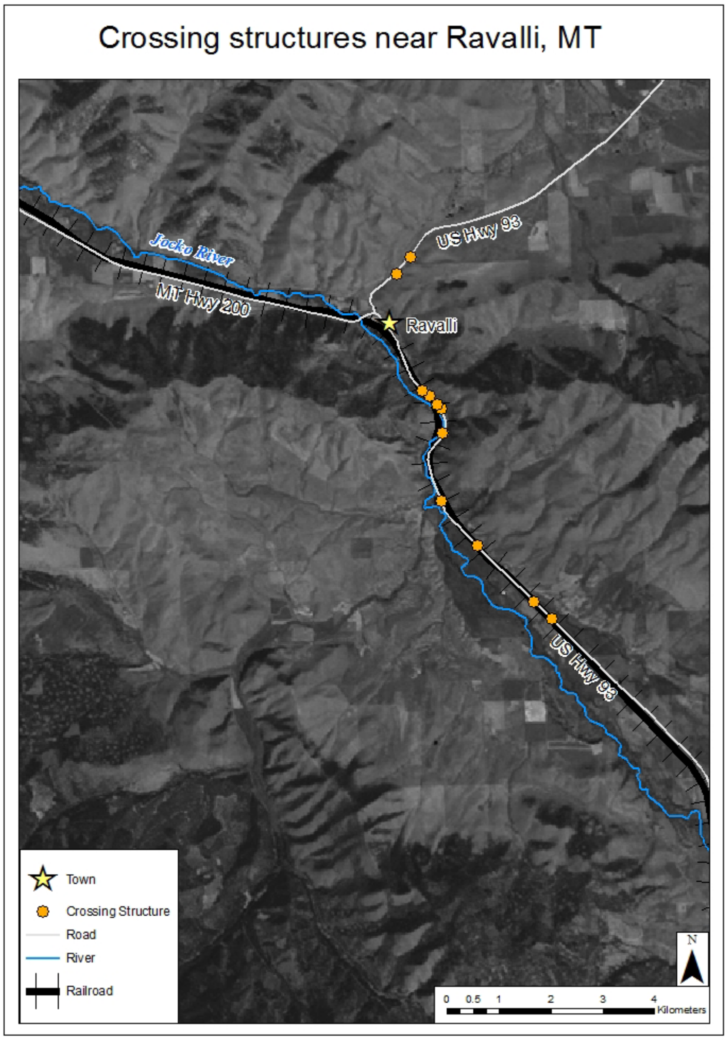

Figure 8. Location of the crossing structures within the 7.7-km study area, with the Ravalli Hill study section to the north of the town of Ravalli, and Ravalli Curves study section to the south of the town of Ravalli.

Methods

Study Design

To monitor wildlife use of the underpasses, sand tracking beds were installed inside 10 of the wildlife crossing structures in May 2008. Tracking beds covered the entire width of the underpasses, excluding areas with standing or moving water, and the tracking beds were about 2 m wide. The tracking beds consisted of weed-free sand, and no weed management was needed for the tracking beds inside the underpasses due to low light and low moisture.

Data were collected twice per week (i.e. once every three to four days) between May and October of 2008 and 2009 and with one week intervals from October to May 2008–2009 and 2009–2010. After checking and recording data from a sand bed, all tracks were erased from the bed. The variables recorded included species, number of crossings, the direction of movement, and the behavior of the animal while on the track bed (crossing, movement parallel to bed, or present on bed but neither of the preceding categories). The observer’s certainty of identification of species was also recorded as “definitely,” “probably,” or “possibly.” In addition, photos of the tracks of all cat and bear species were taken with the date, location, species, and certainty of species recorded in each photo. Data were consistently recorded for all medium to large mammals (i.e. bobcat size and larger). Deer were recorded as mule deer and white-tailed deer combined, because the tracks are indistinguishable (Halfpenny 2001).

Motion sensing and infrared digital trail cameras were used as a remote sensing monitoring tool. One culvert was monitored (about 2.4 m wide and 2.2 m high) with a camera (RECONYX Silent Image^{TM} – Professional, Model PM35) from August 2008 through January 2010. This culvert was inundated with about 0.3 m of water year-round, so it was not possible to monitor this structure with a sand bed.

In addition, we monitored the other 10 underpasses with cameras (RECONYX Silent Image^{TM} – Professional, Model PM35) from March 2010 through July 2010. These cameras allowed us to distinguish between the two deer species. The variables recorded included date and time, species, number of individuals that crossed, number of groups that crossed, and the direction of movement. The observer's certainty of identification of species was also recorded as "definitely," "probably," or "possibly."

To balance the benefit of having data over a longer period of time versus being able to distinguish between deer species, we ran four different analyses, each with a different response variable. We used the sand bed data to quantify crossing structure use in the analyses in which the response variables were 1. the average number of individuals per week of the deer species combined and 2. the average number of individual black bear per week, and we used the photo data to quantify use in the analyses in which the response variables were 3. the average number of groups of mule deer per week and 4. the average number of groups of white-tailed deer per week. For the sand bed data, we counted the number of individual tracks, as we had no way of knowing if it was a single individual crossing or a group crossing together. However, for the photo data, we counted the number of groups that crossed, because several individuals crossing together may only constitute one independent movement. For example, for the photo data, we counted a sow and a cub crossing together as one group movement, because the cub is likely to follow (dependent) the sow.

To investigate the relationship among characteristics of the underpasses, human disturbance, and landscape characteristics surrounding the underpasses to the four above response variables, we measured 15 variables, some at 3 distances for each response variable based on the home range of the different species.

We used 3 different distances for each species to investigate the effects of local and landscape scale variables on black bear and deer use of crossing structures. For the local scale, we examined covariates measured within a 100 m radius of each structure. The furthest distance radii for sample zones was based on estimated home range of each species and was thus different for deer and black bear (Dasmann 1981, Tierson et al. 1985, Mackie et al. 1998, McCoy 2005). For each species, the typical home range was calculated based on previous research. That home range size was then assumed to be a circle, and the radius was calculated for each. The home range of black bears was based on a study conducted on the Highway 93 study area (McCoy) and published in 2005. From that study, we estimated the average radius of the home range of a black bear at 5 km. We found that the radius of a typical home range for mule deer was about 1000 m (Dasmann 1981, Mackie et al. 1998), and the radius of a typical home range for white-tailed deer was about 500 m (Dasmann 1981, Tierson et al. 1985, Mackie et al. 1998). For deer species combined, we chose to use 1000 m for the largest radius, because it covers the typical home range of both species. The middle distance for sampling covariates was calculated by dividing the largest distance (radius), which was species dependent, in half.

The explanatory variables of interest within a 100 m radius of each culvert, with the exception of edge habitat, were measured in the field. The variables of interest beyond 100 m, in addition to edge habitat within 100 m, were measured in ArcEditor (Environmental Systems Research Institute 2009) using a Montana 1:250,000 scale land use layer (USGS 2011).

Structural variables included the amount of water present in the structure and openness (surface area/length) of structures. This is different from most other studies that measured openness. We calculated the actual surface area of the opening of each crossing structure and divided the surface area by the length. Others typically used height*width/length (Reed and Ward 1985), which is imprecise when dealing with oval-shaped underpasses.

Landscape characteristics included distance to the railroad, distance to next nearest crossing structure, distance to nearest coniferous forest cover, distance to nearest riparian cover, distance to nearest building, amount of edge habitat within each of the distances, and the dominant land use within each of the 3 distances. We defined dominant land use as the land use (crop/pasture, grass rangeland, forest, or riparian) that was the most abundant within each of the 3 radii around each crossing structure.

Human disturbance variables included noise level (A-weighted decibels) and human presence. Noise level was measured in the middle of each underpass and 3 feet outside an opening of each underpass and was measured when traffic was passing overhead on the road. Human presence was monitored during the same time periods as animal movements were monitored and was measured as the average number of human tracks on the sand bed per week or the average number of people per week counted in photos. The presence of researchers at each structure was assumed to be equal, and was, therefore, excluded in calculating the average.

We predicted the presence of water would be positively correlated with the use of crossing structures for deer and black bear, as deer and black bear may follow water as a travel corridor or be attracted to water as a drinking source. However, with the exception of the culvert that was continuously inundated, we did not collect data during times when underpasses were inundated with water. Inundation may cause wildlife to be less attracted to structures, because it may result in more difficult passage or create a perceived risk to the animal. We also predicted openness would be positively correlated with deer use and negatively correlated with black bear use. Previous studies found that deer prefer open, less confining structures and black bear prefer less open structures (Reed et al. 1975, Clevenger and Waltho 2005).

We predicted distance to the railroad would be positively correlated with use by deer and black bear. A previous study has shown black bear are more likely to use crossing structures as the distance to the nearest railroad increases (Clevenger and Waltho 2005). We predicted the distance to the next nearest crossing structure would be positively related to use by deer and black bear. The crossing structures within the study area are spaced such that several structures may fall within the home range of black bear and deer (Tierson et al. 1985, McCoy 2005). With all other factors being equal, this reduces the chance that wildlife will use a specific structure. We also predicted that distance to coniferous and riparian cover would be negatively related to black bear and white-tailed deer use and positively correlated with mule deer use. We based our predictions on habitat preferences, as well as on studies of collision sites for white-tailed deer. Several studies have shown that distance to forest is negatively related to the number of white-tailed deer– vehicle collisions (Puglisi et al. 1974, Finder et al. 1999, Nielson et al. 2003). In addition, at least one previous study has shown that deer (*Odocoileus* sp.) prefer structures that do not have cover nearby (Clevenger and Waltho 2005). Other studies have found that black bear select forest habitat (Lyda et al. 2007, Moyer et al. 2008). We predicted that distance to the nearest building would be correlated with use by deer and black bear; however the direction of the relationship is unknown. One study found that deer–vehicle collision sites are negatively correlated with the number of buildings (Nielson et al. 2003). However, another study found that white-tailed deer– vehicle collisions are positively associated with proximity and number of buildings (Huijser et al. 2006). We also predicted that amount of edge habitat would be positively correlated with white-tailed deer use of underpasses, but we did not hypothesize it would be an important predictor for mule deer or black bear. Furthermore, we thought that the dominant land use would be an important predictor for all three species. We predicted that mule deer would prefer more open land use types, and we predicted white-tailed deer and black bear would prefer forest and riparian habitats as dominant land use.

We predicted an increase in noise levels would be negatively correlated with deer and black bear use. Previous studies have found that deer and other species prefer structures with less noise (Clevenger and Waltho 2005, Ruediger 2005). We also predicted that use by all three species would be negatively correlated with human presence. A previous study has shown that as levels of human activity decreased, use by black bear decreased; however, that same study showed that deer use increased (Clevenger and Waltho 2000) (Tables 5–8).

Analyses

Prior to conducting regression analyses, association among continuous explanatory variables was examined using Pearson's correlation analysis, and closely associated variables (≥0.6) were eliminated from each of our model sets. To account for missing data due to flooding or freezing of the sand beds, we used the average number of animals per week as the response variable. We included only observations with an observer certainty of "definitely" in this average. We did not test for seasonal or year effects because of the missing data. However, we examined the response variable for correlation across years using a Pearson's correlation analysis. Averages across years were correlated, so we took one average across both years for each underpass and used it as our response variable for subsequent analyses. Regression analyses were conducted and *a priori* models were ranked based on Akaike's information criterion (AIC).

After conducting our *a priori* analyses, we did exploratory analyses to help formulate hypotheses for future studies. We used forward selection based on AIC, and included all of our variables as potential explanatory variables. All analyses were conducted using R 2.10.1 (R Development Core Team 2009).

Results

Monitoring the underpasses with track beds over a two year period and the cameras over a five month period, we observed 17 medium to large mammal species with an observer certainty of "definitely," including American beaver (*Castor canadensis*), badger (*Taxidea taxus*), black bear, bobcat (*Lynx rufus*), coyote (*Canis latrans*), domestic cat (*Felis catus*), domestic dog (*Canis familiaris*), elk (*Cervus elaphus*), horse (*Equus ferus*), human (*Homo sapiens*), mountain lion (*Puma concolor*), mule deer, northern river otter (*Lutra canadensis*), raccoon (*Procyon lotor*), red fox (*Vulpes vulpes*), striped skunk (*Mephitis mephitis*), and white-tailed deer.

Noise level inside the crossing structures was correlated with openness (0.80) and noise level outside the structures (0.77) and was eliminated from our models. Noise level outside the structures was correlated with edge habitat within all three distances, 100 m (0.63), 250 m (0.74), and 500 m (0.63). We included edge habitat only in models for white-tailed deer and did not include noise in this candidate model list. Distance to the nearest crossing structure was correlated with edge habitat within 250 m and 500 m and was eliminated from our model lists. Finally, edge habitat within 250 m and 500 m was correlated (0.89), as well as edge habitat within 250 m and 100 m (0.71), so only edge habitat within 100 m was included in our model list for white-tailed deer. (Table 9)

Based on our *a priori* analysis, there were two top models for black bears, including distance to forest, $y = \beta_0 + \beta_1(F)$ and the intercept only model, $y = \beta_0$ (Table

10). The effect of distance to forest was not significant (β_1(F), $p = 0.07$; $\beta_1 = -1.15e\text{-}04$, SE = 5.70e-05) at the alpha level of 0.05. The 95 percent confidence interval also overlapped zero (95% CI = -0.0002, 1.36e-05), and only 31.3 percent of the variation was explained with this model ($R^2 = 0.313$). The intercept had a significant p-value (β_0, $p = 0.02$; $\beta_0 = 0.22$, SE = 0.08), and the 95 percent confidence intervals did not overlap zero (β_0, 95% CI = 0.04, 0.40) (Figure 9).

The most parsimonious model for both deer species combined was the intercept only model, $y = \beta_0$. (Table 11). The intercept had a significant p-value (β_0, $p = 0.049$; $\beta_0 = 2.55$, SE = 1.14), and the 95 percent confidence intervals did not overlap zero (β_0, 95% CI = 0.01, 5.08) (Figure 10).

There was one top model for mule deer, which included distance to riparian vegetation, $y = \beta_0 + \beta_1(R)$ (Table 12). About 79.7 percent of the variation was explained in this model ($R^2 = 0.797$). The variable distance to riparian had a highly significant p-value (β_1(R), $p < 0.001$; $\beta_1 = 0.01$, SE = 0.002) and a 95 percent confidence interval that did not overlap zero (95% CI = 0.0077, 0.0185) (Figure 11). In other words, an average of 0.01 more mule deer crossed per week with every one meter increase in the distance to riparian vegetation.

The most parsimonious model for white-tailed deer included distance to forest, $y = \beta_0 + \beta_1(F)$ (Table 13). Forty-five percent of the variation was explained in this model ($R^2 = 0.450$). The variable distance to forest had a significant p-value (β_1(F), $p = 0.03$; $\beta_1 = 0.006$, SE = 0.002) and a 95 percent confidence interval that does not overlap zero

(95% CI = 0.0005, 0.0106) (Figure 12). An average of 0.006 more white-tailed deer crossed per week with every one meter increase in the distance to forest.

In our exploratory analysis for black bear using forward selection based on AIC, we found the model including distance to forest and noise, $y = \beta_0 + \beta_1(F) + \beta_2(noise)$, to have the lowest AIC value. However, all the models including more parameters, including the global model were just as well supported (within 2 AIC points). The p-values were also not significant for the model $y = \beta_0 + \beta_1(F) + \beta_2(noise)$ ($\beta_1(F)$, $p = 0.09$; $\beta_1 = -1.04e-04$, SE = 5.43e-05; $\beta_2(noise)$, $p = 0.18$; $\beta_2 = 1.10e-02$, SE = 7.53e-03). For both deer species combined, mule deer, and white-tailed deer, forward selection based on AIC resulted in the global models, including all possible variables, being the best models.

Discussion

We observed a large variety of species across many taxa moving through the underpasses included in our study. This indicates that there is at least some degree of permeability across the road for many wildlife species.

Our study also identified landscape-based covariates that may have been important for facilitating wildlife use of crossing structures. For mule deer, the best approximating model included distance from an underpass entrance to riparian vegetation. This model suggests that the average number of mule deer increases by 1 for every 100 m further away riparian vegetation is from the underpass. This finding is what we expected given mule deer habitat preference of more open grassland (Martinka 1968).

The best supported model for white-tailed deer included distance from an underpass entrance to forest. This model suggests that the average number of white-tailed deer increases by 0.6 for every 100 m further away forest is from the underpass. However, this effect is the opposite of what we expected based on other studies and literature on white-tailed deer habitat, and we hypothesize that this finding may be an artifact. This result may be due to the presence of cropland and pasture in the immediate vicinity of two of the underpasses that received the most use by white-tailed deer. White-tailed deer may have been attracted to use these two structures more often to gain access to a desirable food source. Given that cropland and forest areas were mutually exclusive, crossing structures with cropland nearby were further from forest. This is perhaps the reason that our results indicated the opposite effect of distance to forest than what we predicted.

Neither our *a priori* analyses to find which factors may influence black bear and deer species combined, nor our exploratory analyses yielded any statistically significant or biologically meaningful results. In addition, our exploratory analyses for both mule and white-tailed deer did not show any significant effects.

Previous studies have shown that habitat variables, including distance to cover, human activity, noise, and openness are all important factors influencing use of crossing structures by wildlife, particularly deer (Reed et al. 1975, Rodriguez et al. 1996, Clevenger and Waltho 2000, Clevenger and Waltho 2005, Ruediger 2005). Openness seems to be particularly important in determining whether or not deer and other wildlife use a crossing structure, as indicated by much of the literature (Reed et al. 1975, Reed 1981, Singer and Doherty 1985, Yanes et al. 1995, Rodriguez et al. 1996, Clevenger and

Waltho 2000, Ng et al. 2003, Clevenger and Waltho 2005, Ruediger 2005, Ascensao and Mira 2007).

The fact that we did not find openness to be an important factor in predicting black bear and deer use of crossing structures may be a product of the way we tested for significance. Of the four medium mammal culverts, only two were used by deer, and those were only used by a total of three deer. Perhaps openness is not linearly related to the number of deer, black bear, or other wildlife crossings, but it may be that there is a minimum or maximum threshold, depending on species.

Previous studies have also suggested a learning curve, or time period in which wildlife adapt to new underpasses (Clevenger and Waltho 2003). Our lack of significant findings may also be at least partially due to the fact that we collected data for two years almost immediately after construction was completed. This could affect the results, especially if the learning curve differs at different sites.

Management Implications

Based on this study, as well as findings from previous studies, the authors recommend that transportation officials and biologists consider landscape factors, especially distance to cover, when deciding on the location of new crossing structures. Our findings indicate that structures near riparian areas may not always be the best location, as is often thought, particularly if the target species is mule deer.

Despite the fact that we did not find openness to be a significant factor, we still suggest that it is important. Depending on the target species, a minimum or maximum openness should be considered when planning construction of future crossing structures.

We also recommend further study. As the number of studies increases, and particularly the sample size within a study, the chance of finding more significant and reliable results increases. This may be particularly important for finding an optimal openness ratio because dimensions not only influence which species use crossing structures and how readily those species will use the structures, but dimensions also play a large part in determining the cost of a structure and its constructability at a given site. Balancing the needs of wildlife while balancing the cost to society will help ensure continued implementation of mitigation measures, such as crossing structures, thereby decreasing the negative impacts of roads on wildlife.

Acknowledgments

The authors would like to thank both of our funding sources: Research and Innovative Technologies Administration, U.S. Department of Transportation and S&K Electronics. We appreciate the cooperation of the Confederated Salish and Kootenai Tribes and their willingness to let us conduct research on the reservation. We would also like to thank the Montana Department of Transportation, especially T. Callahan and C. Smith. We would also like to thank S. Creel for his help and input. In addition, we greatly appreciate the help of J. Purdum, M. Rollins, and C.R. Allen.

Table 4. Dimensions (m) of underpasses as seen by approaching animals.

Underpass type	Height	Width	Length
culvert	1.15	1.83	25
culvert	1.61	1.22	21.32
culvert	1.4	2.8	21.65
culvert	2.24	2.4	29
culvert	4.25	7.4	39.2
culvert	3.4	6.8	25.8
culvert	4.1	7.47	32.5
culvert	3.4	6.8	22.1
culvert	3.5	7.7	18.4
bridge	3.9	28.4	11.5
bridge	3.5	28.6	11.5

Table 5. *A priori* candidate model variable descriptions, abbreviations, structures, and predicted effects of structural characteristics, landscape characteristics, and human activity on black bear.

Variable	Abbreviation	Model structure	Expected effect
Intercept only		β_0	
Openness	O	$\beta_0 + \beta_1(O)$	$\beta_1<0$
Distance to riparian	R	$\beta_0 + \beta_1(R)$	$\beta_1<0$
Dominant land use (100 m)	$DL_{100\text{ m}}$	$\beta_0 + \beta_1(DL_{100\text{ m}})$	$\beta_1>0$
Openness + Distance to riparian	O + R	$\beta_0 + \beta_1(O) + \beta_2(R)$	$\beta_1<0$, $\beta_2<0$
Distance to forest	F	$\beta_0 + \beta_1(F)$	$\beta_1<0$
Openness + Distance to forest	O + F	$\beta_0 + \beta_1(O) + \beta_2(F)$	$\beta_1<0$, $\beta_2<0$
Human presence	H	$\beta_0 + \beta_1(H)$	$\beta_1<0$
All variables	Global	$\beta_0 + \beta_1(O) + \beta_2(R) + \beta_3(DL_{100\text{ m}}) + \beta_4(F) + \beta_5(H)$	$\beta_1<0$, $\beta_2<0$, $\beta_3>0$, $\beta_4<0$, $\beta_5<0$

Table 6. *A priori* candidate model variable descriptions, abbreviations, structures, and predicted effects of structural characteristics, landscape characteristics, and human activity on deer species combined.

Variable	**Abbreviation**	**Model structure**	**Expected effect**
Intercept only		β_0	
Openness	O	$\beta_0 + \beta_1(O)$	$\beta_1>0$
Human presence	H	$\beta_0 + \beta_1(H)$	$\beta_1<0$
Openness + Human presence	O + H	$\beta_0 + \beta_1(O) + \beta_2(H)$	$\beta_1>0$, $\beta_2<0$
Openness + Water	O + W	$\beta_0 + \beta_1(O) + \beta_2(W)$	$\beta_1>0$, $\beta_1>0$
Human presence + Water	H + W	$\beta_0 + \beta_1(H) + \beta_2(W)$	$\beta_1<0$, $\beta_1>0$
All variables	Global	$\beta_0 + \beta_1(O) + \beta_2(H) + \beta_3(W)$	$\beta_1<0$, $\beta_2<0$, $\beta_3>0$

Table 7. *A priori* candidate model variable descriptions, abbreviations, structures, and predicted effects of structural characteristics, and landscape characteristics on mule deer.

Variable	**Abbreviation**	**Model structure**	**Expected effect**
Intercept only		β_0	
Openness	O	$\beta_0 + \beta_1(O)$	$\beta_1>0$
Distance to forest	F	$\beta_0 + \beta_1(F)$	$\beta_1>0$
Distance to riparian	R	$\beta_0 + \beta_1(R)$	$\beta_1>0$
Dominant land use (100 m)	$DL_{100\text{ m}}$	$\beta_0 + \beta_1(DL_{100\text{ m}})$	$\beta_1<0$
Dominant land use (500 m)	$DL_{500\text{ m}}$	$\beta_0 + \beta_1(DL_{500\text{ m}})$	$\beta_1<0$
Openness + Distance to forest	O + F	$\beta_0 + \beta_1(O) + \beta_2(F)$	$\beta_1>0$, $\beta_2>0$
Openness + Distance to riparian	O + R	$\beta_0 + \beta_1(O) + \beta_2(R)$	$\beta_1>0$, $\beta_2>0$
All variables	Global	$\beta_0 + \beta_1(O) + \beta_2(F) + \beta_3(R) + \beta_4(DL_{100\text{ m}}) + \beta_5(DL_{500\text{ m}})$	$\beta_1<0$, $\beta_2>0$, $\beta_3>0$, $\beta_4<0$, $\beta_5<0$

Table 8. *A priori* candidate model variable descriptions, abbreviations, structures, and predicted effects of structural characteristics, and landscape characteristics on white-tailed deer.

Variable	**Abbreviation**	**Model structure**	**Expected effect**
Intercept only		β_0	
Openness	O	$\beta_0 + \beta_1(O)$	$\beta_1>0$
Distance to forest	F	$\beta_0 + \beta_1(F)$	$\beta_1>0$
Distance to riparian	R	$\beta_0 + \beta_1(R)$	$\beta_1>0$
Dominant land use (100 m)	$DL_{100\ m}$	$\beta_0 + \beta_1(DL_{100\ m})$	$\beta_1<0$
Dominant land use (500 m)	$DL_{500\ m}$	$\beta_0 + \beta_1(DL_{500\ m})$	$\beta_1<0$
Openness + Distance to forest	O + F	$\beta_0 + \beta_1(O) + \beta_2(F)$	$\beta_1>0$, $\beta_2>0$
Openness + Distance to riparian	O + R	$\beta_0 + \beta_1(O) + \beta_2(R)$	$\beta_1>0$, $\beta_2>0$
All variables	Global	$\beta_0 + \beta_1(O) + \beta_2(F) + \beta_3(R) + \beta_4(DL_{100\ m}) + \beta_5(DL_{500\ m})$	$\beta_1<0$, $\beta_2>0$, $\beta_3>0$, $\beta_4<0$, $\beta_5<0$

Table 9. Results of Pearson correlation for all continuous explanatory variables.

	openness	**noise (inside)**	**noise (outside)**	**human presence**	**dist to CS**	**dist to forest**	**dist to riparian**	**edge habitat (100m)**	**edge habitat (250m)**	**edge habitat (500m)**
openness	1.00									
noise (inside)	0.80	1.00								
noise (outside)	0.49	0.77	1.00							
human presence	-0.01	-0.18	-0.36	1.00						
dist to CS	0.16	0.02	-0.31	0.30	1.00					
dist to forest	0.37	0.20	-0.14	-0.05	0.43	1.00				
dist to riparian	-0.11	-0.50	-0.48	-0.07	0.04	-0.14	1.00			
edge habitat (100m)	0.15	0.50	0.63	-0.18	-0.35	-0.39	-0.20	1.00		
edge habitat (250m)	0.01	0.41	0.74	-0.36	-0.73	-0.41	-0.37	0.71	1.00	
edge habitat (500m)	-0.18	0.27	0.63	-0.44	-0.64	-0.32	-0.43	0.47	0.89	1.00

Table 10. *A priori* model selection results based on a multiple regression of the average number of black bears per week (via 11 crossing structures) on various habitat covariates. Candidate models were ranked by AIC (and ΔAIC), where *k* is number of parameters, w_i is the model weight.

Model	***k***	**AIC**	**ΔAIC**	**w_i**
distance to forest	2	-30.23	0.00	0.4297
intercept only	1	-29.10	1.13	0.2442
human presence	2	-26.80	3.43	0.0773
distance to riparian	2	-26.65	3.58	0.0717
openness + distance to forest	3	-26.30	3.93	0.0602
dominant land use (100 m)	2	-26.16	4.07	0.0561
openness	2	-26.11	4.12	0.0548
openness + distance to riparian	3	-21.65	8.58	0.0059
global	5	-12.52	17.71	0.0001

Table 11. *A priori* model selection results based on a multiple regression of the average number of white-tailed and mule deer, combined, per week (via 11 crossing structures) on various habitat covariates. Candidate models were ranked by AIC (and ΔAIC), where *k* is number of parameters, *wi* is the model weight.

Model	***k***	**AIC**	**ΔAIC**	**w_i**
intercept only	1	28.18	0.00	0.56
openness	2	30.21	2.03	0.20
human presence	2	32.18	4.00	0.08
openness + water	3	32.53	4.35	0.06
human presence + water	3	32.76	4.58	0.06
openness + noise	3	33.84	5.66	0.03
openness + human presence	3	35.21	7.03	0.02
global	5	46.05	17.87	0.00

Table 12. *A priori* model selection results based on a multiple regression of the average number of mule deer per week (via 10 crossing structures) on various habitat covariates. Candidate models were ranked by AIC (and ΔAIC), where *k* is number of parameters, w_i is the model weight.

Model	***k***	**AIC**	**ΔAIC**	$\mathbf{w_i}$
distance to riparian	2	1.05	0.00	0.85590
openness + distance to riparian	3	4.66	3.61	0.14077
intercept only	1	14.01	12.96	0.00131
dominant land use (100 m)	2	14.91	13.86	0.00084
dominant land use (500 m)	2	15.85	14.80	0.00052
distance to forest	2	16.89	15.84	0.00031
openness	2	17.00	15.95	0.00029
openness + distance to forest	3	21.68	20.63	0.00003
global	6	22.80	21.75	0.00002

Table 13. *A priori* model selection results based on a multiple regression of the average number of white-tailed deer per week (via 10 crossing structures) on various habitat covariates. Candidate models were ranked by AIC (and ΔAIC), where *k* is number of parameters, w_i is the model weight.

Model	***k***	**AIC**	**ΔAIC**	$\mathbf{w_i}$
distance to forest	2	40.83	0.00	0.66533
intercept only	1	43.80	2.97	0.15070
edge habitat (100 m)	2	45.95	5.12	0.05143
openness	2	46.34	5.51	0.04232
distance to riparian	2	46.57	5.74	0.03772
water + edge habitat (100 m)	3	46.60	5.77	0.03716
openness + edge habitat (100 m)	3	50.21	9.38	0.00611
edge habitat (100 m) + distance to riparian	3	50.45	9.62	0.00542
openness + distance to riparian	3	51.18	10.35	0.00376
global	6	60.43	19.60	0.00004

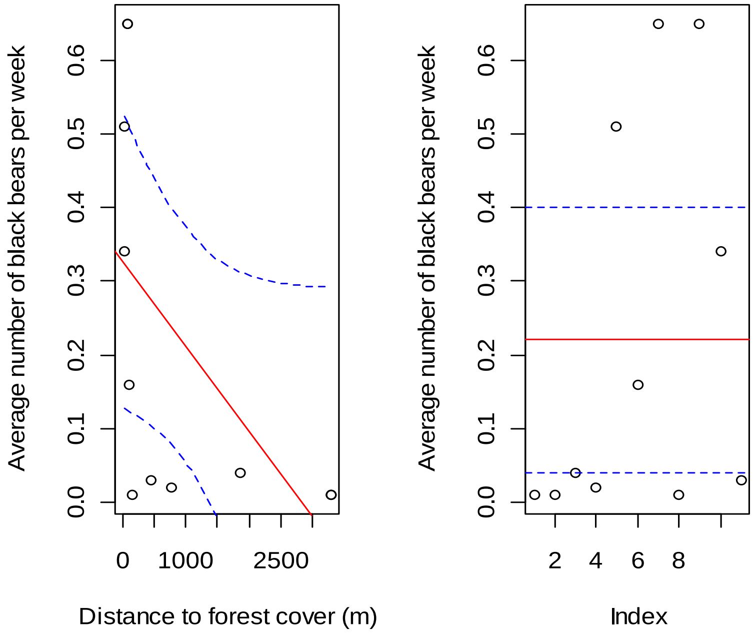

Figure 9. Plots of the raw data, the function fit to the data, and 95% confidence bands for the two top models for black bear, including distance to forest ($y = \beta_0 + \beta_1(F)$) and the intercept only model ($y = \beta_0$).

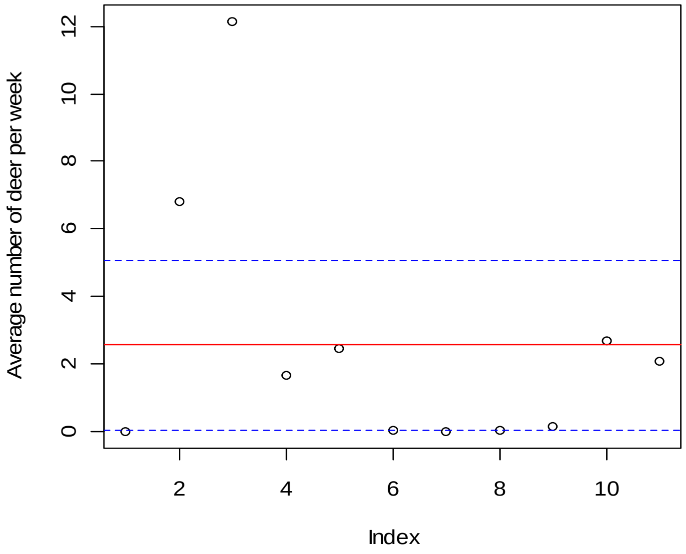

Figure 10. Plot of the raw data, the function fit to the data, and 95% confidence bands for the top model for deer species combined, the intercept only model ($y = \beta_0$).

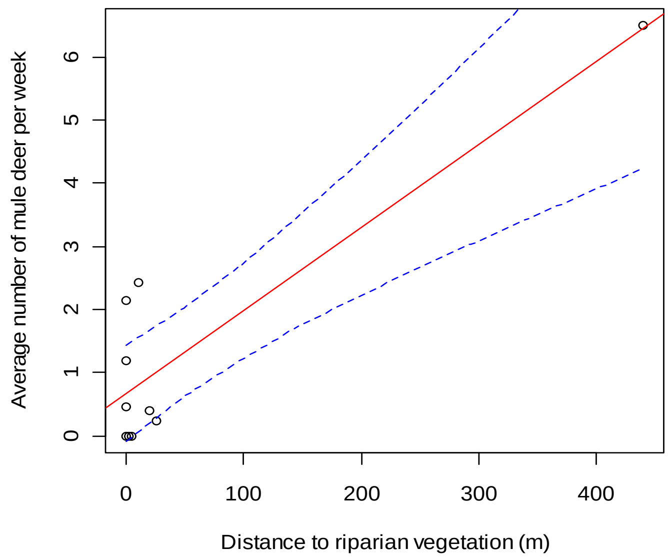

Figure 11. Plot of the raw data, the function fit to the data, and 95% confidence bands for the top model for mule deer, including distance to riparian ($y = \beta_0 + \beta_1(R)$).

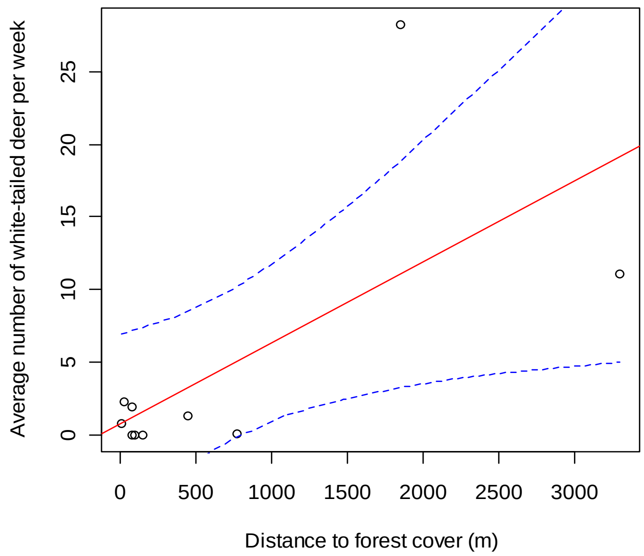

Figure 12. Plot of the raw data, the function fit to the data, and 95% confidence bands for the top model for white-tailed deer, including distance to forest ($y = \beta_0 + \beta_1(F)$).

Literature Cited

Ascensao, F. and A. Mira. 2007. Factors affecting culvert use by vertebrates along two stretches of road in Southern Portugal. Ecological Research, Vol. 22, pp. 57–66.

Camel, W.R. 2007. Where does a deer cross a road? Road and landcover characteristics affecting deer crossing and mortality across the US 93 corridor on the Flathead Indian Reservation, Montana. Thesis, Montana State University, Bozeman, Montana, USA.

Clark, R.W., W.S. Brown, R. Stechert and K.R. Zamudio. 2010. Roads, interrupted dispersal, and genetic diversity in timber rattlesnakes. Conservation Biology, Vol. 24, No. 4, pp. 1059–1069.

Clevenger, A.P., B. Chruszez and K.E. Gunson. 2001. Highway mitigation fencing reduces wildlife–vehicle collisions. Wildlife Society Bulletin, Vol. 29, No. 2, pp. 646–653.

Clevenger, A.P. and N. Waltho. 2000. Factors influencing the effectiveness of wildlife underpasses in Banff National Park, Alberta, Canada. Conservation Biology, Vol.14, No. 1, pp. 47–56.

Clevenger, A.P. and N. Waltho. 2003. Long-term, year-round monitoring of wildlife crossing structures and the importance of temporal and spatial variability in performance studies. ICOET Proceedings, 2003, pp. 293–302.

Clevenger, A.P. and N. Waltho. 2005. Performance Indices to identify attributes of highway crossing structures facilitating movement of large mammals. Biological Conservation, Vol. 121, No. 3, pp. 453–464.

Dasmann,W. 1981. Deer range: improvement and management. McFarland & Company, Inc. Jefferson, North Carolina, USA.

Dodd, N. L., J. W. Gagnon, S. Boe, A. Manzo and R. E. Schweinsburg. 2007. Evaluation of measures to minimize wildlife–vehicle collisions and maintain permeability across highways: Arizona Route 260. Final Report 540. FHWA-AZ-07-540. Arizona Department of Transportation, Phoenix, Arizona, USA.

Environmental Systems Research Institute. 2009. ArcEditor GIS Version 9.3.1. Redlands, California, USA.

Epps, C.W., P.J. Palsbøll, J.D. Wehausen, G.K. Roderick, R.R. Ramey II and D.R. McCullough. 2005. Highways block gene flow and cause a rapid decline in genetic diversity of desert bighorn sheep. Ecology Letters, Vol. 8, pp. 1029–1038.

Falk, N.W., H.B. Graves and E.D. Bellis. 1978. Right-of-way fences as deer deterrents. The Journal of Wildlife Management, Vol. 42, No. 3, pp.646–650.

Ferreras, P. 2001. Landscape structure and asymmetrical inter-patch connectivity in a metapopulation of the endangered Iberian lynx. Biological Conservation, Vol. 100, pp. 125–136.

Finder, R.A., J.L. Roseberry and A. Woolf. 1999. Site and landscape conditions at white-tailed deer/vehicle collision locations in Illinois. Landscape and Urban Planning, Vol. 44, pp. 77–85.

Forman, R.T.T. and L.E. Alexander. 1998. Roads and their major ecological effects. Annual Review of Ecological Systems, Vol. 29, pp. 207–231.

Foster, M.L. and S.R. Humphrey.1995. Use of highway underpasses by Florida panthers and other wildlife. Wildlife Society Bulletin, Vol. 23, No. 1, pp. 95–100.

Grilo, C., J.A. Bissonette and M. Santos-Reis. 2008. Response of carnivores to existing highway culverts and underpasses: implications for road planning and mitigation. Biodiversity and Conservation, Vol. 17, pp. 1685–1699.

Halfpenny, J.C. 2001. Scats and tracks of the Rocky Mountains: a field guide to the signs of seventy wildlife species, second ed. The Global Pequot Press. Guilford, Connecticut, USA.

Huijser, M.P., K.E. Gunson and C. Abrams. 2006. Animal–vehicle collisions and habitat connectivity along Montana highway 83 in the Seeley Swan Valley. Montana: a reconnaissance. Final Report. FHWA/MT-06-002/8177. Western Transportation Institute, College of Engineering, Montana State University, Bozeman, MT, USA.

Huijser, M.P., P. McGowen, J. Fuller, A. Hardy, A. Kociolek, A.P. Clevenger, D. Smith and R. Ament. 2008. Wildlife–vehicle collision reduction study. Report to congress. U.S. Department of Transportation, Federal Highway Administration, Washington D.C., USA. Available from the internet: http://www.tfhrc.gov/safety/pubs/08034/index.htm

Kendall, K.C., J.B. Stetz, J. Boulanger, A.C. MacCleod, D. Paetkau and G.C. White. 2009. Demography and genetic structure of a recovering grizzly bear population. The Journal of Wildlife Management, Vol. 73, No. 1, pp. 3–17.

Kuehn, R., K.E. Hindenlang, O. Holzgang, J. Senn, B. Stoeckle and C. Sperisen. 2007. Genetic effect of transportation infrastructure on roe deer populations (*Capreolus capreolus*). Journal of Heredity, Vol. 98, No. 1, pp. 13–22.

Lyda, S. B., E.C. Hellgren and D.M. Leslie, Jr. 2007. Diurnal habitat selection and home-range size of female black bears in the Ouachita Mountains of Oklahoma. Proceedings of the Oklahoma Academy of Science, Vol. 87, pp.55–64.

Mackie,R. J., D.F. Pac, K.L. Hamlin and G.L. Dusek. 1998. Ecology and management of mule deer and white-tailed deer in Montana. Montana Fish, Wildlife and Parks, Wildlife Division. Helena, Montana, USA.

Martinka, C.J. 1968. Habitat relationships of white-tailed and mule deer in northern Montana. The Journal of Wildlife Management, Vol. 32, No. 3, pp. 558–565.

McCoy. K.R. 2005. Effects of transportation and development on black bear movement, mortality, and use of the Highway 93 corridor in NW Montana. Thesis, University of Montana, Missoula, Montana, USA.

Mills, L.S. and P.E. Smouse. 1994. Demographic consequences of inbreeding in remnant populations. The American Naturalist, Vol. 144, No. 3, pp. 412–431.

Moyer, M.A., J. McCown, O. Walter and K. Madan. 2008. Scale-dependent habitat selection by female Florida black bears in Ocala National Forest, Florida. Southeastern Naturalist, Vol. 7, No. 1, pp. 111–124.

Natural Resources Conservation Service (NRCS). 2005. Montana climate summaries: St. Ignatius. http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?mtstig (accessed on 19 October 2010)

Ng, S.J., J.W. Dole, R.M. Sauvajot, S.P.D. Riley and T.J. Valone. 2004. Use of highway undercrossings by wildlife in southern California. Biological Conservation, Vol. 115, pp. 499–507.

Nielson, C.K., R.G. Anderson and M.D. Grund. 2003. Landscape influences on deer–vehicle accident areas in an urban environment. Journal of Wildlife Management, Vol. 67, No. 1, pp. 46–51.

Puglisi, M.J., J.S. Lindzey and E.D. Bellis. 1974. Factors associated with highway mortality of white-tailed deer. The Journal of Wildlife Management, Vol. 38, No. 4, pp. 799–807.

R Development Core Team. 2009. A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0. Available from the internet: http://www.R-project.org

Reed, D.F. 1981. Mule deer behavior at a highway underpass exit. The Journal of Wildlife Management, Vol. 45, No. 2, pp. 542–543.

Reed, D.F., T.D.I. Beck and T.N. Woodard. 1982. Methods of reducing deer-vehicle accidents: Benefit–cost analysis. Wildlife Society Bulletin, Vol. 10, pp. 349–354.

Reed, D.F. and A.L. Ward. 1985. Efficacy of methods advocated to reduce deer–vehicle collision accidents: research and rationale in the USA. Routes et faune sauvage. Service d'Etudes Techniques de Routes et Autoroutes, Bagneaux, France, pp. 285–293.

Reed, D.F., T.N. Woodward and T.M. Pojar. 1975. Behavioral response of mule deer to a highway underpass. Journal of Wildlife Management, Vol. 39, No. 2, pp. 361–367.

Reh, W. and A. Seitz. 1990. The influence of land use on the genetic structure of populations of the common frog *Rana temporaria*. Biological Conservation, Vol. 54, pp. 239–249.

Rodriguez, A., G. Crema and M. Delibes. 1996. Use of non-wildlife passages across a high speed railway by terrestrial vertebrates. Journal of Applied Ecology, Vol. 33, pp. 1527–1540.

Ruediger, B. 2005. Management considerations for designing carnivore highway crossings. USDA Forest Service, Wildlife, Fish and Watershed Unit.

Saunders, D.A., R.J. Hobbs and C.R. Margules. 1991. Biological consequences of ecosystem fragmentation: a review. Conservation Biology, Vol. 5, No. 1, pp. 18–32.

Singer, F.J. and J.L. Doherty. 1985. Managing mountain goats at a highway crossing. Wildlife Society Bulletin, Vol. 13, pp. 469–477.

Tierson, W.C., G.F. Mattfeld, R.W. Sage, Jr. and D.F. Behrend. 1985. Seasonal movements and home ranges of white-tailed deer in the Adirondacks. Journal of Wildlife Management, Vol. 49, No. 3, pp. 760–769.

United States Geological Survey (USGS). 2011. Land use: 1985. Montana State Library. Available from the internet: http://nris.mt.gov/gis/.

Wilcox, B.A. and D.D. Murphy. 1985. Conservation strategy: the effects of fragmentation on extinction. The American Naturalist, Vol. 125, No. 6, pp. 879–887.

Yanes, M., J.M. Velasco and F. Suárez. 1995. Permeability of roads and railways to vertebrates: the importance of culverts. Biological Conservation, Vol. 71, pp. 217–222.

CHAPTER 4

CONCLUSION

Summary

A majority of the more than 8.4 million lane miles of highway in the United States is in rural areas (Federal Highway Administration 2007). Wildlife biologists and transportation officials are now aware of the ecological effects of vehicles and roads on wildlife and the potential for human injury and property damage resulting from wildlife on the road. Mitigation measures may play an important role in reducing adverse effects on both wildlife and humans. There are four main effects of roads on wildlife: loss of habitat, direct mortality, habitat fragmentation, and reduced habitat quality (Forman and Alexander 1998). In this study, we investigated the effectiveness of mitigation measures aimed at reducing two of these effects, direct mortality and habitat fragmentation. We also investigated factors that may influence the effectiveness of these mitigation measures. In particular, we studied the effectiveness of wildlife guards, which are designed to reduce ungulate access to the road corridor. Restricted access may reduce the risk of ungulate–vehicle collisions, while still allowing vehicles to use access roads. We also studied how structural characteristics, landscape attributes, and human diturbance influence black bear and deer use of underpasses. Previous studies have shown that mitigation measures including fencing or a barrier wall, particularly in combination with crossing structures, reduce vertebrate mortality (Clevenger et al. 2001, Dodd et al. 2004). In reducing mortality and providing a means of crossing the road, it is thought that these mitigation measures also maintain or perhaps improve habitat connectivity. There are a few studies showing crossing structures can increase connectivity at the population level (Mansergh and Scotts 1989, van der Ree et al. 2009), however, further research is needed. Before–after control impact study designs are especially useful in showing these benefits and should be implemented in future research.

Our study did not address changes in direct mortality or habitat connectivity, though we did observe a large variety of medium to large mammal species moving through underpasses in our study area, including American beaver (*Castor canadensis*), badger (*Taxidea taxus*), black bear (*Ursus americanus*), bobcat (*Lynx rufus*), coyote (*Canis latrans*), domestic cat (*Felis catus*), domestic dog (*Canis familiaris*), elk (*Cervus elaphus*), horse (*Equus ferus*), human (*Homo sapiens*), mountain lion (*Puma concolor*), mule deer (*Odocoileus hemionus*), northern river otter (*Lutra canadensis*), raccoon (*Procyon lotor*), red fox (*Vulpes vulpes*), striped skunk (*Mephitis mephitis*), and white-tailed deer (*O. virginianus*). Our study also identified landscape-based covariates that may have been important for facilitating wildlife use of crossing structures. We found that increasing distance between a crossing structure and riparian vegetation or forest cover may have increased use of the structures by mule deer and white-tailed deer, respectively. This finding might be expected given mule deer habitat preference of more open grassland (Martinka 1968); however, the effect was opposite from what we predicted based on other studies of underpass use and literature on white-tailed deer habitat use. The effects we observed on deer may be related to the presence of cropland and pasture attracting white-tailed deer to the area surrounding the two underpasses that received the most use. We were unable to identify which factors influenced black bear and deer species combined.

To our knowledge, only one other study has investigated the effectiveness of wildlife guards at access roads. Our results show the wildlife guards were ≥85% effective as abarrier to deer. The guards were less effective (33 to 55%) for black bear and coyotes, but these species were still moderately deflected from crossing guards. In addition, when presented with two options, most animals crossed the road using the crossing structure rather than the guard, indicating the crossing structure was perceived as a less risky pathway.

We think wildlife guards, particularly the design in our study, should be considered in other areas where transportation professionals and wildlife biologists are attempting to balance the need for access roads and wildlife mitigation measures.

Management Implications

Based on this study, as well as findings from previous studies, the authors recommend that transportation officials and biologists consider landscape factors, especially distance to cover, when deciding on the location of new crossing structures. Our findings indicate that structures near riparian areas may not always be the best location, as is often thought, particularly if the target species is mule deer.

Transportation officials and biologists should also keep in mind that gaps in a fence, even when mitigated with wildlife guards, may reduce the barrier effect of the fence. Though in developed areas where such gaps are necessary, guards do appear to be an effective means of mitigation, particularly where deer are the main species of concern. In addition, pairing a crossing structure with a wildlife guard may further increase the effectiveness of the guard.

Further study is also recommended. As the number of studies of wildlife mitigation measures increases, and particularly as the sample size within studies gets larger, the chance of finding more significant and reliable results increases. Finding optimal designs for mitigation measures not only influences the effectiveness of the measures, but also plays a large part in determining the cost of the measures. Balancing the needs of wildlife while balancing the cost to society will help ensure continued implementation of mitigation measures, such as crossing structures and wildlife guards, thereby decreasing the negative impacts of roads on wildlife.

Literature Cited

Clevenger, A.P., B. Chruszez and K.E. Gunson. 2001. Highway mitigation fencing reduces wildlife–vehicle collisions. Wildlife Society Bulletin, Vol. 29, No. 2, pp. 646–653.

Dodd, C.K. Jr., W.J. Barichivich and L.L. Smith. 2004. Effectiveness of a barrier wall and culverts in reducing wildlife mortality on a heavily traveled highway in Florida. Biological Conservation, Vol. 118, pp, 619–631.

Federal Highway Administration. 2007. Highway Statistics 2007. Lane miles by functional system. http://www.fhwa.dot.gov/policyinformation/statistics/hm60_summary.cfm (accessed on 01 May 2009)

Forman, R.T.T. and L.E. Alexander. 1998. Roads and their major ecological effects. Annual Review of Ecological Systems, Vol. 29, pp. 207–231.

Mansergh, I.M. and D.J. Scotts. 1989. Habitat continuity and social organization of the mountain pygmy-possum restored by tunnel. The Journal of Wildlife Management, Vol. 53, No. 3, pp. 701–707.

Martinka, C.J. 1968. Habitat relationships of white-tailed and mule deer in northern Montana. The Journal of Wildlife Management, Vol. 32, No. 3, pp. 558–565.

van der Ree, R., D. Heinze, M. McCarthy and I. Mansergh. 2009. Wildlife tunnel enhances population viability. Ecology and Society, Vol. 14, No. 2, pp. 7–15.

LITERATURE CITED

Ascensao, F. and A. Mira. 2007. Factors affecting culvert use by vertebrates along two stretches of road in Southern Portugal. Ecological Research, Vol. 22, pp. 57–66.

Bashore, T.L. and E.D. Bellis. 1982. Deer on Pennsylvania airfields: problems and means of control. Wildlife Society Bulletin, Vol. 10, No. 4, pp. 386–388.

Belant, J.L., T.W. Seamans and C.P. Dwyer. 1998. Cattle guards reduce white-tailed deer crossings through fence openings. International Journal of Pest Management, Vol. 44, No. 4, pp. 247–249.

Camel, W.R. 2007. Where does a deer cross a road? Road and landcover characteristics affecting deer crossing and mortality across the US 93 corridor on the Flathead Indian Reservation, Montana. Thesis, Montana State University, Bozeman, Montana, USA.

Clark, R.W., W.S. Brown, R. Stechert and K.R. Zamudio. 2010. Roads, interrupted dispersal, and genetic diversity in timber rattlesnakes. Conservation Biology, Vol. 24, No. 4, pp. 1059–1069.

Clevenger, A.P., B. Chruszez and K.E. Gunson. 2001. Highway mitigation fencing reduces wildlife–vehicle collisions. Wildlife Society Bulletin, Vol. 29, No. 2, pp. 646–653.

Clevenger, A.P. and N. Waltho. 2000. Factors influencing the effectiveness of wildlife underpasses in Banff National Park, Alberta, Canada. Conservation Biology, Vol.14, No. 1, pp. 47–56.

Clevenger, A.P. and N. Waltho. 2003. Long-term, year-round monitoring of wildlife crossing structures and the importance of temporal and spatial variability in performance studies. ICOET Proceedings, 2003, pp. 293–302.

Clevenger, A.P. and N. Waltho. 2005. Performance Indices to identify attributes of highway crossing structures facilitating movement of large mammals. Biological Conservation, Vol. 121, No. 3, pp. 453–464.

Dasmann,W. 1981. Deer range: improvement and management. McFarland & Company, Inc. Jefferson, North Carolina, USA.

Dodd, C.K. Jr., W.J. Barichivich and L.L. Smith. 2004. Effectiveness of a barrier wall and culverts in reducing wildlife mortality on a heavily traveled highway in Florida. Biological Conservation, Vol. 118, pp, 619–631.

Dodd, N. L., J. W. Gagnon, S. Boe, A. Manzo and R. E. Schweinsburg. 2007. Evaluation of measures to minimize wildlife–vehicle collisions and maintain permeability across highways: Arizona Route 260. Final Report 540. FHWA-AZ-07-540. Arizona Department of Transportation, Phoenix, Arizona, USA.

Environmental Systems Research Institute. 2009. ArcEditor GIS Version 9.3.1. Redlands, California, USA.

Epps, C.W., P.J. Palsbøll, J.D. Wehausen, G.K. Roderick, R.R. Ramey II and D.R. McCullough. 2005. Highways block gene flow and cause a rapid decline in genetic diversity of desert bighorn sheep. Ecology Letters, Vol. 8, pp. 1029–1038.

Falk, N.W., H.B. Graves and E.D. Bellis. 1978. Right-of-way fences as deer deterrents. The Journal of Wildlife Management, Vol. 42, No. 3, pp.646–650.

Federal Highway Administration. 2007. Highway Statistics 2007. Lane miles by functional system. http://www.fhwa.dot.gov/policyinformation/statistics/hm60_summary.cfm (accessed on 14 October 2010)

Ferreras, P. 2001. Landscape structure and asymmetrical inter-patch connectivity in a metapopulation of the endangered Iberian lynx. Biological Conservation, Vol. 100, pp. 125–136.

Finder, R.A., J.L. Roseberry and A. Woolf. 1999. Site and landscape conditions at white-tailed deer/vehicle collision locations in Illinois. Landscape and Urban Planning, Vol. 44, pp. 77–85.

Forman, R.T.T. 2000. Estimate of the area affected ecologically by the road system in the United States. Conservation Biology, Vol. 14, No. 1, pp. 31–35.

Forman, R.T.T. and L.E. Alexander. 1998. Roads and their major ecological effects. Annual Review of Ecological Systems, Vol. 29, pp. 207–231.

Foster, M.L. and S.R. Humphrey.1995. Use of highway underpasses by Florida panthers and other wildlife. Wildlife Society Bulletin, Vol. 23, No. 1, pp. 95–100.

Grilo, C., J.A. Bissonette and M. Santos-Reis. 2008. Response of carnivores to existing highway culverts and underpasses: implications for road planning and mitigation. Biodiversity and Conservation, Vol. 17, pp. 1685–1699.

Halfpenny, J.C. 2001. Scats and tracks of the Rocky Mountains: a field guide to the signs of seventy wildlife species, second ed. The Global Pequot Press. Guilford, Connecticut, USA.

Hardy, A., J. Fuller, M.P. Huijser, A. Kociolek and M. Evans. 2007. Evaluation of wildlife crossing structures and fencing on US Hwy 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 (2007) 210 pp. Available from the internet: http://www.mdt.mt.gov/research/projects/env/wildlife_crossing.shtml

Huijser, M.P., R. Ament, W. Camel and D. Becker. 2010. US 93 Post-construction wildlife–vehicle collision and wildlife crossing monitoring and research proposal. Western Transportation Institute and Department of Ecology at Montana State University – Bozeman, Montana, USA.

Huijser, M.P., K.E. Gunson and C. Abrams. 2006. Animal–vehicle collisions and habitat connectivity along Montana highway 83 in the Seeley Swan Valley. Montana: a reconnaissance. Final Report. FHWA/MT-06-002/8177. Western Transportation Institute, College of Engineering, Montana State University, Bozeman, MT, USA.

Huijser, M.P., P. McGowen, A.P. Clevenger and R. Ament. 2008. Best Practices Manual. Report to congress. U.S. Department of Transportation, Federal Highway Administration, Washington D.C., USA.

Huijser, M.P., P. McGowen, J. Fuller, A. Hardy, A. Kociolek, A.P. Clevenger, D. Smith and R. Ament. 2008. Wildlife–vehicle collision reduction study. Report to congress. U.S. Department of Transportation, Federal Highway Administration, Washington D.C., USA. Available from the internet: http://www.tfhrc.gov/safety/pubs/08034/index.htm

Kendall, K.C., J.B. Stetz, J. Boulanger, A.C. MacCleod, D. Paetkau and G.C. White. 2009. Demography and genetic structure of a recovering grizzly bear population. The Journal of Wildlife Management, Vol. 73, No. 1, pp. 3–17.

Kuehn, R., K.E. Hindenlang, O. Holzgang, J. Senn, B. Stoeckle and C. Sperisen. 2007. Genetic effect of transportation infrastructure on roe deer populations (*Capreolus capreolus*). Journal of Heredity, Vol. 98, No. 1, pp. 13–22.

Lyda, S. B., E.C. Hellgren and D.M. Leslie, Jr. 2007. Diurnal habitat selection and home-range size of female black bears in the Ouachita Mountains of Oklahoma. Proceedings of the Oklahoma Academy of Science, Vol. 87, pp.55–64.

Mackie,R. J., D.F. Pac, K.L. Hamlin and G.L. Dusek. 1998. Ecology and management of mule deer and white-tailed deer in Montana. Montana Fish, Wildlife and Parks, Wildlife Division. Helena, Montana, USA.

Mansergh, I.M. and D.J. Scotts. 1989. Habitat continuity and social organization of the mountain pygmy-possum restored by tunnel. The Journal of Wildlife Management, Vol. 53, No. 3, pp. 701–707.

Martinka, C.J. 1968. Habitat relationships of white-tailed and mule deer in northern Montana. The Journal of Wildlife Management, Vol. 32, No. 3, pp. 558–565.

McCoy. K.R. 2005. Effects of transportation and development on black bear movement, mortality, and use of the Highway 93 corridor in NW Montana. Thesis, University of Montana, Missoula, Montana, USA.

Mills, L.S. and P.E. Smouse. 1994. Demographic consequences of inbreeding in remnant populations. The American Naturalist, Vol. 144, No. 3, pp. 412–431.

Moyer, M.A., J. McCown, O. Walter and K. Madan. 2008. Scale-dependent habitat selection by female Florida black bears in Ocala National Forest, Florida. Southeastern Naturalist, Vol. 7, No. 1, pp. 111–124.

Natural Resources Conservation Service (NRCS). 2005. Montana climate summaries: St. Ignatius. http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?mtstig (accessed on 19 October 2010)

Ng, S.J., J.W. Dole, R.M. Sauvajot, S.P.D. Riley and T.J. Valone. 2004. Use of highway undercrossings by wildlife in southern California. Biological Conservation, Vol. 115, pp. 499–507.

Nielson, C.K., R.G. Anderson and M.D. Grund. 2003. Landscape influences on deer–vehicle accident areas in an urban environment. Journal of Wildlife Management, Vol. 67, No. 1, pp. 46–51.

Peterson, M.N., R.R. Lopez, N.J. Silvy, C.B. Owen, P.A. Frank and A.W. Braden. 2003. Evaluation of deer-exclusion grates in urban areas. Wildlife Society Bulletin, Vol. 31, pp. 1198–1204.

Puglisi, M.J., J.S. Lindzey and E.D. Bellis. 1974. Factors associated with highway mortality of white-tailed deer. The Journal of Wildlife Management, Vol. 38, No. 4, pp. 799–807.

R Development Core Team. 2009. A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0. Available from the internet: http://www.R-project.org

Reed, D.F. 1981. Mule deer behavior at a highway underpass exit. The Journal of Wildlife Management, Vol. 45, No. 2, pp. 542–543.

Reed, D.F., T.D.I . Beck and T.N. Woodard. 1982. Methods of reducing deer–vehicle accidents: Benefit–cost analysis. Wildlife Society Bulletin, Vol. 10, pp. 349–354.

Reed, D.F., T.M. Pojar and T.N. Woodard. 1974. Mule deer responses to deer guards. Journal of Range Management, Vol. 27, No. 2, pp. 111–113.

Reed, D.F. and A.L. Ward. 1985. Efficacy of methods advocated to reduce deer-vehicle collision accidents: research and rationale in the USA. Routes et faune sauvage. Service d'Etudes Techniques de Routes et Autoroutes, Bagneaux, France, pp. 285–293.

Reed, D.F., T.N. Woodward and T.M. Pojar. 1975. Behavioral response of mule deer to a highway underpass. Journal of Wildlife Management, Vol. 39, No. 2, pp. 361–367.

Reh, W. and A. Seitz. 1990. The influence of land use on the genetic structure of populations of the common frog *Rana temporaria*. Biological Conservation, Vol. 54, pp. 239–249.

Rodriguez, A., G. Crema and M. Delibes. 1996. Use of non-wildlife passages across a high speed railway by terrestrial vertebrates. Journal of Applied Ecology, Vol. 33, pp. 1527–1540.

Ruediger, B. 2005. Management considerations for designing carnivore highway crossings. USDA Forest Service, Wildlife, Fish and Watershed Unit.

Saunders, D.A., R.J. Hobbs and C.R. Margules. 1991. Biological consequences of ecosystem fragmentation: a review. Conservation Biology, Vol. 5, No. 1, pp. 18–32.

Sebesta, J.D., S.W. Whisenant, R.R. Lopez and N.J. Silvy. 2003. Development of a deer-guard prototype for Florida Key deer. Proceedings of the Annual Conference, Southeast Fish and Wildlife Agencies, Vol. 57, pp. 337–347.

Singer, F.J. and J.L. Doherty. 1985. Managing mountain goats at a highway crossing. Wildlife Society Bulletin, Vol. 13, pp. 469–477.

Tierson, W.C., G.F. Mattfeld, R.W. Sage, Jr. and D.F. Behrend. 1985. Seasonal movements and home ranges of white-tailed deer in the Adirondacks. Journal of Wildlife Management, Vol. 49, No. 3, pp. 760–769.

United States Geological Survey (USGS). 2011. Land use: 1985. Montana State Library. Available from the internet: http://nris.mt.gov/gis/

van der Ree, R., D. Heinze, M. McCarthy and I. Mansergh. 2009. Wildlife tunnel enhances population viability. Ecology and Society, Vol. 14, No. 2, pp. 7–15.

Wilcox, B.A. and D.D. Murphy. 1985. Conservation strategy: the effects of fragmentation on extinction. The American Naturalist, Vol. 125, No. 6, pp. 879–887.

Yanes, M., J.M. Velasco and F. Suárez. 1995. Permeability of roads and railways to vertebrates: the importance of culverts. Biological Conservation, Vol. 71, pp. 217–222.