EVALUATION OF WILDLIFE CROSSING STRUCTURES ON US 93 IN MONTANA'S BITTERROOT VALLEY

FHWA/MT-17-003/8194

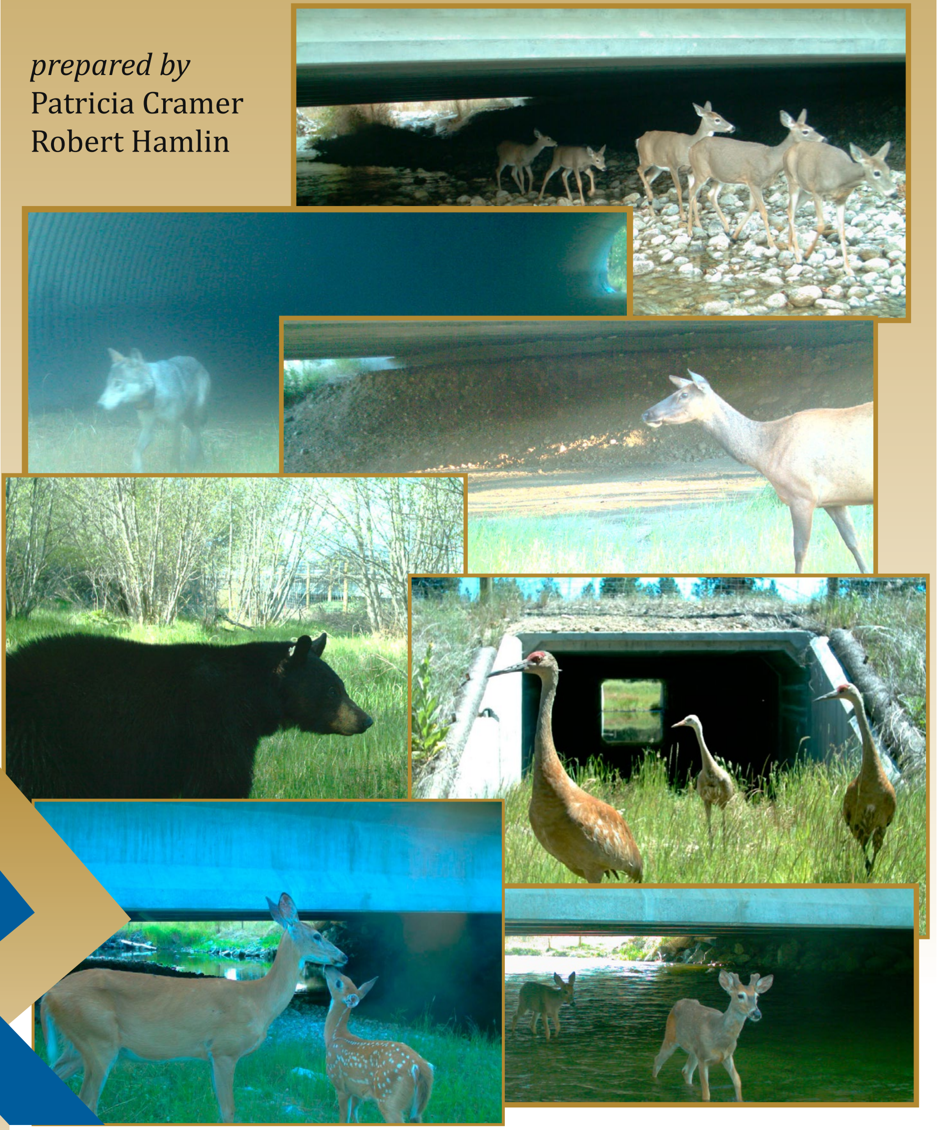
Final Report

prepared for
THE STATE OF MONTANA
DEPARTMENT OF TRANSPORTATION

in cooperation with
THE U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

January 2017

prepared by
Patricia Cramer
Robert Hamlin



RESEARCH PROGRAMS

MDT

Evaluation of Wildlife Crossing Structures on US 93 in Montana's Bitterroot Valley

Final Report

Prepared by

Patricia Cramer
and
Robert Hamlin

Prepared for
Montana Department of Transportation

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16. Abstract

Wildlife-vehicle collisions (WVC) are an ecological problem and a safety issue. Wildlife crossing structures are effective for reducing WVC. Twelve pre-construction sites, three control sites, and 19 wildlife crossing structures (12 bridges, seven culverts) were monitored with motion-detection cameras to determine white-tailed deer (*Odocoileus virginianus*) use rates. Performance measures were established from pre-construction and control monitoring, and were used to evaluate post construction use rates. Cameras recorded white-tailed deer moving through structures on 24,878 occasions. Nine structures (eight bridges, one culvert) exceeded performance measures. Statistical analyses were used to assess differences and relationships among post-construction rates, structural characteristics, and environmental characteristics. Structure type and dimensions, guard rail length, and shrub cover had significant effects on rates. Bridges had higher success than culverts. Changes in WVC crash rates were evaluated. Structures did not have a significant effect on WVC crash rates. However, substantial relative reductions and increases in WVC crash rates did occur at structures. The largest reduction was -2.6 crashes/year/mile. White-tailed deer abundance appears to be the most dynamic and important variable affecting WVC crash rates. Width (span) should be maximized for wildlife crossing structures, length should be minimized, and height should be maximized. Dimension recommendations should be prioritized in the order listed.

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AVC, Animal-vehicle collisions, Before and after studies, Bridges, Cameras, Crash data, Culverts, Deer, Habitat, Highway safety, Ungulates, Wildlife crossings, WVC.

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Table of Acronyms

Acronym	Definition
ANOVA	Analysis of Variance
BACI	Before After Control Intervention
GPS	Global Positioning System
km	Kilometers
m	Meters
MDT	Montana Department of Transportation
mp	Mile Post
MTFWP	Montana Fish Wildlife and Parks
U.S.	United States
WVC	Wildlife-Vehicle Collisions

Executive Summary

Wildlife-vehicle collisions (WVC) are an ecological problem for wildlife populations and a safety issue for the motorists of Montana and across North America. Wildlife crossing structures with wildlife exclusion fence are the most cost-effective method to both reduce WVC (Hedlund et al. 2003) and promote connectivity for wildlife species. Monitoring of structures is crucial to evaluating their efficacy in reducing WVC and promoting wildlife permeability across highways. The primary target species for this research was the white-tailed deer (*Odocoileus virginianus*). This research evaluated the efficacy of wildlife crossing structures for white-tailed deer, and can inform future wildlife mitigation planning across the United States.

The purpose of this research was to determine the effectiveness of wildlife crossing structures by investigating:

1. White-tailed deer use of wildlife crossing structures and wildlife crossing sites. These results are presented in Chapter 2.
2. White-tailed deer use rates of wildlife crossing structures by type and across types including height, width, length, and material. These results are presented in Chapter 3.
3. Relationships between use rates of wildlife crossing structures and landscape variables. These results are presented in Chapter 3.
4. Changes in WVC between pre-construction and post-construction of wildlife crossing structures and wildlife exclusion fence within the 40 kilometer (twenty-five mile) stretch of US 93, from mile post (mp) 49 to 74. These results are presented in Chapter 4.
5. Relationships between WVC changes and wildlife crossing structures and fence over space and time. These results are presented in Chapter 4.

Chapter 5 presents conclusions and recommendations. Appendix A presents photos of individual wildlife crossing structures. Appendix B presents data on other species of wildlife and domestic animals photographed at wildlife crossing structures. Appendices C and D present meta-data of white-tailed deer abundance estimates and WVC crash rates.

White-tailed deer use was monitored at pre-construction sites, control sites, and post-construction wildlife crossing structures with motion activated cameras. Unique individual white-tailed deer movements were categorized and tallied as follows:

- **Success** = pre-construction movements through original bridges or original culverts, pre-construction movements across US 93, or post-construction movements through wildlife crossing structures;
- **Repellency** = pre-construction movements away from original bridges or original culverts, pre-construction movements away from US 93, or post-construction movements away from wildlife crossing structures;
- **Parallel** = pre-construction movements parallel to original bridges or original culverts, pre-construction movements parallel to US 93, or post-construction movements parallel to wildlife crossing structures.

Success + **Repellency** + **Parallel** = **Total Movements**.

The following calculations were made, where appropriate:

- Success Rate = Success movements divided by Total Movements;
- Rate of Repellency = Repellency movements divided by Total Movements;
- Parallel Rate = Parallel movements divided by Total Movements;
- Success per Camera Day = Success movements divided by the number of days the camera(s) was in operation;
- Abundance = Total Movements divided by the number of days the camera(s) was in operation.

Pre-construction monitoring began in March 2009 and was completed in April 2011. The overall success rate for white-tailed deer crossing US 93 was 64 percent, and the overall rate of repellency was 10 percent.

Control monitoring began in late May 2009 and was completed on March 1, 2015. The success rate for white-tailed deer crossing County Road 370 (Bell Crossing Road, a control site) was 63 percent and the rate of repellency was five percent. Based on pre-construction and control monitoring, performance measures of 60 percent or greater success rate and 10 percent or less rate of repellency were established to evaluate post construction use rates of wildlife crossing structures.

During post-construction monitoring (October 2008 through March 1, 2015) cameras recorded white-tailed deer successfully moving through wildlife crossing structures on 24,878 occasions. Dawns Crossing Bridge had the most success movements (5,204) and the highest success rate (97 percent). Bear Creek South Bridge had the highest success per camera day (3.7). Fun Park Culvert was the least successful structure. Nine wildlife crossing structures (eight bridges, one culvert) exceeded the performance measures. Ten structures (four bridges, six culverts) did not exceed the performance measures.

Statistical analyses were used to assess differences and relationships among post-construction white-tailed deer use rates of wildlife crossing structures, structural characteristics of crossing structures, and environmental characteristics associated with crossing structures. Explanatory variables included: height, width, length, and openness of structures, fence lengths, guardrail lengths, humans per camera day, and average site values for percent cover of grass, forbs, shrubs, trees, bare ground, water, and number of deer fecal pellets.

The difference in white-tailed deer success rate, rate of repellency, and parallel rate between structure types was assessed using a generalized linear mixed model with a binomial response and a logit link. White-tailed deer success rate was higher for bridges than for culverts (model predicted values, 81 percent and 16 percent, respectively), counter-balanced by a lower parallel rate for bridges than for culverts (model predicted values, 12 percent and 57 percent, respectively). There was no significant difference in rate of repellency for structure type. The difference in success per camera day between structure types was assessed using a one-way ANOVA in a completely randomized design. White-tailed deer success per camera day was higher for bridges than for culverts (ANOVA predicted values, 0.9 and 0.2, respectively).

Assessment of the relationships between success rate, rate of repellency, and parallel rate and each explanatory variable used a generalized linear mixed model with a binomial response and a logit link. The relationships between each of the explanatory variables and white-tailed deer success per camera day were assessed using a simple linear regression. Success rate increased with increasing width, openness, guardrail length, and shrub cover, and decreased with increasing length. Rate of repellency decreased with increasing height, width, openness, guardrail length, and shrub cover. Parallel rate decreased with increasing width, openness, and guardrail length, and increased with increasing length. Success per camera day increased with structure width and openness. There was little to no evidence that fence length, humans per camera day, grass, forbs, trees, bare ground, water, and fecal pellets were related to white-tailed deer use rates of wildlife crossing structures.

A two-sample test was used to test for equal means of bridges and culverts for each explanatory variable. Bridges and culverts differed in width, length, openness, and number of humans per camera day. Bridges were wider, shorter, more open, and had higher human use. A Pearson product-moment correlation coefficient was computed to assess the relationship between white-tailed deer abundance and number of fecal pellets. There was a very weak positive linear relationship between white-tailed deer abundance and number of fecal pellets: $r = 0.23$.

WVC carcass and crash data were obtained from Montana Department of Transportation (MDT). The number of WVC carcasses decreased 59 percent from 2012 to 2013, and decreased 84 percent from 2012 to 2014. WVC carcass data in all forms appeared to be unreliable from 2013 through October 2015.

The Kernel2d function in the Splancs package in R was used to compute and map smooth representations of the spatial-temporal variations in intensities of WVC carcasses and WVC crashes relative to wildlife crossing structure locations within the study area. Kernel2d representations provided displays of the variation in WVC intensities within the entire study area during the past 16 years. Temporary increases in WVC carcass and crash intensities were observed after the construction of most of the wildlife crossing structures. These temporary increases have two possible explanations. They may represent white-tailed deer adaptations to the structures, four lanes rather than two, and increases in traffic speed following an entire season of construction. It is also possible that the temporary increases were not related to the construction of wildlife crossing structures. WVC intensities at many given locations appear to increase and decrease over time, before and after the construction of wildlife crossing structures. Kernel2d representations do not provide statistical evidence for or against a relationship between WVC rates and wildlife crossing structures. They simply display variations in WVC intensities over space and time relative to wildlife crossing structure locations. However, Kernel2d representations become more powerful for observing WVC patterns over the long term.

White-tailed deer annual hunter harvest rates from Hunting District 260, obtained from Montana Fish Wildlife and Parks (MTFWP), were used as an estimate of white-tailed deer abundance for the entire study area. Monthly traffic volume data from two traffic counters were obtained from MDT. Attempts were made to program a fine-scale predictive statistical model to measure changes in WVC rates and determine the effectiveness of wildlife crossing structures. The model was to measure and control for the influence of white-tailed deer abundance, traffic volume, and potentially other independent variables on WVC rates during pre-construction and post-construction of wildlife crossing structures. Attempts to program a fine-scale predictive statistical model were unsuccessful for several reasons: it required white-tailed deer abundance and traffic volume data at a fine scale, ideally at the 19 wildlife crossing structure locations, and required accurate and complete WVC carcass data.

Before-After-Control-Intervention (BACI) design analysis was used to evaluate changes in WVC crash rates between pre-construction and post-construction of wildlife crossing structures. The BACI analysis found that none of the 19 wildlife crossing structures had a statistically significant effect on WVC crash rates. However, substantial relative reductions and increases in WVC crash rates did occur at wildlife crossing structures. These rate changes were measured, and not statistically computed. The largest reduction in WVC crash rate (-2.6 crashes per mile per year), relative to the change in WVC crash rate at a control section, occurred at Kootenai Creek Bridge and McCalla Creek North Bridge (mp 66.4 to mp 65.9). Other substantial relative WVC crash rate reductions occurred at McCalla Creek South Bridge and Kootenai Springs Ranch Culvert (mp 65.3 to mp 63.8), Big Creek Bridge (mp 61.8 to mp 61.4), Bear Creek South Bridge (mp 57.3 to 56.9), and Fun Park Culvert (mp 55.7 to mp 55.3). The largest relative increases in WVC crash rates occurred at Blodgett Creek Bridge (1.4 crashes per year per mile, mp 50.5 to 50.1) and at Bass Creek Fishing Access Culvert and Dawns Crossing Bridge (0.9 crashes per year per mile, mp 70.7 to mp 69.0).

The relative changes in WVC crash rates appear to be related to changes in white-tailed deer abundance. Abundance does not appear to be well controlled in the BACI analysis. In two examples, relative crash rate changes may be related to extended sections of wildlife exclusion fence. Overall, it appears that white-tailed deer abundance is the most dynamic and important variable affecting WVC crash rates. Other independent variables such as traffic volume, highway configuration, and adjacent land use appear to have been well controlled in the BACI analysis. Adjacent land use may be an important variable in determining WVC location rather than WVC rate.

Recommendations include:

- WVC carcass data collection and management should be complete, accurate, and consistent within MDT. All records and sources of WVC carcass data should be rectified.
- Carcass data should be located, input, and managed in a smart phone application or other Global Positioning System (GPS) based format that uploads carcass locations to an on-line user-interfaced map. Carcass data and locations that are available in real-time may provide quick solutions to many WVC situations, and assist with the planning of future transportation projects.
- There were very strong relationships between openness ratio (height multiplied by width (span) divided by length, in meters) and use rates in this study. Wildlife crossing structures should be designed to maximize openness ratio. We choose not to recommend a minimum openness ratio for wildlife crossing structures. High openness ratios are easier to achieve with bridges than with culverts.
- Width (span) should be maximized for wildlife crossing structures, length should be minimized, and height should be maximized. These recommendations for structure dimensions should be prioritized in the order they are listed.

- Extended sections of wildlife exclusion fence are not recommended as a means to improve the use of wildlife crossing structures by white-tailed deer. However, extended sections of fence may have an effect on the relative reduction of WVC crash rate at wildlife crossing structures.
- Wildlife crossing structures are recommended in suburban-wildland settings. In this study, several highly successful structures were located in close proximity to humans and their infrastructure. Puma, wolf, and black bear were observed successfully utilizing these structures, in addition to white-tailed deer.
- Future transportation planning should include consultation with MTFWP to consider multiple wildlife species in the area under consideration. Species such as moose and elk require specifically designed wildlife crossing structures.
- Pre-construction monitoring of future wildlife crossing structure sites, and monitoring of control sites are recommended. In this study, monitoring of pre-construction sites and control locations provided performance measures used to evaluate post-construction use rates of wildlife crossing structures and their effectiveness.
- Right of way cameras should be installed whenever possible during pre-construction monitoring. In this study they provided success rates, repel rates, and quantified the permeability of US 93 across two lanes of traffic for white-tailed deer and elk.
- In addition to post-construction monitoring, wildlife crossing structures and wildlife exclusion fence should be regularly inspected and adaptively managed.

Chapter 1 Introduction, Background, Study Area, and Purpose

Wildlife-vehicle collisions (WVC) are an ecological problem for wildlife populations and a safety issue for the motorists of Montana and across North America. It is estimated that a minimum of 1.5 million WVC are reported to insurance companies across the United States (U.S.) each year (State Farm Insurance 2014). The average annual WVC reported to Montana Department of Transportation (MDT) as crash data was 2,023 during the period of 2010 to 2014. Reported WVC are only a fraction of the true number of collisions; the number of deer carcasses collected along highways can be 5.3 (Olson et al. 2014) to 9.7 (Donaldson and Lafon 2008) times higher than reported WVC crashes.

Wildlife crossing structures with wildlife exclusion fence are the most cost-effective method to both reduce WVC (Hedlund et al. 2003) and promote connectivity for wildlife species. Montana has more wildlife crossing structures than any other state. Over 75 structures have been installed along US Highway 93 (Bissonette and Cramer 2008). With human safety, wildlife populations, and millions of taxpayer dollars at stake, it is crucial these structures are monitored to evaluate their efficacy in reducing WVC and promoting wildlife permeability across highways. The primary target species for this research was the white-tailed deer (*Odocoileus virginianus*). The white-tailed deer is involved in more of the annual reported WVC than any other species. This research evaluated the efficacy of wildlife crossing structures for white-tailed deer and can inform future mitigation planning across the U.S.

MDT installed 19 wildlife crossing structures for large animals along US Highway 93 (US 93) between Florence and Hamilton from 2004 to 2012. Seven of these wildlife crossing structures were completed before this study began and 12 were completed during this study. Wildlife exclusion fence was installed during construction at 17 of these structures. The height of the fence was 2.3 meters (8 feet), and the fence extended various distances from the entrances of the structures. Fence was not installed at Bass Creek North Bridge and Bass Creek South Bridge. Additional details of the 19 wildlife crossing structures are presented in Table 1. A map of the study area is presented in Figure 1. Photos of all structures are presented in Appendix A.

Table 1. Wildlife Crossing Structures, US Highway 93 South, Montana.

Structures	Year Completed	Approximate Mile Post	Structure Type and Dimensions height x width (span) x length in Meters
Bass Creek North Bridge	2005	71	Single Span Bridge 3 x 14 x 23.2 (9.8x46x76 feet)
Bass Creek South Bridge	2005	70	Single Span Bridge 4 x 14 x 27.4 (13x46x90 feet)
Bass Creek Fishing Access Culvert	2005	70	Round Corrugated Steel Culvert 3.9 x 6 x 58 (12.7x20x190 feet)
Dawns Crossing Bridge	2005	70	Single Span Bridge 4 x 35 x 24 (13x115x79 feet)
Kootenai Creek Bridge	2009	66	Single Span Bridge 1.8 x 24 x27 (5.9x79x88.6 feet)
McCalla Creek North Bridge	2009	66	Single Span Bridge 1.9 x 24 x 26.4 (6x79x86 feet)
McCalla Creek South Bridge	2010	65	Single Span Bridge 1.4 x 19 x 26.5 (4.5x62x87 feet)
Kootenai Springs Ranch Culvert	2010	65	Concrete Box Culvert 2 x 3.6 x 44 (6.5x11.8x144 feet)
Indian Prairie Loop Culvert	2010	63	Concrete Box Culvert 2.7 x 3.7 x 47 (8.8x12x154 feet)
Big Creek Bridge	2011	62	Double Span Bridge 1.8 x 56 x 23.2 (5.9x183x76 feet)
Axmen Propane Culvert	2010	61	Round Corrugated Steel Culvert 3 x 4 x 51 (9.8x13x161 feet)
Sweathouse Creek Bridge	2011	60	Single Span Bridge 2.2 x 25.5 x 29.3 (7.2x84x96 feet)
Bear Creek North Bridge	2012	58	Single Span Bridge 1.3 x 21 x 27.4 (4.3x68.9x90 feet)
Bear Creek South Bridge	2012	57	Single Span Bridge 3.8 x 36.3 x 27.3 (12.5x119x89.5 feet)
Lupine Culvert	2012	57	Concrete Box Culvert 2.7 x 2.7 x 52 (9x9x170 feet)
Mountain Gallery Culvert	2011	56	Concrete Box Culvert 2.7x 2.7 x 54 (9x9x177 feet)
Fun Park Culvert	2011	55	Concrete Box Culvert 2.7 x 2.7 x 58 (9x9x190 feet)
Mill Creek Bridge	2011	55	Single Span Bridge 1.4 x 24 x 23.2 (4.6x78.7x76 feet)
Blodgett Creek Bridge	2008	50	Single Span Bridge 2.7 x 25 x 27.4 (9x82x90 feet)

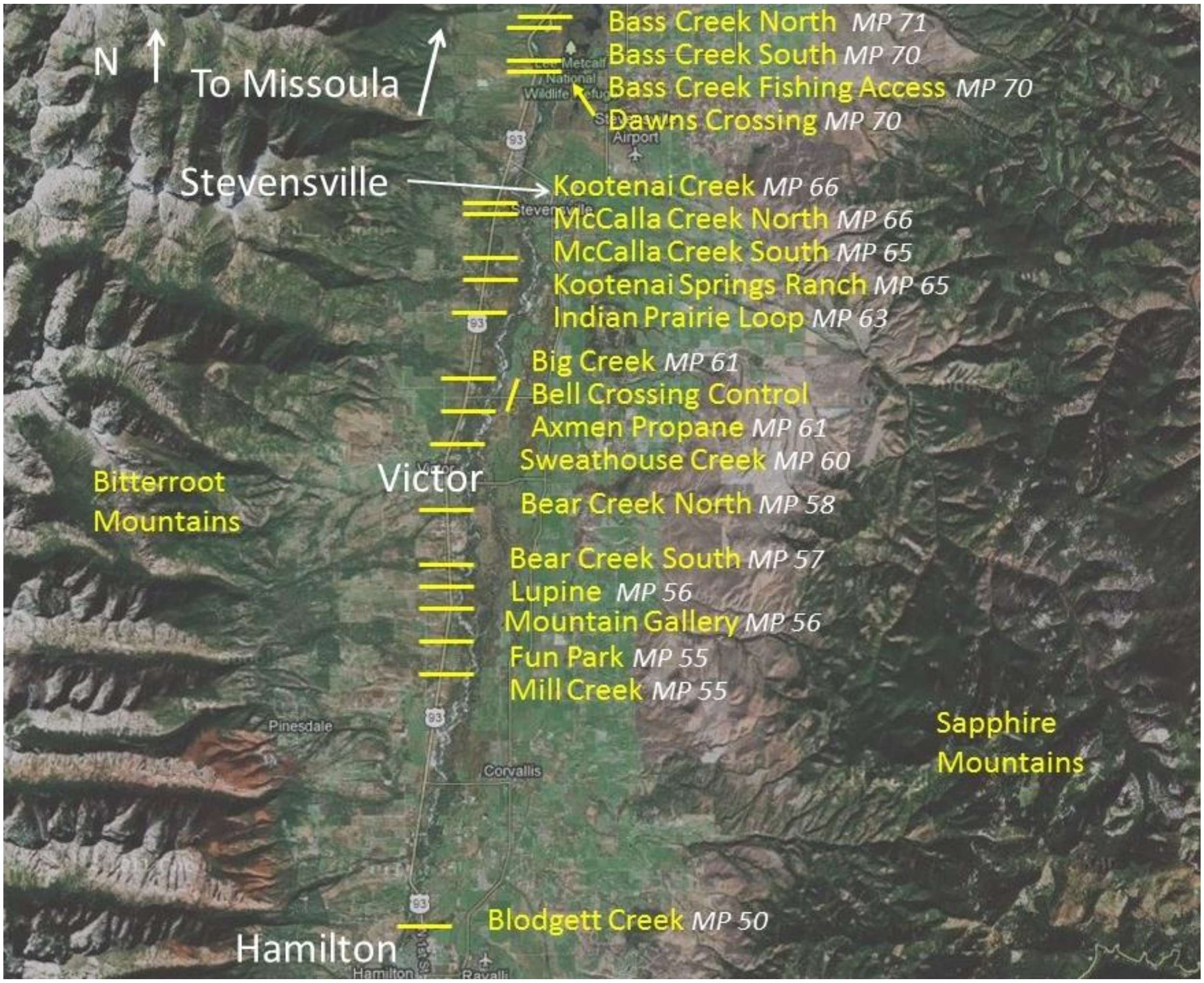

Figure 1. Map of US Highway 93 South Study Area, Montana.

The purpose of this research was to determine the effectiveness of wildlife crossing structures by investigating:

1. White-tailed deer use of wildlife crossing structures and wildlife crossing sites. These results are presented in Chapter 2.
2. White-tailed deer use rates of wildlife crossing structures by type and across types including height, width, length, and material. These results are presented in Chapter 3.
3. Relationships between use rates of wildlife crossing structures and landscape variables. These results are presented in Chapter 3.
4. Changes in WVC between pre-construction and post-construction of wildlife crossing structures and wildlife exclusion fence within the 40 kilometer (twenty-five mile) stretch of US 93, from mile post (mp) 49 to 74. These results are presented in Chapter 4.

5. Relationships between WVC changes and wildlife crossing structures and fence over space and time. These results are presented in Chapter 4.

Chapter 5 presents conclusions and recommendations. Appendix A presents photos of individual wildlife crossing structures. Appendix B presents data on other species of wildlife and domestic animals photographed at wildlife crossing structures. Appendices C and D present meta-data of white-tailed deer abundance estimates and WVC crash rates.

Chapter 2 White-tailed Deer Use of Wildlife Crossing Structure Sites and Wildlife Crossing Structures

2.1. Pre-construction Monitoring

This section presents white-tailed deer use of wildlife crossing structure **sites** during **pre-construction** monitoring.

2.1.1 Methods

Twelve wildlife crossing structure sites were monitored during pre-construction with 26 Reconyx Professional Cameras, Model PC85. Cameras were installed from late March 2009 through late July 2009. Sites were monitored for various lengths of time. Cameras were removed when construction began (two exceptions are detailed in section 2.2.1). Cameras were triggered by motion and took pictures of large and small animals, day and night. Cameras were programed with the following Reconyx trigger-settings: high sensitivity, five pictures per trigger, rapid fire picture interval, and no delay quiet period. Cameras were installed inside metal telephone-utility boxes. Each telephone-utility box was secured by a cable locked to the camera on one end and buried in concrete at the other. Electronic code locks also secured all cameras. Two cameras were installed at each of the 12 wildlife crossing structure sites (the Lupine site was an exception; four cameras were placed there over time during pre-construction monitoring). One camera was placed approximately eight meters (26 feet) from original bridges or original culverts, or the proposed locations of the wildlife crossing structures. These cameras were designated **structure cameras** if they recorded white-tailed deer use of the original bridges or original culverts; otherwise, they were designated either **right of way cameras** or **habitat cameras**. A second camera was placed within 50 meters (164 feet) of the first camera at each site. These cameras were designated either right of way cameras or habitat cameras. Right of way cameras recorded animal movements as they approached or departed US 93. Habitat cameras monitored movements in natural areas nearby; they did not monitor original bridges, original culverts, or animal movements across US 93. During pre-construction monitoring, there were six structure cameras, 11 right of way cameras, and nine habitat cameras.

For each pre-construction monitoring camera location, unique individual white-tailed deer movements recorded by the cameras were categorized and tallied as follows:

- **Success** = movements through original bridges or original culverts, or movements across US 93;
- **Repellency** = movements away from original bridges or original culverts, or movements away from US 93;
- **Parallel** = movements parallel to original bridges or original culverts, or movements parallel to US 93.

Success + **Repellency** + **Parallel** = **Total Movements** for each pre-construction monitoring camera location. Habitat cameras recorded only parallel movements. Individual repellency and parallel movements were tallied only once when the same deer moved in front of a camera for an extended period of time. Multiple success movements were tallied, even when the same deer made more than one success movement. When deer moved continuously in front of a camera for an extended period of time, a final movement determination was made after 15 minutes. The following calculations were made for each pre-construction monitoring camera location, where appropriate:

- **Success Rate** = Success movements divided by Total Movements;
- **Rate of Repellency** = Repellency movements divided by Total Movements;
- **Parallel Rate** = Parallel movements divided by Total Movements;
- **Success per Camera Day** = Success movements divided by the number of days the camera was in operation;
- **Abundance** = Total Movements divided by the number of days the camera was in operation.

2.1.2 Results

Pre-construction data are presented by camera designation in Table 2. The order of camera locations is based on success rate for structure and right of way camera locations, and abundance for habitat camera locations. Pre-construction monitoring ranged from 55 to 629 days, depending upon camera location. The original Bear Creek South bridge was functioning as a successful wildlife crossing structure, even though it was not designed as one (success rate 98 percent). The overall success rate for the other five original bridges was 12 percent. For US 93 right of way cameras, the overall success rate was 64 percent and the overall rate of repellency was 10 percent. The right of way cameras recorded deer successfully crossing US Highway 93 on 1,755 occasions during pre-construction.

Table 2. White-Tailed Deer Use of Pre-Construction Sites.

Structure Camera Location	**Success**	**Repellency**	**Parallel**	**Total Movements**	**Success Rate (%)**	**Rate of Repellency (%)**	**Parallel Rate (%)**	**Camera Days**	**Success/ Camera Day**	**Abundance**
Bear Creek South	1662	10	17	1689	98	1	1	629	2.6	2.7
Big Creek	33	32	165	230	14	14	72	277	0.1	0.8
Bear Creek North	2	2	10	14	14	14	72	536	0.004	0.03
Sweathouse Creek	65	3	48	516	13	1	87	452	0.1	1.1
McCalla Creek South	21	18	216	255	8	7	85	109	0.2	2.3
Mill Creek	1	0	38	39	3	0	97	599	0.002	0.07
Right of Way Camera Location	**Success**	**Repellency**	**Parallel**	**Total Movements**	**Success Rate (%)**	**Rate of Repellency (%)**	**Parallel Rate (%)**	**Camera Days**	**Success/ Camera Day**	**Abundance**
Lupine (south camera)	16	3	1	20	80	15	5	172	0.09	0.1
Fun Park (east camera)	606	85	80	771	79	11	10	490	1.2	1.6
Mill Creek	525	115	111	751	70	15	15	566	0.9	1.3
Bear Creek South	140	15	52	207	68	7	25	509	0.3	0.4
Mountain Gallery (south camera)	24	1	14	39	61	3	36	587	0.04	0.07
Kootenai Springs Ranch (west camera)	26	5	17	48	54	10	36	55	0.5	0.9

Right of Way Camera Location	**Success**	**Repellency**	**Parallel**	**Total Movements**	**Success Rate (%)**	**Rate of Repellency (%)**	**Parallel Rate (%)**	**Camera Days**	**Success/ Camera Day**	**Abundance**
Sweathouse Creek	219	17	189	425	52	4	44	496	0.4	0.9
Fun Park (west camera)	57	4	49	110	52	4	44	556	0.1	0.2
Mountain Gallery (north camera)	64	6	72	142	45	4	51	440	0.1	0.3
Kootenai Springs Ranch (east camera)	72	12	142	226	32	5	63	106	0.7	2.1
Lupine (north camera)	0	1	0	1	0	100	0	204	0	0.005

Habitat Camera Location	**Total Movements (Parallel)**	**Camera Days**	**Abundance**
McCalla Creek South	467	93	5.0
Indian Prairie Loop (north camera)	369	78	4.7
Indian Prairie Loop (south camera)	670	150	4.5
Big Creek	582	260	2.2
Axmen Propane (north camera)	319	212	1.5
Lupine (west camera)	509	382	1.3
Bear Creek North	266	454	0.6
Lupine (east camera)	224	385	0.6
Axmen Propane (south camera)	66	176	0.4

2.1.3 Discussion

Six structure cameras, 11 right of way cameras, and nine habitat cameras were used during pre-construction monitoring. The original pre-construction monitoring plan called for two cameras to be installed at each of the 12 wildlife crossing structure sites: 12 structure cameras and 12 right of way cameras. The plan was to have both cameras at each site record success, repellency, and parallel movements by white-tailed deer. This plan proved difficult to implement. Several of the original bridges had water between the abutments most of the year with very little dry ground on which to install cameras. Other original bridges had large rock rip-rap at their approaches and extensive vegetation along their right of ways, making it difficult to record deer moving toward or through the original bridges. Right of way camera locations also had several challenges. They required a view of US 93 where deer could be recorded moving on to and away from the highway without the motions of automobiles triggering the cameras. Specifically, right of way cameras needed to be shielded from traffic by either vegetation or elevation differences between the cameras and the road. Too little vegetation on right of ways that were relatively flat resulted in memory cards being filled with images of cars. Too much vegetation resulted in memory cards being filled with images of blowing vegetation. Our solution to these many challenges was to designate the cameras that did not function as structure or right of way cameras as habitat cameras.

During pre-construction, structure cameras clearly showed that white-tailed deer were heavily using the original Bear Creek South Bridge to move under US 93. White-tailed deer were not heavily using any of the other five original bridges. Right of way cameras showed that white-tailed deer readily moved across US 93 at most locations (1,755 occasions) during pre-construction. At Fun Park and Mill Creek, the success rate from right of way cameras was 74 percent. The overall success rate from right of way cameras was 64 percent and the overall rate of repellency was 10 percent. The pre-construction success rate and rate of repellency at right of way camera locations were important numbers. They provided a basis to evaluate post-construction use rates.

2.2. Control Monitoring

2.2.1 Methods

Two cameras were installed 1.2 km (0.75 of a mile) east of US 93 at a small bridge over an unnamed spring run on County Road 370 (Bell Crossing Road), approximately 0.4 km (0.25 of a mile) east of the Bitterroot River. Cameras were installed in late May 2009. This control site was named Bell Crossing. One camera was a habitat camera located approximately eight meters (26 feet) from the bridge, and the other was a road right of way camera located approximately 50 meters (164 feet) west of the bridge. This location was selected as a long-term control site to monitor white-tailed deer abundance and use rates at County Road 370, in an area near US 93 where road construction, wildlife crossing structure construction, and wildlife exclusion fence were not scheduled to occur. Two pre-construction monitoring habitat cameras, McCalla Creek South (mp 65) and Big Creek (mp 61), remained in place during construction and post-construction monitoring as long-term control cameras. Installation methods, camera settings, and calculations for use rates and abundance for these four control cameras were described in section 2.1.1. Control camera monitoring at all three sites was completed on March 1, 2015.

2.2.2 Results

At the Bell Crossing control site right of way camera, deer successfully crossed County Road 370 on 5,381 occasions. The success rate was 63 percent (5,381 success movements/8,524 total movements), the rate of repellency was 5 percent, and the parallel rate was 32 percent. Success per camera day was 2.9 (5,381 success movements/1,883 camera days). The right of way camera recorded deer abundance of 4.5 (8,524 total movements/1,883 camera days). Deer abundance of 2.9 was recorded by the habitat camera at the Bell Crossing control site (5,381 total movements/1868 camera days). It was coincidental that the 5,381 total movements at the habitat camera were equal to the 5,381 success movements at the right of way camera. At McCalla Creek South (mp 65), deer abundance of 5.0 was recorded during pre-construction (93 days), 0.5 during construction (93 days), and 1.0 during post-construction (1,356 days). At Big Creek (mp 61), deer abundance during pre-construction monitoring was 2.2 (260 days), 1.3 during construction (407 days), and 1.3 (1,098 days) during post-construction.

2.2.3 Discussion

Results from the right of way camera at the Bell Crossing control site also provided a basis to evaluate post-construction use rates. The success rate and rate of repellency at this right of way camera (63 percent and five percent respectively) were very similar to the overall success rate and overall rate of repellency of pre-construction right of way camera locations described in the previous section (64 and 10 percent, respectively). Based on these values, performance measures of 60 percent or greater success rate and 10 percent or less rate of repellency were established to evaluate post construction use rates of wildlife crossing structures in section 2.3.3.2.

Results from the control cameras at Bell Crossing, McCalla Creek South, and Big Creek provided a baseline for deer abundance during the study, and an estimate of changes in deer abundance over time. It is important to note that the high abundance observed at McCalla Creek South during pre-construction monitoring is based on only 3 months of monitoring (93 days).

2.3 Post-construction Monitoring and Comparisons

This section presents white-tailed deer use of wildlife crossing structures during post-construction monitoring. This use is compared with white-tailed deer use of wildlife crossing sites during pre-construction.

2.3.1 Methods

Post-construction monitoring occurred at all 19 wildlife crossing structures. The length of time each structure was monitored varied. Post-construction monitoring began in late 2008 and early 2009 for structures completed prior to this study. Monitoring began within one month post-construction for structures completed during this study. Cameras were programed and installed as described in section 2.1.1. Reconyx Professional Cameras, Model PC85 and Model PC800 were used during post-construction monitoring. Cameras were installed in Reconyx Bear Boxes at several wildlife crossing structures. Structures completed prior to this study were monitored with one camera (McCalla Creek North Bridge (mp 66) was an exception). Structures completed during this study were monitored with two or more cameras (Lupine Culvert (mp 56) was an exception). A single structure camera was installed approximately eight meters (26 feet) from a single entrance of the following wildlife crossing structures: Bass Creek North Bridge (mp 71), Bass Creek South Bridge (mp 70), Bass Creek Fishing Access Culvert (mp 70), Dawns Crossing Bridge (mp 70), Kootenai Creek Bridge (mp 66), and Blodgett Creek Bridge (mp 50). Two structure cameras were installed approximately eight meters (26 feet) from each entrance of the following wildlife crossing structures: McCalla Creek North Bridge (mp 66), McCalla Creek South Bridge (mp 65), Kootenai Springs Ranch Culvert (mp 65), Indian Prairie Loop Culvert (mp 63), Axmen Propane Culvert (mp 61), Sweathouse Creek Bridge (mp 60), Bear Creek North Bridge (mp 58), Lupine Culvert (mp 56), Mountain Gallery Culvert (mp 56), Fun Park Culvert (mp 55), and Mill Creek Bridge (mp 55). Lupine Culvert (mp 56) was monitored with only one structure camera after September 13, 2012. Three structure cameras were installed at Bear Creek South Bridge (mp 57) and at Big Creek Bridge (mp 61) because of their large width (spans).

During post-construction monitoring, unique individual white-tailed deer movements recorded by cameras at each wildlife crossing structure were categorized and tallied as follows:

- **Success** = movements through the wildlife crossing structure;
- **Repellency** = movements away from wildlife crossing structure;
- **Parallel** = movements parallel to the wildlife crossing structure.

Success + **Repellency** + **Parallel = Total Movements** for each wildlife crossing structure. For wildlife crossing structures that were monitored with more than one camera, individual deer movements were tallied only once, even if more than one camera recorded the movement (on these occasions, individual deer movements were assigned to the first camera that recorded them). Individual repellency and parallel movements were tallied only once when the same deer moved in front of a camera for an extended period of time. Multiple success movements were tallied, even when the same deer made more than one success movement. When deer moved continuously in front of a camera for an extended period of time, a final movement determination was made after 15 minutes. The following calculations were made for each wildlife crossing structure:

- **Success Rate** = Success movements divided by Total Movements;
- **Rate of Repellency** = Repellency movements divided by Total Movements;
- **Parallel Rate** = Parallel movements divided by Total Movements;
- **Success per Camera Day** = Success movements divided by the number of days the camera was in operation for structures monitored with one camera, and Success movements divided by the mean number of days cameras were in operation for structures monitored with more than one camera;
- **Abundance** = Total Movements divided by the number of days the camera was in operation for structures monitored with one camera, and Total Movements divided by the average number of days the cameras were in operation for structures monitored with more than one camera.

2.3.2 Results

2.3.2.1 Post-Construction Monitoring

Post-construction monitoring was completed on March 1, 2015. White-tailed deer use of wildlife crossing structures is presented in Table 3. The order of camera locations is based on success rate. During post-construction monitoring (October 2008 through March 1, 2015) cameras recorded white-tailed deer successfully moving through wildlife crossing structures on 24,878 occasions.

Table 3. White-Tailed Deer Use of Wildlife Crossing Structures.

Wildlife Crossing Structure	Success	Repel-lency	Parallel	Total Movements	Success Rate (%)	Rate of Repel-lency (%)	Parallel Rate (%)	Camera Days	Success Per Camera Day	Abundance
Dawns Crossing Bridge	5204	65	94	5363	97	1	2	2162	2.4	2.5
Bass Creek Fishing Access Culvert	3257	118	21	3396	96	3	1	1985	1.6	1.7
Bear Creek South Bridge	2554	30	113	2697	95	1	4	685	3.7	3.9
Sweathouse Creek Bridge	2419	61	102	2582	94	2	4	1158	2.1	2.2
Blodgett Creek Bridge	1037	25	36	1098	94	3	3	1766	0.6	0.6
Kootenai Creek Bridge	2470	150	97	2717	91	5	4	1763	1.4	1.5
Big Creek Bridge	2769	237	317	3323	83	7	10	1227	2.3	2.7
McCalla Creek North Bridge	2058	142	265	2465	83	6	11	1690	1.2	1.5
Mill Creek Bridge	1036	117	283	1436	72	8	20	1110	0.9	1.3
Bass Creek North Bridge	260	33	188	481	54	7	39	1977	0.1	0.2
Indian Prairie Loop Culvert	1039	228	1403	2670	39	8	53	1311	0.8	2.0
McCalla Creek South Bridge	293	154	310	757	39	20	41	1452	0.2	0.5
Bear Creek North Bridge	35	21	39	95	37	22	41	696	0.05	0.1
Bass Creek South Bridge	13	6	17	36	36	17	47	1930	0.007	0.02
Lupine Culvert	70	43	132	245	29	17	54	977	0.07	0.3
Axmen Propane Culvert	235	133	969	1337	18	10	72	1165	0.2	1.1
Mountain Gallery Culvert	26	28	307	361	7	8	85	1000	0.03	0.4
Kootenai Springs Ranch Culvert	103	329	2170	2602	4	13	83	1332	0.08	2.0
Fun Park Culvert	0	40	410	450	0	9	91	730	0	0.6

2.3.2.2 Monthly Use of Sites and Structures

Figure 2 through Figure 20 present white-tailed deer monthly use of wildlife crossing sites and wildlife crossing structures from north to south, during the entire study period. For each of the monthly-paired blue (left) and red (right) columns, the ratio of the red (right) column's value to blue (left) column's value is equal to monthly success rate. The closer the values of the paired columns, the higher the monthly success rate.

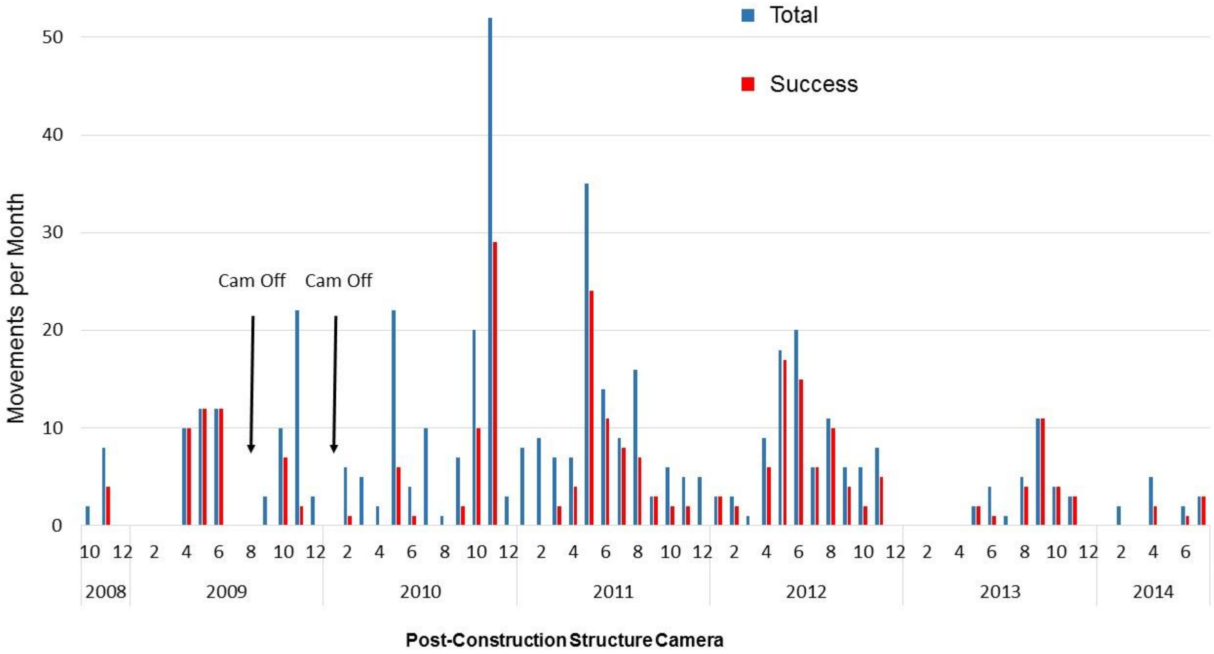

Figure 2. Bass Creek North Bridge, mp 71, White-Tailed Deer Monthly Use, 2008-2014.

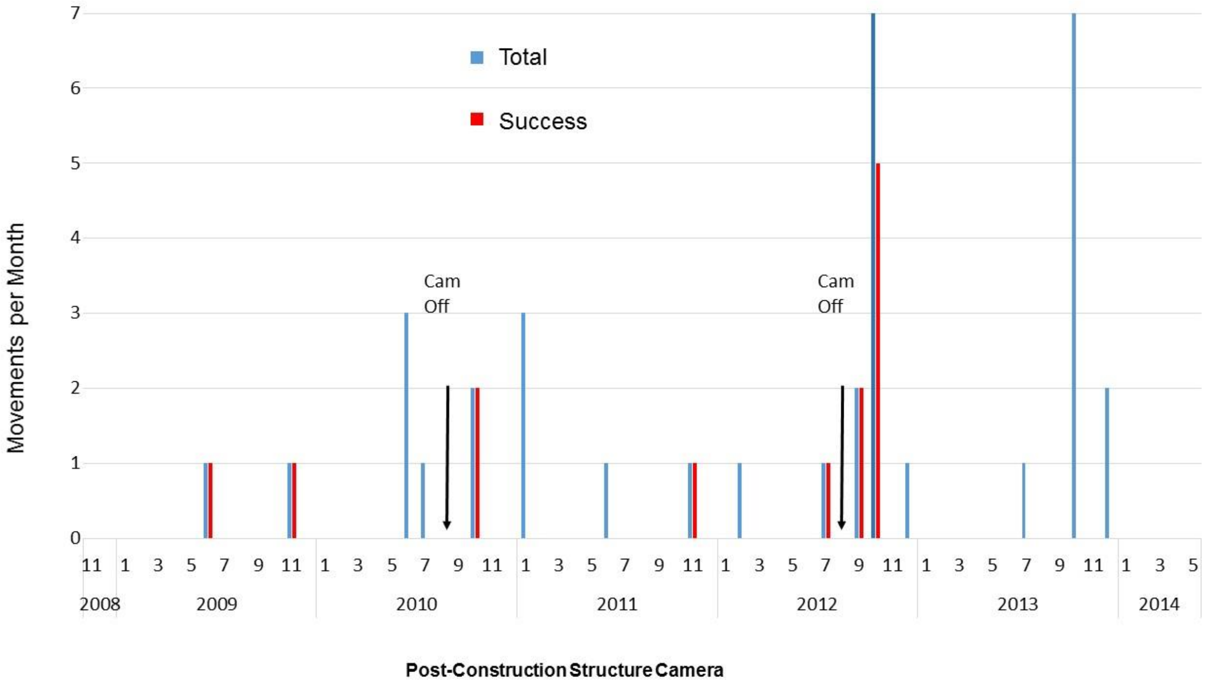

Figure 3. Bass Creek South Bridge, mp 70, White-Tailed Deer Monthly Use, 2008-2014.

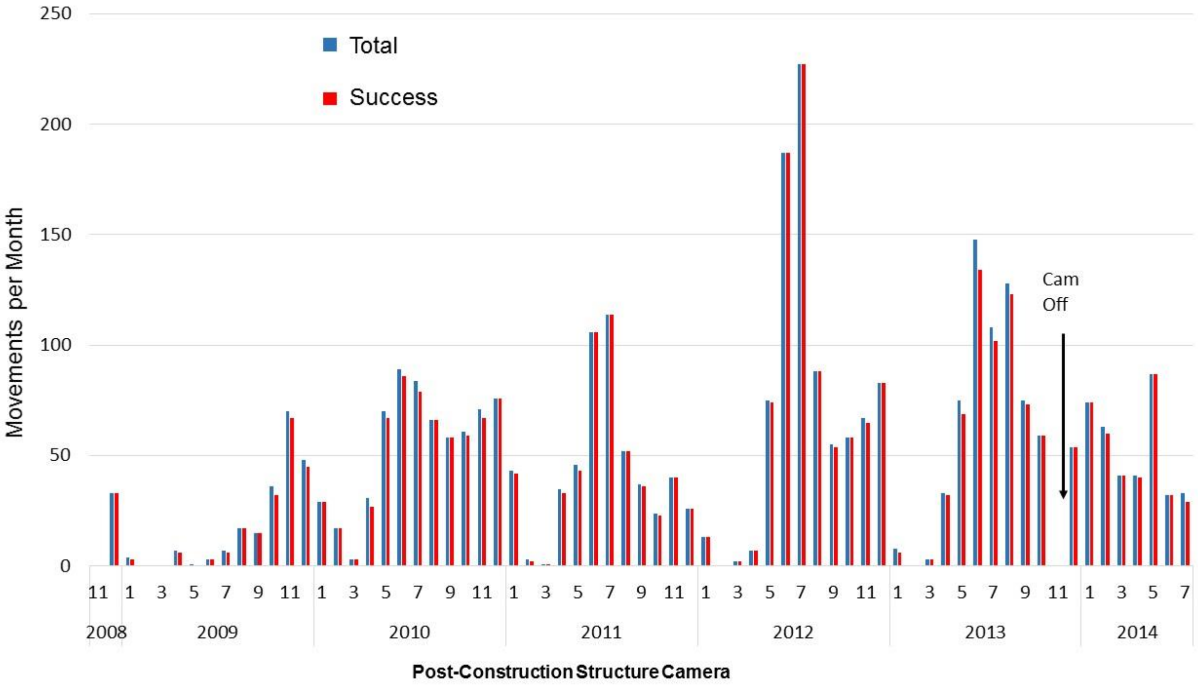

Figure 4. Bass Fishing Access Culvert, mp 70, White-Tailed Deer Monthly Use, 2008-2014.

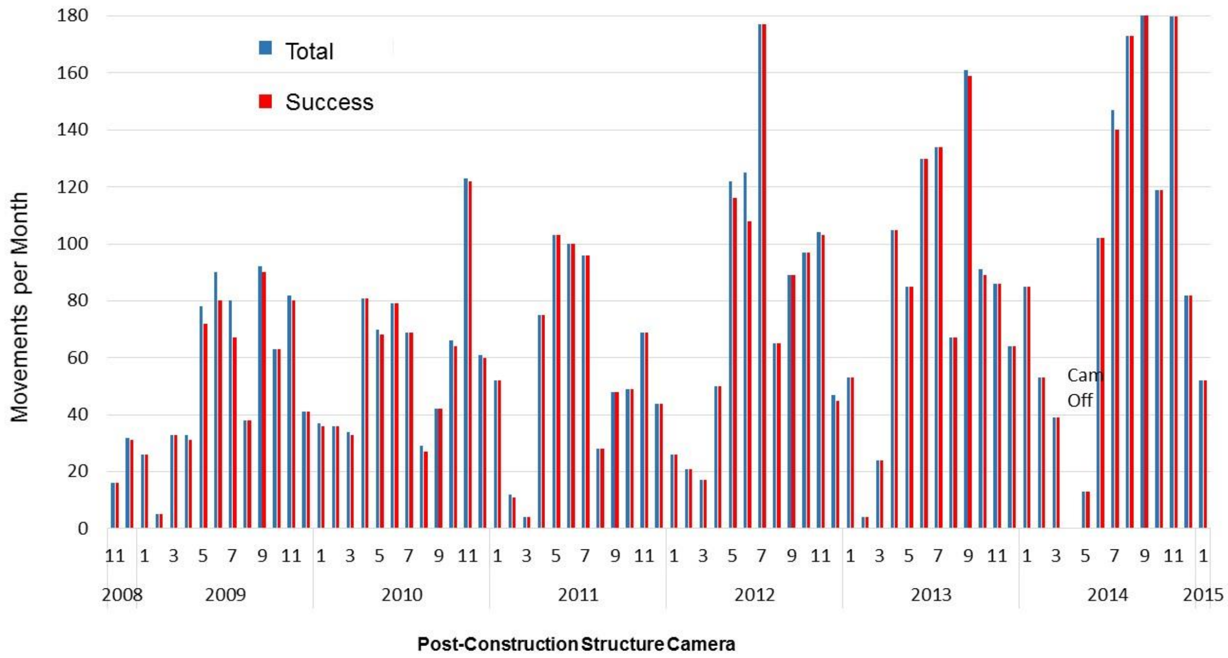

Figure 5. Dawns Crossing Bridge, mp 70, White-Tailed Deer Monthly Use, 2008-2015.

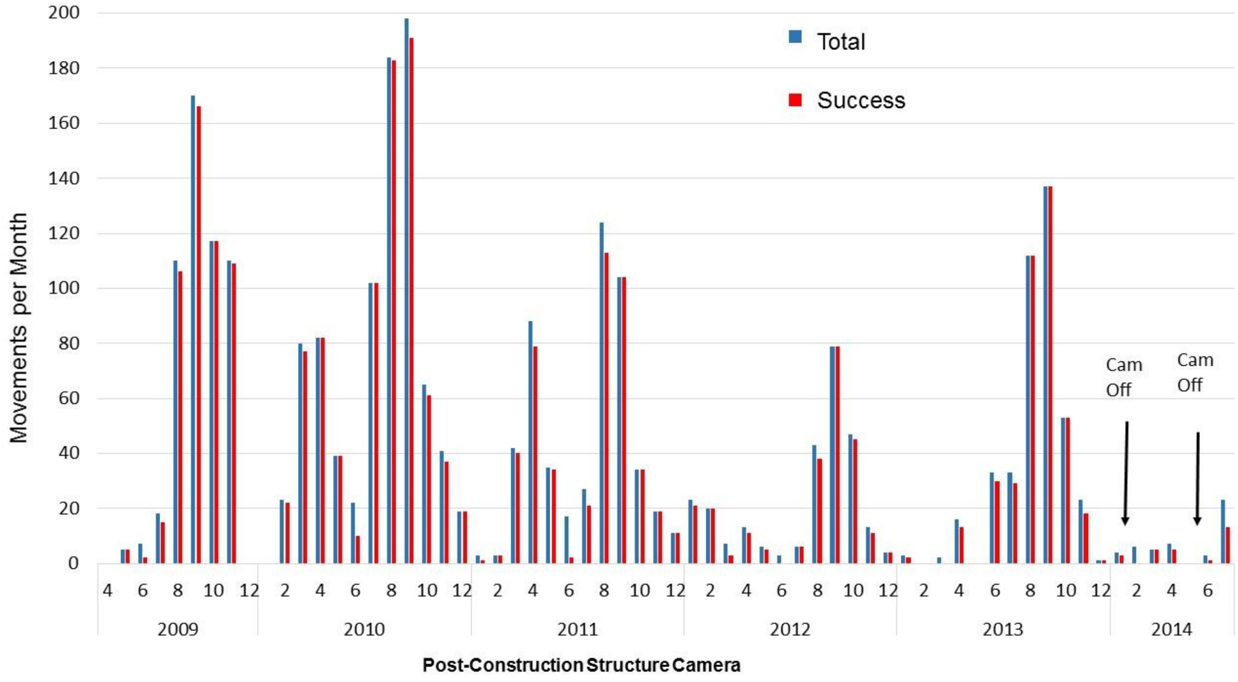

Figure 6. Kootenai Creek Bridge, mp 66, White-Tailed Deer Monthly Use, 2009-2014.

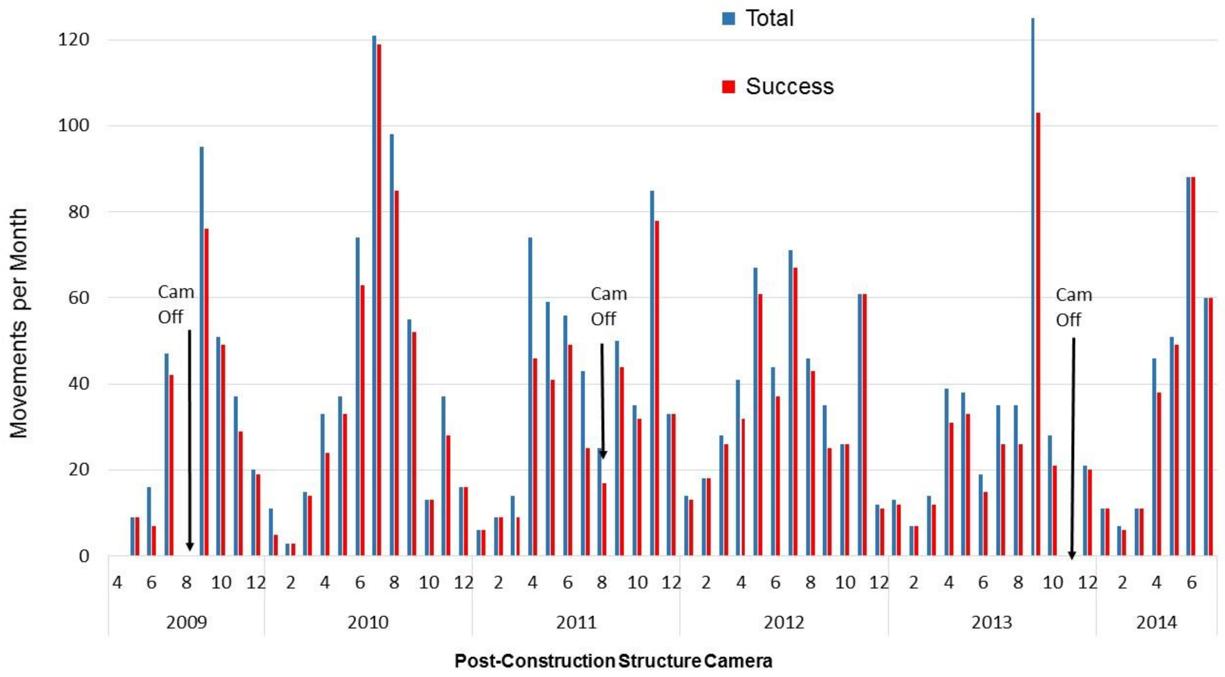

Figure 7. McCalla Creek North Bridge, mp 66, White-Tailed Deer Monthly Use, 2009-2014.

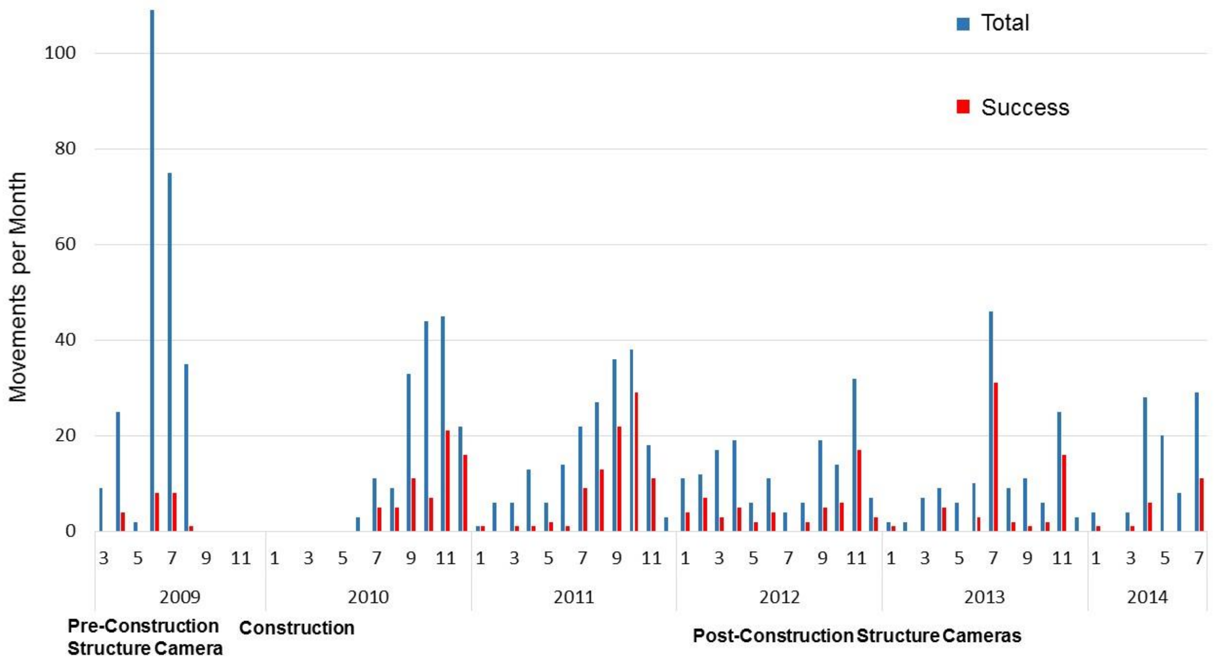

Figure 8. McCalla Creek South Bridge, mp 65, White-Tailed Deer Monthly Use, 2009-2014.

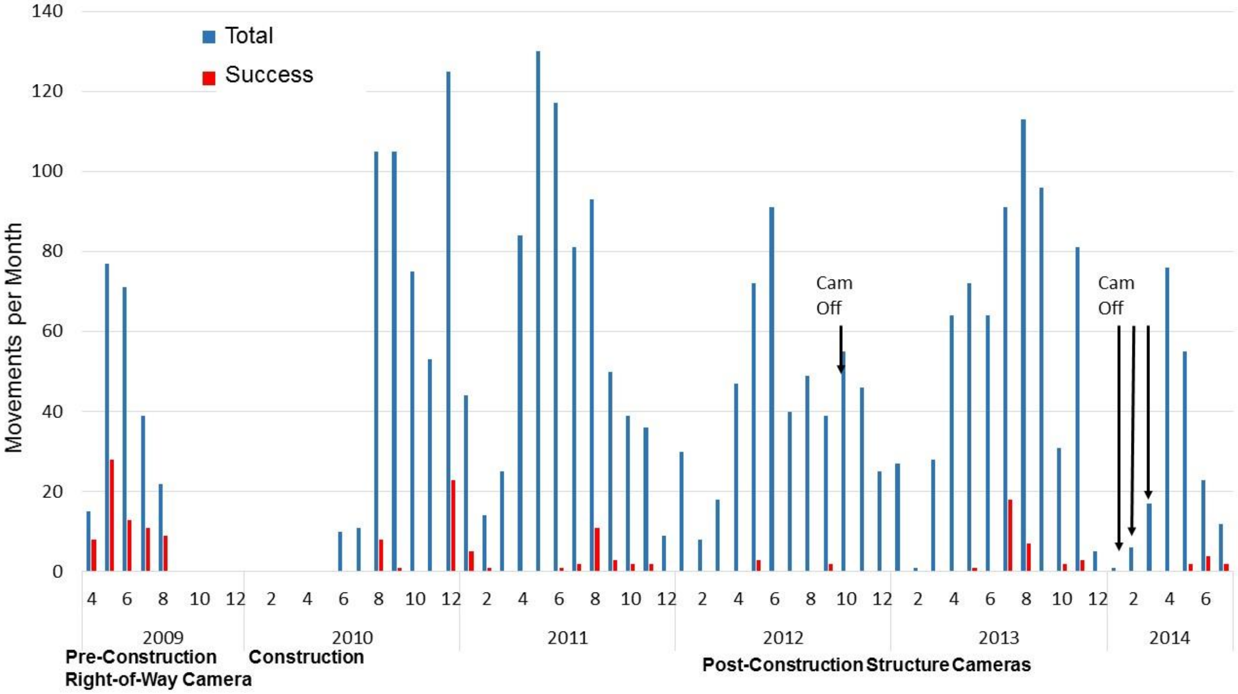

Figure 9. Kootenai Springs Ranch Culvert, mp 65, White-Tailed Deer Monthly Use, 2009-2014.

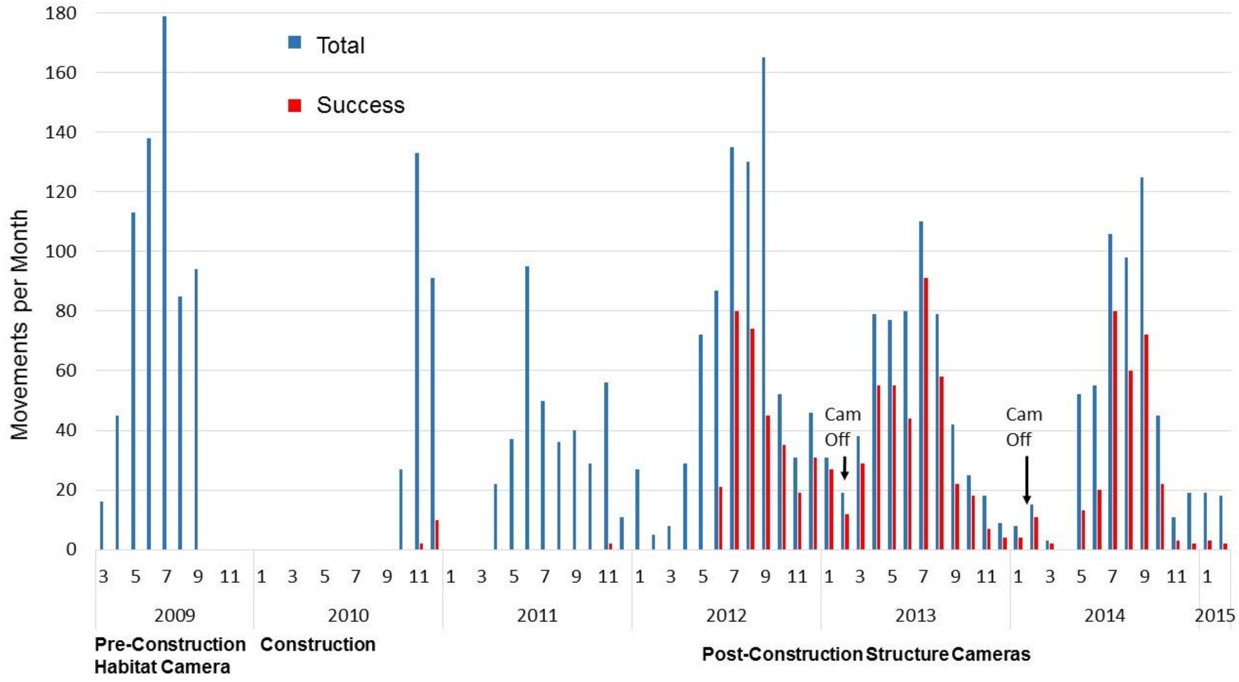

Figure 10. Indian Prairie Loop Culvert, mp 63, White-Tailed Deer Monthly Use, 2009-2015.

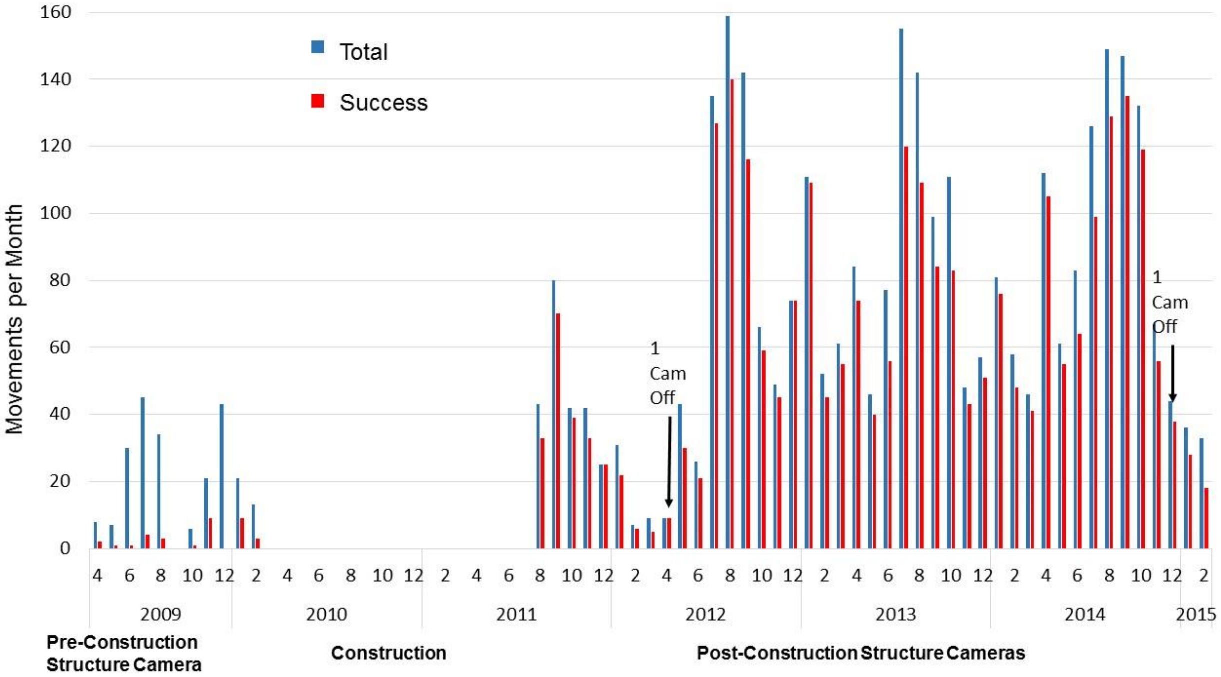

Figure 11. Big Creek Bridge, mp 61, White-Tailed Deer Monthly Use, 2009-2015.

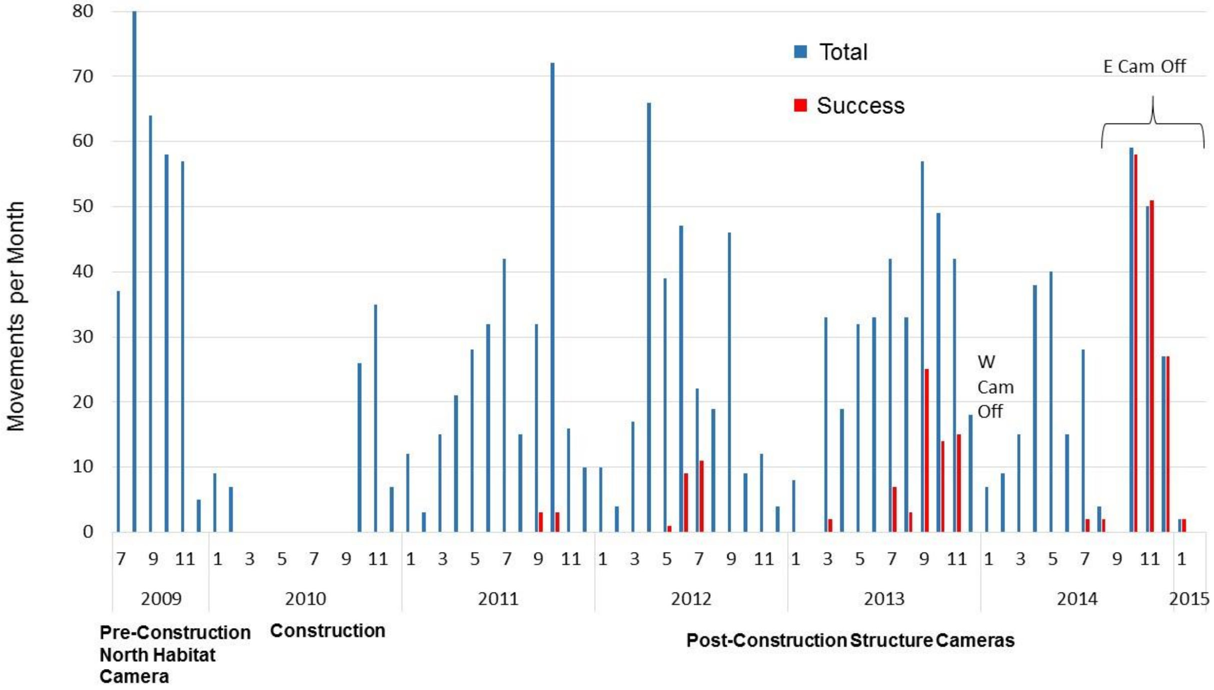

Figure 12. Axmen Culvert, mp 61, White-Tailed Deer Monthly Use, 2009-2015.

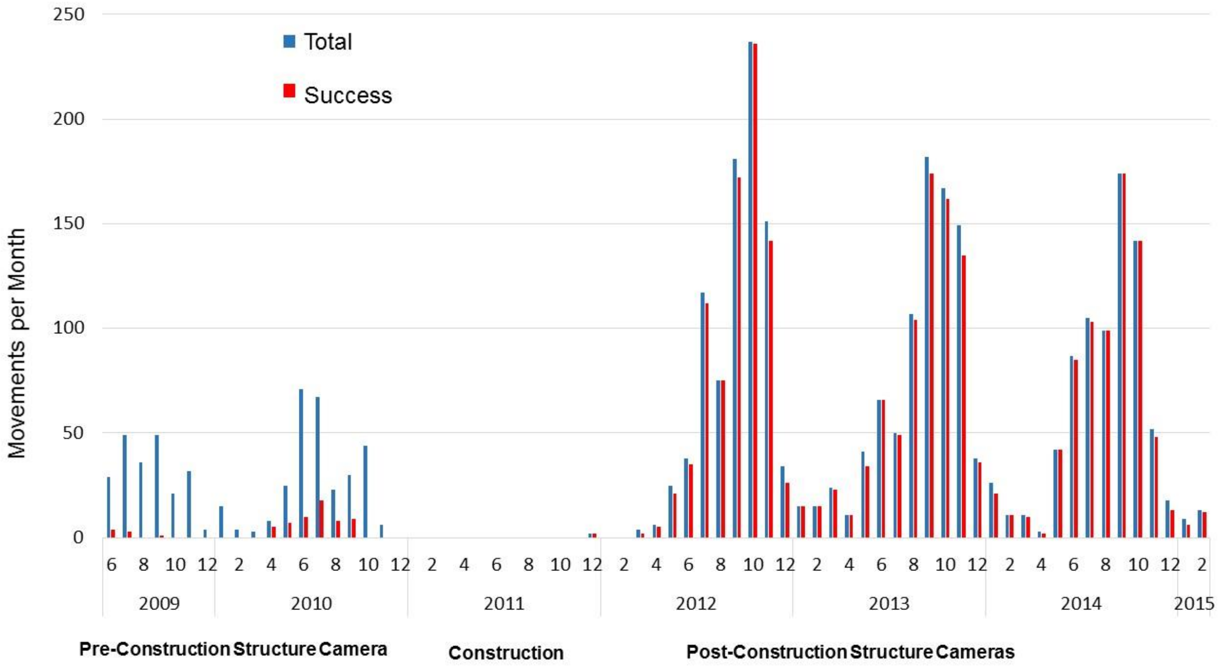

Figure 13. Sweathouse Creek Bridge, mp 60, White-Tailed Deer Monthly Use, 2009-2015.

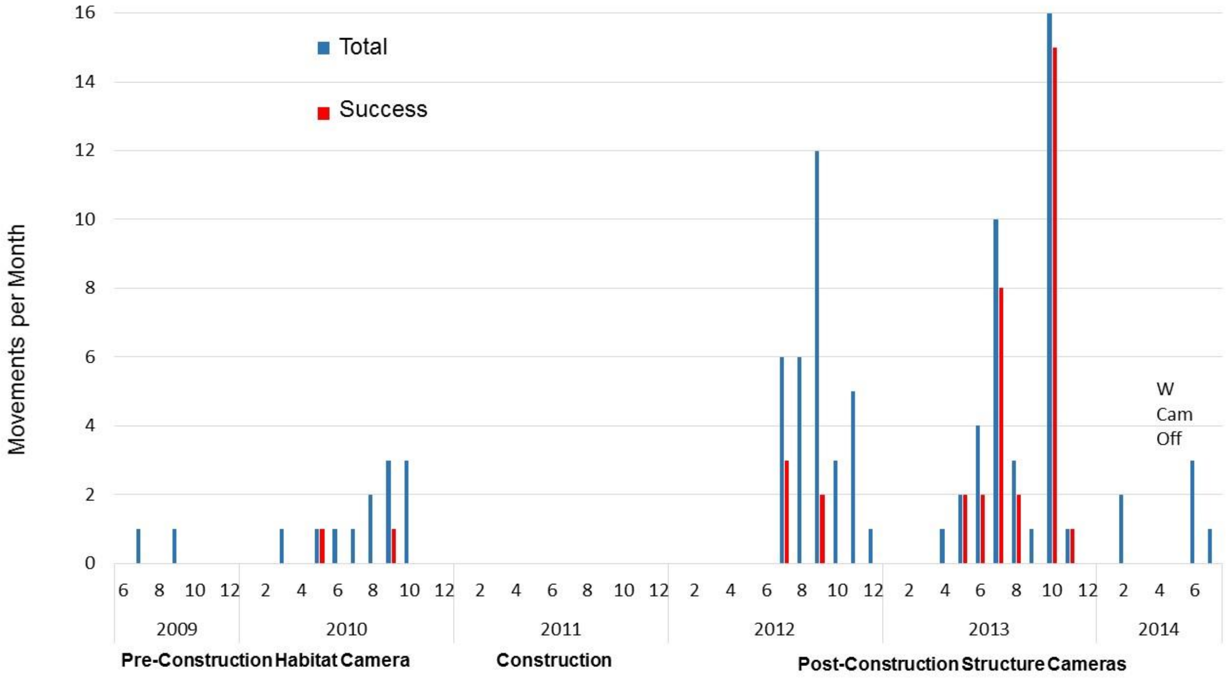

Figure 14. Bear Creek North Bridge, mp 58, White-Tailed Deer Monthly Use, 2009-2014.

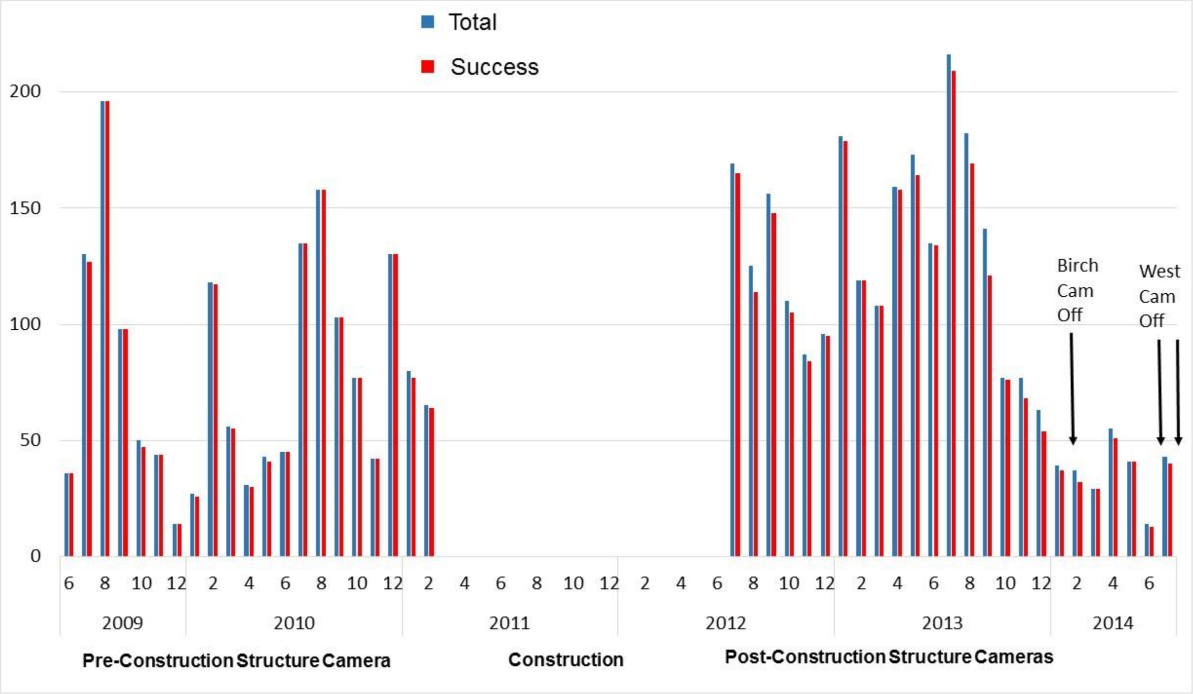

Figure 15. Bear Creek South Bridge, mp 57, White-Tailed Deer Monthly Use, 2009-2014.

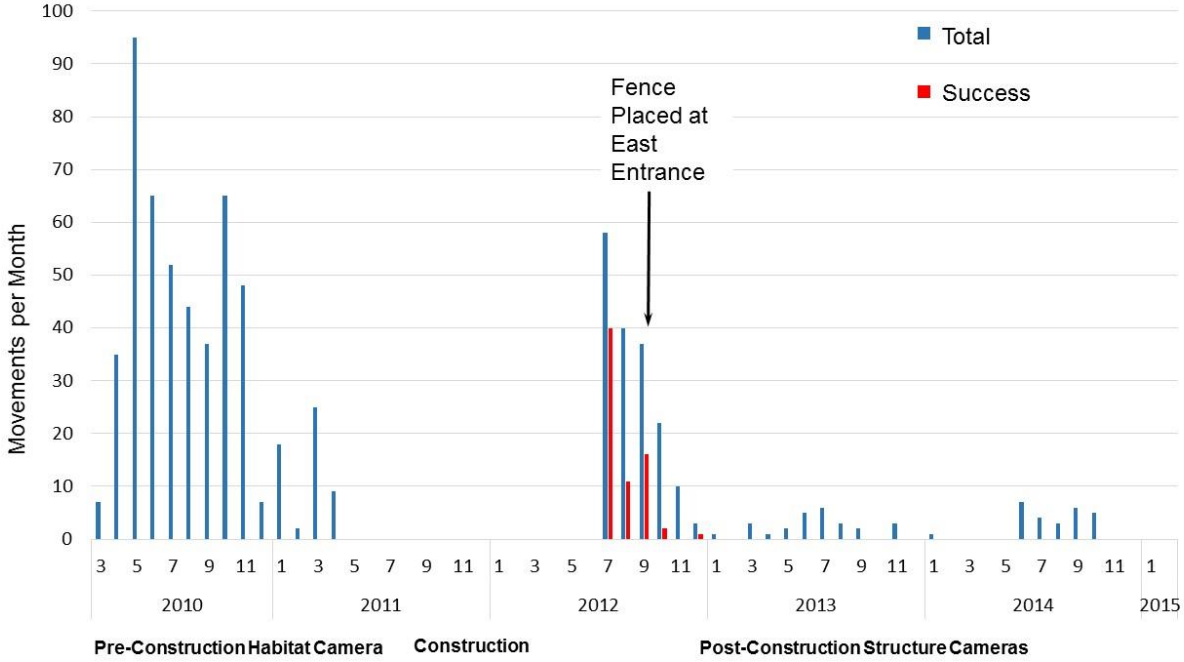

Figure 16. Lupine Culvert, mp 56, White-Tailed Deer Monthly Use, 2009-2015.

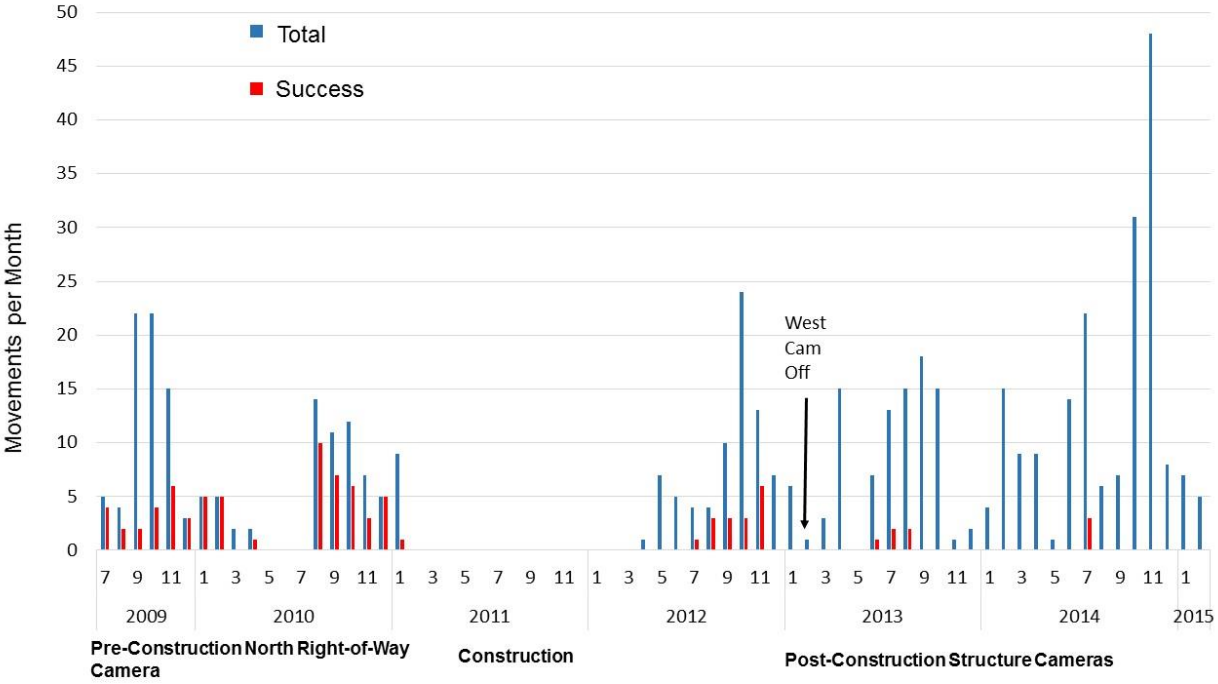

Figure 17. Mountain Gallery Culvert, mp 56, White-Tailed Deer Monthly Use, 2009-2015.

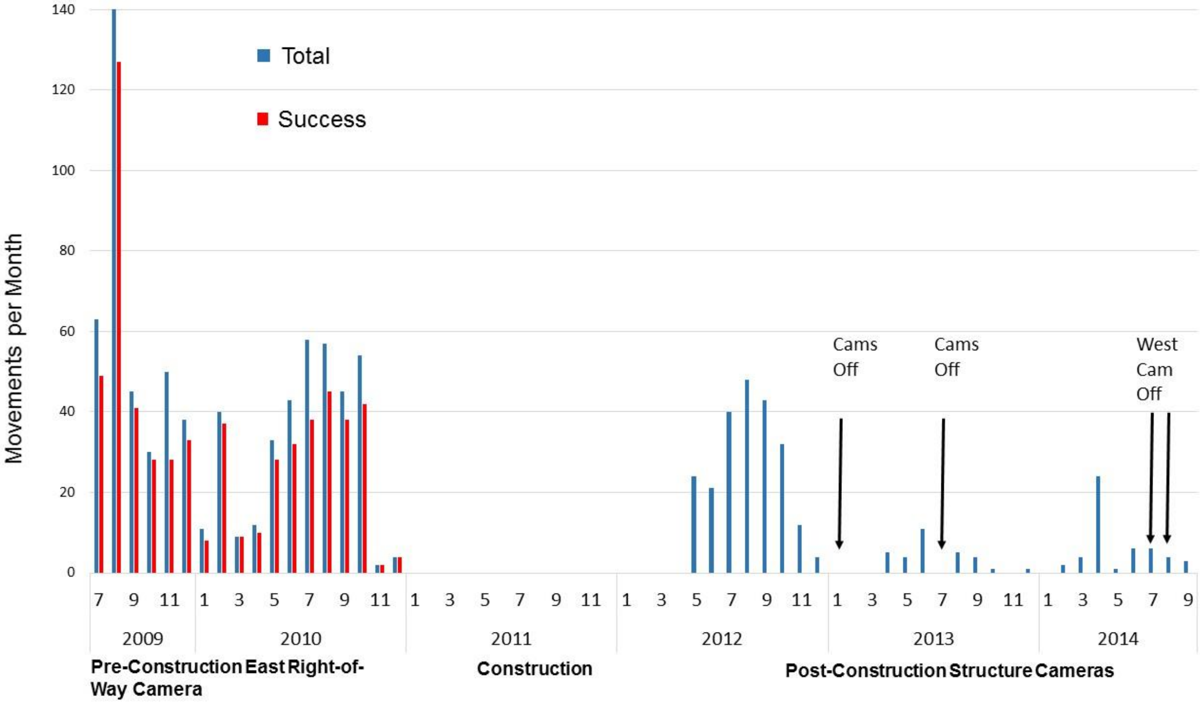

Figure 18. Fun Park Culvert, mp 55, White-Tailed Deer Monthly Use, 2009-2014.

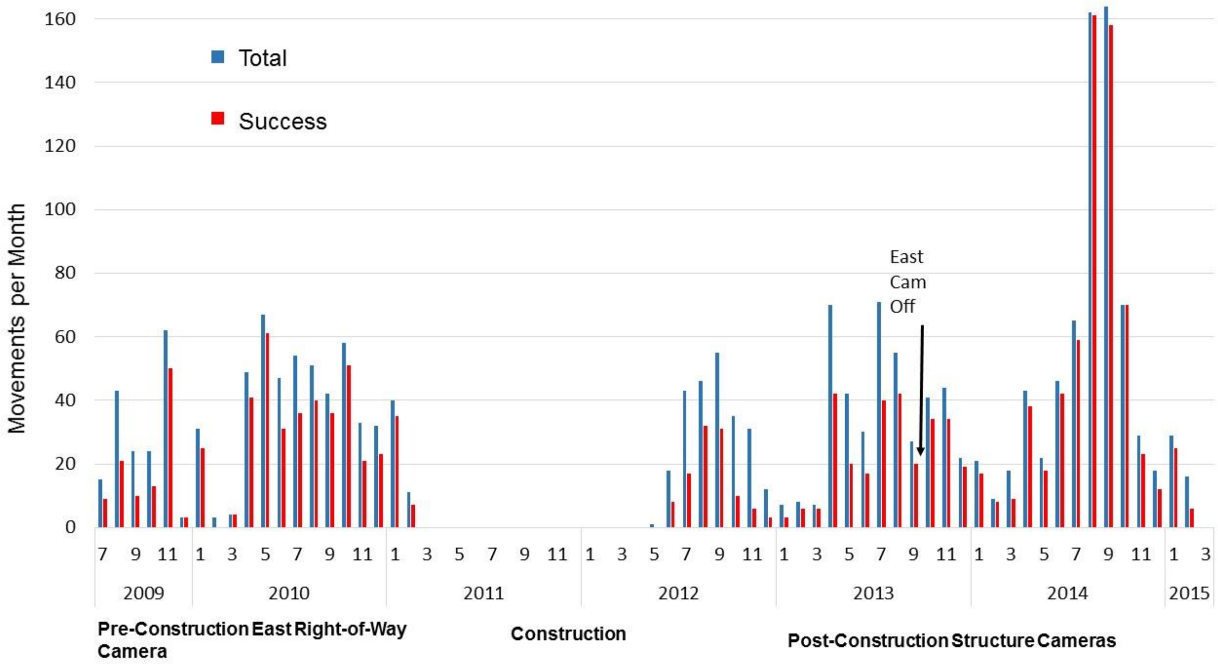

Figure 19. Mill Creek Bridge, mp 55, White-Tailed Deer Monthly Use, 2009-2015.

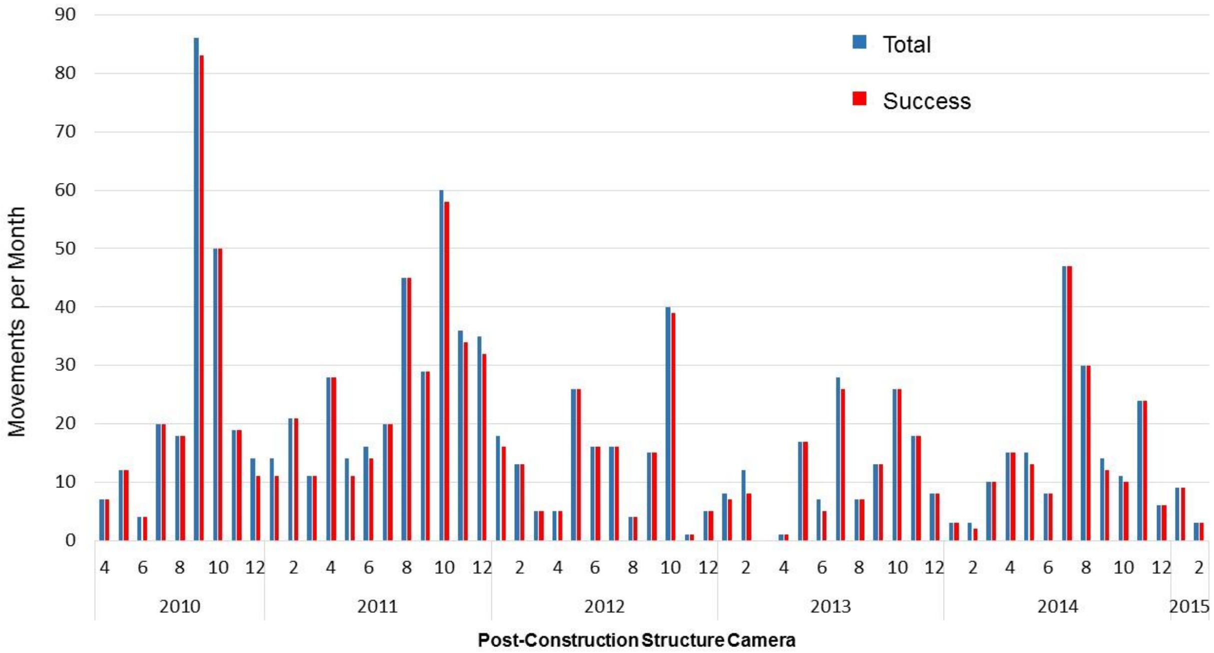

Figure 20. Blodgett Creek Bridge, mp 50, White-Tailed Deer Monthly Use, 2009-2015.

2.3.2.3 Comparing White-Tailed Deer Use of Pre-Construction Sites and Post-Construction Structures

Table 4 presents detailed comparisons of:

- pre-construction **success rates** at original bridges and right-of-ways with post-construction success rates (three left columns, dark blue),
- pre-construction **success per camera day** at original bridges and right-of-ways with post-construction success per camera day (three middle columns, slate blue), and
- pre-construction **abundance** at original bridges, right-of-ways, and habitat cameras with post-construction abundance (four right columns, light blue).

Table 4. White-Tailed Deer Pre-Construction Use Compared with Post-Construction Use for Success Rate (Dark Blue), Success Per Camera Day (Slate Blue), and Abundance (Light Blue).

Pre-Construction Site	Pre Suc Rate Orig Brdg	Pre Suc Rate Orig ROW	Post Suc Rate	Pre Suc/Day Orig Brdg	Pre Suc/Day Orig ROW	Post Suc/Day	Pre Abund Orig Brdg	Pre Abund Orig ROW	Pre Abund Hab	Post Abund
McCalla South (structure camera)	8		39	0.2		0.2	2.3			0.5
McCalla South (habitat camera)									5.0	0.5
Kootenai Spngs (east ROW camera)		32	4		0.7	0.08		2.1		2.0
Kootenai Spngs (west ROW camera)		54	4		0.5	0.08		0.9		2.0
Indian Prairie (north habitat camera)									4.7	2.0
Indian Prairie (south habitat camera)									4.5	2.0
Big Creek (structure camera)	14		83	0.1		2.3	0.8			2.7
Big Creek (habitat camera)									2.2	2.7
Axmen (north habitat camera)									1.5	1.1
Axmen (south habitat camera)									0.4	1.1

Pre-Construction Site	**Pre Suc Rate Orig Brdg**	**Pre Suc Rate Orig ROW**	**Post Suc Rate**	**Pre Suc/Day Orig Brdg**	**Pre Suc/Day Orig ROW**	**Post Suc/Day**	**Pre Abund Orig Brdg**	**Pre Abund Orig ROW**	**Pre Abund Hab**	**Post Abund**
Sweathouse (Structure Camera)	13		94	0.1		2.1	1.1			2.2
Sweathouse (ROW Camera)		52	94		0.4	2.1		0.9		2.2
Bear North (Structure Camera)	14		37	0.004		0.05	0.03			0.1
Bear North (Habitat Camera)									0.6	0.1
Bear South (Structure Camera)	98		95	2.6		3.7	2.7			3.9
Bear South (ROW Camera)		68	95		.3	3.7		0.4		3.9
Lupine (South ROW Camera)		80	29		0.09	0.07		0.1		0.3
Lupine (West Habitat Camera)									1.3	0.3
Gallery (North ROW Camera)		45	7		0.1	0.03		0.3		0.4
Gallery (South ROW Camera)		61	7		0.04	0.03		0.07		0.4
Fun Park (East ROW Camera)		79	0		1.2	0		1.6		0.6
Fun Park (West ROW Camera)		52	0		0.1	0		0.2		0.6
Mill Creek (Structure Camera)	3		72	0.002		0.9	0.07			1.3
Mill Creek (ROW Camera)		70	72		0.9	0.9		1.3		1.3

2.3.3 Discussion

2.3.3.1 Post-construction Monitoring

Success rate calculations did not include the amount of time wildlife crossing structures were monitored or deer abundance. This should be taken into account when comparing success rates between structures. Success rate said more about the performance of the structures rather than the structures location on the landscape or deer abundance. Dawns Crossing Bridge clearly had the most success movements (5,204) and the highest success rate (97 percent) of all structures.

Success per camera day allowed for a direct comparison of structures that were monitored for different lengths of time. Comparisons of success per camera day among wildlife crossing structures should take into account that structure locations naturally had different deer abundances. Thus, success per camera day said more about the location of the structures on the landscape rather than the performance of structures when compared to each other. Bear Creek South Bridge clearly had a higher success per camera day (3.7) than the other structures.

This analysis showed that both the location and the design of wildlife crossing structures are important.

2.3.3.2 Monthly Use and Comparing White-Tailed Deer Use of Pre-Construction Sites and Post-Construction Structures

Nine structures (eight bridges, one culvert) exceeded the performance measures. Ten structures (four bridges, six culverts) did not exceed the performance measures. Structures were evaluated relative to performance measures using the following subjective scale: highly negative, negative, slightly negative, neutral, slightly positive, positive, and highly positive.

Bass Creek North Bridge, mp 71

Total movements and success movements peaked between 2010 and 2012, then decreased through 2014 (Figure 2). Post-construction success rate (54 percent) was slightly less than the 60 percent or greater performance measure established in section 2.2.3. Post-construction rate of repellency (7 percent) was slightly less than the 10 percent or less performance measure. Relative to these performance measures, the overall post-construction effect of this structure on white-tailed deer attempting to move from one side of US 93 to the other was neutral. This structure ranked 13th for success per camera day (0.1) and 10th for success rate among the 19 wildlife crossing structures. There were 260 success movements by white-tailed deer during five years of monitoring. This bridge was completed in 2005. Pre-construction monitoring did not occur at this location.

Bass Creek South Bridge, mp 70

Total movements and success movements were low throughout the study, and peaked in 2012 (Figure 3). Post-construction success rate (36 percent) and rate of repellency (17 percent) were well below the performance measures established in section 2.2.3. The overall post-construction effect of this structure on white-tailed deer attempting to move from one side of US 93 to the other was highly negative. This structure ranked 18th for success per day (0.01) and 14th for success rate among the 19 wildlife crossing structures. It was the least successful bridge. There were only 13 success movements by white-tailed deer during five years of monitoring. This bridge was completed in 2005. Pre-construction monitoring did not occur at this location.

Bass Creek Fishing Access Culvert, mp 70

Total movements and success movements were high throughout the study, and peaked slightly between 2010 and 2012, with particularly high values during the summer of 2012 (Figure 4). Post-construction success rate (96 percent) and rate of repellency (3 percent) greatly exceeded the performance measures described in section 2.2.3. The overall post-construction effect of this structure on white-tailed deer attempting to move from one side of US 93 to the other was highly positive. This structure ranked fifth for success per camera day (1.6) and second for success rate among the 19 wildlife crossing structures. It was the most successful culvert. There were 3,257 success movements by white-tailed deer during more than five years of monitoring. This culvert was completed in 2005. Pre-construction monitoring did not occur at this location.

Dawns Crossing Bridge, mp 70

Total movements and success movements increased slightly each year of the study, particularly from 2012 through 2014, and remained very high (Figure 5). Post-construction success rate (97 percent) and rate of repellency (1 percent) greatly exceeded the performance measures described in section 2.2.3. The overall post-construction effect of this structure on white-tailed deer attempting to move from one side of US 93 to the other was highly positive. This structure ranked second for success per camera day (2.4) and first for success rate among the 19 wildlife crossing structures. It was the most successful wildlife crossing structure. There were 5,204 success movements by white-tailed deer during nearly six years of monitoring. This bridge was completed in 2005. Pre-construction monitoring did not occur at this location.

Kootenai Creek Bridge, mp 66

Total movements and success movements increased through the first 18 months of post-construction monitoring (2009-2010) as white-tailed deer quickly adapted to this structure. Movements then declined over time. There were camera failures in early summer-late spring 2014 which made the white-tailed deer use of the structure look less than it may have been (Figure 6). Post-construction success rate (91 percent) and rate of repellency (5 percent) exceeded the performance measures described in section 2.2.3. The overall post-construction effect of this structure on white-tailed deer attempting to move from one side of US 93 to the other was positive. This structure ranked sixth for success per camera day (1.4) and sixth for success rate among the 19 wildlife crossing structures. There were 2,470 success movements by white-tailed deer during nearly five years of monitoring. This bridge was completed in 2009. Pre-construction monitoring did not occur at this location.

McCalla Creek North Bridge, mp 66

Total movements and success movements steadily increased from 2009 to 2010, decreased in 2011 and 2012, and then increased again in 2014 (Figure 7). It appeared that deer may have shifted their movements from Kootenai Creek Bridge to McCalla Creek North Bridge after 2010. Post-construction success rate (83 percent) and rate of repellency (6 percent) exceeded the performance measures described in section 2.2.3. The overall post-construction effect of this structure on white-tailed deer attempting to move from one side of US 93 to the other was positive. This structure ranked seventh for success per camera day (1.2) and tied for seventh for success rate among the 19 wildlife crossing structures. There were 2,058 success movements by white-tailed deer during nearly five years of monitoring. This bridge was completed in 2009. Pre-construction monitoring did not occur at this location.

McCalla Creek South Bridge, mp 65

Total post-construction movements and success movements peaked in 2012 then declined (Figure 8). Post-construction success rate (39 percent) and rate of repellency (20 percent) were well below the performance measures established in section 2.2.3. Pre-construction monitoring included a structure camera at the original bridge and a habitat camera. Pre-construction success per camera day at the original bridge (0.2) was identical to post-construction success per camera day (0.2). Pre-construction success rate at the original bridge (9 percent) was lower than post-construction success rate (39 percent). However, the camera location at the original bridge was less than ideal for photographing deer that approached the structure because of vegetation and stream morphology. Pre-construction abundance at the original bridge (2.3) and habitat camera (5.0) were much higher than post-construction abundance at the structure (0.5). It appeared that deer abundance drastically decreased during post-construction monitoring. Specifically, the control camera at this location recorded abundance of 1.0 post-construction (section 2.3.2). However, it is important to note that pre-construction habitat monitoring occurred for only 93 days during the summer. The overall post-construction effect of this structure on white-tailed deer attempting to move from one side of US 93 to the other was slightly negative. This structure ranked 11th for success per camera day and tied for 11th for success rate among the 19 wildlife crossing structures. There were 293 success movements by white-tailed deer during four years of post-construction monitoring.

Kootenai Springs Ranch Culvert, mp 65

This culvert was not designed specifically as a wildlife crossing structure. It was installed primarily to provide ranch access under the highway. This culvert held water for approximately 8 months per year. For the purposes of this study, the culvert was monitored to assess its potential as a wildlife crossing structure. Total movements and success movements decreased slightly during the entire study, with a particular dip in 2012 (Figure 9). Post-construction success rate (4 percent) and rate of repellency (13 percent) were well below the performance measures established in section 2.2.3. Pre-construction monitoring included two right-of-way cameras (Table 4). Pre-construction success per camera day across US 93 at the right-of-way cameras (0.7 and 0.5) was much higher than the post-construction success per camera day (0.08) through the structure. Pre-construction success rates at right-of-way cameras (32 percent and 54 percent) were much higher than post-construction success rate. Pre-construction abundance at the right-of-way cameras (2.1 and 0.9) was nearly equal to post-construction abundance (2.0). The overall post-construction effect of this structure on white-tailed deer attempting to move from one side of US 93 to the other was highly negative. This structure ranked 14th for success per camera day and 18th for success rate among the 19 wildlife crossing structures. There were 103 success movements by white-tailed deer during nearly four years of post-construction monitoring.

As mentioned above, the Kootenai Springs Ranch Culvert was not designed specifically as a wildlife crossing structure, and elk were not known to be present at the site during the design phase of the project. However, elk were photographed on 50 occasions during pre-construction at the right-of-way cameras. The success rate for elk moving across US 93 during pre-construction was 58 percent. In post-construction monitoring, elk were photographed on 207 occasions near the entrances to the culvert. Only one elk calf successfully crossed through the structure, resulting in a post-construction success rate of less than one percent. The overall post-construction effect of this structure on elk attempting to move from one side of US 93 to the other was highly negative. Fifteen elk were photographed crossing across US 93 above the culvert during the early days of post-construction monitoring. These elk apparently used the escape ramp to successfully exit from the highway.

Indian Prairie Culvert, mp 63

Total movements per year were steady throughout post-construction monitoring. Success movements per month were minimal through May 2012, increased dramatically in June 2012, and remained consistent though the end of the study (Figure 10). Post-construction success rate (39 percent) and rate of repellency (8 percent) were below and slightly above, respectively, the performance measures established in section 2.2.3. However, post-construction success rate during the final 15 months of monitoring was 50 percent. Pre-construction monitoring included two habitat cameras. Pre-construction abundance at the right-of-way cameras (4.7 and 4.5) was much higher than post-construction abundance at the structure (2.0). The overall post-construction effect of this structure on white-tailed deer attempting to move from one side of US 93 to the other was slightly negative. This structure ranked ninth for success per camera day (0.8) and tied for 11th for success rate among the 19 wildlife crossing structures. There were 1039 success movements by white-tailed deer during nearly four years of post-construction monitoring.

This site had one of the highest pre-construction white-tailed deer WVC hotspots between 2000 to 2005 (Chapter 4). Deer may have been adapted to making highway crossing attempts at this site. The site was drastically altered during construction. A borrow pit was created on the east side of the site and became an open-water pond, approximately 6 meters (20 feet) from the entrance to the culvert. The west side was altered by the removal of numerous cottonwood trees and shrubs to accommodate utility lines. MDT biologist Pat Basting removed the top strand of barbed wire on the right of way fence (not the wildlife fence) in several sections on each side of the structure in early 2011 to encourage deer use.

Big Creek Bridge, mp 61

Total movements and success movements increased after the first year of post-construction monitoring then remained steady and high (Figure 11). Post-construction success rate (83 percent) and rate of repellency (7 percent) exceeded the performance measures established in section 2.2.3. Pre-construction monitoring included a structure camera at the original bridge and a habitat camera. Pre-construction success per camera day at the original bridge (0.1) was much less than post-construction success per camera day (2.3). Pre-construction success rate at the original bridge (14 percent) was lower than post-construction success rate. However, the camera location at the original bridge was less than ideal for photographing deer that approached the structure because of vegetation and stream morphology. Pre-construction abundance at the original bridge (0.8) was much lower than post-construction abundance at the structure (2.7). Pre-construction abundance at the habitat camera (2.2) was similar to post-construction abundance at the structure. The overall post-construction effect of this structure on white-tailed deer attempting to move from one side of US 93 to the other was positive. This structure ranked third for success per camera day and tied for seventh for success rate among the 19 wildlife crossing structures. There were 2,769 success movements by white-tailed deer during more than three years of post-construction monitoring.

Axmen Propane Culvert, mp 61
Post-construction total movements and success movements increased slightly from 2011 through 2013, decreased in the first half of 2014, then increased dramatically in the last half of 2014. The increase in the last half of 2014 was the result of numerous success movements by a single young male white-tailed deer (Figure 12). Post-construction success rate (18 percent) and rate of repellency (10 percent) were well below and equal to, respectively, the performance measures established in section 2.2.3. Pre-construction monitoring included two habitat cameras. Pre-construction abundance at the habitat cameras (1.5 and 0.4) was similar to post-construction abundance at the structure (1.1). The overall post-construction effect of this structure on white-tailed deer attempting to move from one side of US 93 to the other was negative. This structure ranked 12th for success per camera day (0.2) and 16th for success rate among the 19 wildlife crossing structures. There were 235 success movements by white-tailed deer during more than three years of post-construction monitoring.

Sweathouse Creek Bridge, mp 60
Total movements and success movements remained high and steady during the study (Figure 13). Post-construction success rate (94 percent) and rate of repellency (2 percent) greatly exceeded the performance measures established in section 2.2.3. Pre-construction monitoring included a structure camera at the original bridge and a right of way camera. Pre-construction success per camera day at the original bridge (0.1) and the right of way (0.4) were much lower than post-construction success per day (2.1). Pre-construction success rates at the original bridge (13 percent) and right of way (52 percent) were lower than the post-construction success rate. Pre-construction abundance at the original bridge (1.1) and the right of way (0.9) was lower than post-construction abundance at the structure (2.2). The overall post-construction effect of this structure on white-tailed deer attempting to move from one side of US 93 to the other was highly positive. This structure ranked fourth for success per camera day and tied for fourth for success rate among the 19 wildlife crossing structures. There were 2,419 success movements by white-tailed deer during more than three years of monitoring.

Bear Creek North Bridge, mp 58
Post-construction total movements and success movements increased in 2013 then decreased in 2014. Values remained low throughout the study (Figure 14). Post-construction success rate (37 percent) and rate of repellency (22 percent) were well below the performance measures established in section 2.2.3. Pre-construction monitoring included a structure camera at the original bridge and a habitat camera. Pre-construction success per camera day at the original bridge (0.004) was less than post-construction success per camera day (0.05). Pre-construction success rate at the original bridge (14 percent) was lower than post-construction success rate. Pre-construction abundance at the original bridge (0.03) and habitat camera (0.6) were much lower than and greater than, respectively, the post-construction abundance at the structure (0.1). The overall post-construction effect of this structure on white-tailed deer attempting to move from one side of US 93 to the other was highly negative. This structure ranked 16th for success

per camera day and 13th for success rate among the 19 wildlife crossing structures. There were only 35 success movements by white-tailed deer during nearly two years of post-construction monitoring.

Bear Creek South Bridge, mp 57

Post-construction total movements and success movements peaked in 2013 and declined sharply in 2014 (Figure 15). This decline may have been artificial, the result of camera failures and a camera theft. In addition, a landowner east of the structure was observed feeding wildlife in 2013, and moved away in 2014. Post-construction success rate (95 percent) and rate of repellency (1 percent) greatly exceeded the performance measures established in section 2.2.3. Pre-construction monitoring included a structure camera at the original bridge and a right of way camera. Pre-construction success per camera day at the original bridge (2.6) and the right of way (0.3) were lower than post-construction success per camera day (3.7). Pre-construction success rates at the original bridge (98 percent) and right of way (68 percent) were similar to and lower than, respectively, the post-construction success rate. Pre-construction abundance at the original bridge (2.7) and the right of way (0.4) was lower than post-construction abundance at the structure (3.9). The overall post-construction effect of this structure on white-tailed deer attempting to move from one side of US 93 to the other was highly positive. This structure ranked first for success per camera day and third for success rate among the 19 wildlife crossing structures. There were 2,554 success movements by white-tailed deer during nearly two years of post-construction monitoring.

Lupine Culvert, mp 56

Post-construction total movements and success movements peaked in the last half of 2012 and declined sharply through the beginning of 2015 (Figure 16). Success movements did not occur after 2012. Post-construction success rate (29 percent) and rate of repellency (17 percent) were well below the performance measures established in section 2.2.3. Pre-construction monitoring included two right of way cameras and two habitat cameras. Pre-construction success per camera day at the south right of way camera (0.09) was similar to post-construction success per camera day (0.07). Pre-construction success rate at the south right of way camera (80 percent) was much greater than post-construction success rate. Pre-construction abundance at the west habitat camera (1.3) was greater than post-construction abundance at the structure (0.3). The overall post-construction effect of this structure on white-tailed deer attempting to move from one side of US 93 to the other was highly negative. This structure ranked 15th for success per camera day and success rate among the 19 wildlife crossing structures. There were 70 success movements by white-tailed deer during nearly three years of post-construction monitoring. Sixty-seven of these success movements occurred in the first three months of monitoring in 2012. The right of way fence was placed approximately 2 meters (6 feet) from the east structure entrance in September 2012 (Figure 16). This culvert conveyed water during the spring and early summer.

Mountain Gallery Culvert, mp 56

Total movements increased slightly during post-construction monitoring. Success movements peaked in 2012 and steadily decreased thereafter (Figure 17). Post-construction success rate (7 percent) was well below the 60 percent performance measure established in section 2.2.3. Post-construction rate of repellency (8 percent) was slightly less than the overall rate of repellency of pre-construction right of way cameras. Pre-construction monitoring included two right-of-way cameras. Pre-construction success per camera day across US 93 at the right-of-way cameras (0.1 and 0.04) was higher than the post-construction success per camera day (0.03) through the structure. Pre-construction success rates at right-of-way cameras (45 percent and 61 percent) were much higher than post-construction success rate. Pre-construction abundance at the right-of-way cameras (0.3 and 0.07) was less than post-construction abundance (0.4). The overall post-construction effect of this structure on white-tailed deer attempting to move from one side of US 93 to the other was highly negative. This structure ranked 17th for success per camera day and 17th for success rate among the 19 wildlife crossing structures. There were 26 success movements by white-tailed deer during nearly three years of post-construction monitoring. The west side of this culvert held water during the spring and early summer.

Fun Park Culvert, mp 55

Total movements peaked in 2012 then decreased during post-construction monitoring (Figure 18). Post-construction success rate (0 percent) was well below the 60 percent performance measure established in section 2.2.3. Post-construction rate of repellency (9 percent) was similar to the overall rate of repellency of pre-construction right of way cameras. Pre-construction monitoring included two right-of-way cameras. Pre-construction success per camera day across US 93 at the right-of-way cameras (1.2 and 0.1) was much higher than post-construction success per camera day (0.0). Pre-construction success rates at right-of-way cameras (79 percent and 52 percent) were much higher than post-construction success rate. Pre-construction abundance at the east right-of-way camera (1.6) was much greater than post-construction abundance (0.6). The overall post-construction effect of this structure on white-tailed deer attempting to move from one side of US 93 to the other was highly negative. This structure ranked 19th for success per camera day and 19th for success rate among the 19 wildlife crossing structures. There were no success movements by white-tailed deer during two years of post-construction monitoring. This culvert conveyed water at all times during post-construction monitoring.

Mill Creek Bridge, mp 55

Total movements and success movements increased during post-construction monitoring and peaked substantially in 2014 (Figure 19). Post-construction success rate (72 percent) and rate of repellency (8 percent) exceeded the performance measures established in section 2.2.3. Pre-construction monitoring included a structure camera at the original bridge and a right of way camera. Pre-construction success per camera day at the right of way camera (0.9) was equal to post-construction success per day. Pre-construction success rate at the right of way (70 percent) was slightly less than the post-construction success rate. Pre-construction abundance at the right of way (1.3) was equal to the post-construction abundance at the structure. The overall post-construction effect of this structure on white-tailed deer attempting to move from one side of US 93 to the other was slightly positive. This structure ranked eighth for success per camera day and ninth for success rate among the 19 wildlife crossing structures. There were 1,036 success movements by white-tailed deer during three years of monitoring.

Blodgett Creek Bridge, mp 50

Post-construction total movements and success movements peaked in 2010 and 2011, decreased in 2012 and 2013, and increased slightly in 2014 (Figure 20). Post-construction success rate (94 percent) and rate of repellency (3 percent) greatly exceeded the performance measures established in section 2.2.3. The overall post-construction effect of this structure on white-tailed deer attempting to move from one side of US 93 to the other was positive. This structure ranked 10th for success per camera day (0.6) and tied for fourth for success rate among the 19 wildlife crossing structures. There were 1,037 success movements by white-tailed deer during nearly five years of monitoring. This bridge was completed in 2008. Pre-construction monitoring did not occur at this location.

2.4 Other Species

Data summaries for all other species of wildlife, domestic animals, and humans photographed at each structure are presented in Appendix B.

2.5 Summary

Pre-construction monitoring began in March 2009 and was completed in April 2011. The overall success rate for white-tailed deer crossing US 93 was 64 percent, and the overall rate of repellency was 10 percent. Control monitoring began in late May 2009 and was completed on March 1, 2015. The success rate for white-tailed deer crossing County Road 370 (Bell Crossing Road, a control site), was 63 percent and the rate of repellency was five percent. Based on these rates, performance measures of 60 percent or greater success rate and 10 percent or less rate of repellency were established to evaluate post construction use rates of wildlife crossing structures. During post-construction monitoring (October 2008 through March 1, 2015) cameras recorded white-tailed deer successfully moving through wildlife crossing structures on 24,878 occasions. Dawns Crossing Bridge had the most success movements (5,204) and the highest success rate (97 percent). Bear Creek South Bridge had the highest success per camera day (3.7). Fun Park Culvert was the least successful structure. Nine structures (eight bridges, one culvert) exceeded the performance measures. Ten structures (four bridges, six culverts) did not exceed the performance measures.

Chapter 3 Relationships Between White-Tailed Deer Use Rates of Wildlife Crossing Structures and Explanatory Variables

3.1 Introduction

Statistical analyses were used to assess differences and relationships among post-construction white-tailed deer use rates of wildlife crossing structures, structural characteristics of crossing structures, and environmental characteristics associated with crossing structures. These included:

- differences in use rates between structure types;
- relationships between use rates of wildlife crossing structures and explanatory variables;
- differences in explanatory variables between bridges and culverts;
- correlation between deer abundance and deer fecal pellets.

White-tailed deer use rates included: success rate, rate of repellency, parallel rate, and success per camera day. Explanatory variables included: height, width, length, and openness ratio of structures, fence lengths, guardrail lengths, humans per camera day, and average site values for percent cover of grass, forbs, shrubs, trees, bare ground, water, and number of deer fecal pellets. Comparisons of means for explanatory variables between bridges and culverts did not evaluate deer use, but aided interpretation of use rate analyses.

3.2 Methods

Formulas for use rates were described in Section 2.2.3. Structure height, width (span), length, fence length, and guardrail length were measured in meters, and were determined from physical measurements, MDT records, and Google Earth images. Height values for bridges were subjectively taken as the average height at locations where deer were successful moving through the bridges, and for culverts as the top to bottom distance at their openings. Width (span) was defined as left to right distance parallel to the road inside wildlife crossing structures, specifically, the distance between abutments for bridges, and the widest left to right point for culverts. Length was defined as the linear distance deer traveled to successfully move through a wildlife crossing structure. Openness ratio was calculated as height multiplied by width (span) divided by length, in meters (Reed et al. 1979). Humans per day was calculated as the number of human observations divided by the number of days the camera was in operation (average number of days for structures with more than one camera). Landscape variables (grass, forbs, shrubs, trees, bare ground, water, and pellets) were collected at all structures and control sites. Data were collected in 30 plots within 125-meter x 125-meter (410 feet x 410 feet) grids on each side of the structures (60 total plots at each structure). Within each 125-meter x 125-meter grid, 19 of the plots were 25 meters (82 feet) apart, and 11 of the plots near the structure entrances were 12.5 meters (41 feet) apart. Each plot was a circle with a 2 meter (6.5 feet) radius. Vegetation was categorized as grass, forbs, shrubs, or trees, and the percentage cover of each category was visually estimated. The number of deer pellets were counted in each plot.

Data calculations were made using the GLIMMIX, MULTTEST, and CORR procedures in SAS/STAT 13.2 in the SAS System for Windows 9.4 (SAS Institute 2014). Statistics were performed by Susan Durham of Utah State University Ecology Center.

3.2.1 White-Tailed Deer Use Rates for Bridges and Culverts

The difference in white-tailed deer success rate, rate of repellency, and parallel rate between structure types was assessed using a generalized linear mixed model with a binomial response and a logit link. The response was specified as the number of a given deer movement (success, repellency, or parallel) divided by total movements. Structure type was incorporated in the model as a fixed-effects factor. Structures were incorporated in the model as random blocks to reflect the role of structure as the replicating factor and to accommodate the clustering of counts by structure. The difference in success per camera day between structure types was assessed using a one-way ANOVA in a completely randomized design.

3.2.2. White-Tailed Deer Use Rates and Explanatory Variables

Assessment of the relationships between success rate, rate of repellency, or parallel rate and each explanatory variable used a generalized linear mixed model with a binomial response and a logit link, assuming a linear relationship on the link scale. Adjustment for over-dispersion because of clustering of observations at a given structure was achieved by estimating a scale parameter. The relationships between each of the explanatory variables and white-tailed deer success per camera day were assessed using a simple linear regression. Success per camera day data were square-root transformed prior to analysis to better meet assumptions of normality and homogeneity of variance. In the analysis of guardrail length, only bridges were included because culverts did not have guardrails.

3.2.3. Test for Equal Means

A two-sample test was used to test for equal means of bridges and culverts for each explanatory variable. Guardrail length was not included because culverts did not have guardrails. The assumptions were not well met for many of the explanatory variables, so a permutation test analogous to the standard *t*-test was used.

3.2.4 Correlation Between Abundance and Number of Fecal Pellets

A Pearson product-moment correlation coefficient was computed to assess the relationship between white-tailed deer abundance and number of fecal pellets.

3.3 Results

Table 5 summarizes results of statistical tests assessing the difference in white-tailed deer use rates between structure types, the regressions of white-tailed deer use rates on explanatory variables, and mean differences in explanatory variables between structure types.

The *p*-value for each test is reported in each square. Dark highlighted squares have a p-value $\leq$ 0.05, representing good evidence of a difference in use rates between structure types, a relationship with an explanatory variable, or unequal means for structure types. Light highlighted squares have *p*-value between 0.05 and 0.10, and show less certain evidence of a difference in use rates between types, a relationship with an explanatory variable, or unequal means for structure types. Highlighted squares include model-predicted values for bridges and culverts, estimated slope parameters, and means for bridges and culverts. Slopes are on the logit scale for success rate, rate of repellency, and parallel rate, and on the square-root scale for success per camera day.

3.3.1. White-Tailed Deer Use Rates for Bridges and Culverts

Results for comparisons of white-tailed deer use rates between bridges and culverts are presented in the first row of Table 5. White-tailed deer success rate was higher for bridges than for culverts (81 percent and 16 percent, respectively), counter-balanced by a lower parallel rate for bridges than for culverts (12 percent and 57 percent, respectively). White-tailed deer success per camera day was higher for bridges than for culverts (0.9 and 0.2, respectively).

Table 5. Results of Statistical Analyses Comparing White-Tailed Deer Use Rate, Structure Type, and Explanatory Variables.

	Success Rate	Rate of Repellency	Parallel Rate	Success per Camera Day	Structure Type
Structure Type	$p < 0.01$ B: 81% C: 16%	$p = 0.19$	$p = 0.01$ B: 12% C: 57%	$p = 0.08$ B: 0.9 C: 0.2	**B: bridge** **C: culvert**
Height	$p = 0.20$	$p = 0.01$ Slope = -0.56	$p = 0.28$	$p = 0.70$	$p = 0.26$
Width	$p = 0.01$ Slope = 0.08	$p = 0.10$ Slope = -0.02	$p < 0.01$ Slope = -0.09	$p < 0.01$ Slope = 0.03	$p < 0.01$ B: 26.8 C: 3.8
Length	$p = 0.04$ Slope = -0.06	$p = 0.25$	$p = 0.03$ Slope = 0.06	$p = 0.09$ Slope = -0.02	$p < 0.01$ B: 26.0 C: 52.0
Openness	$p < 0.01$ Slope = 0.74	$p < 0.01$ Slope= -0.28	$p < 0.01$ Slope = -0.86	$p < 0.01$ Slope = 0.24	$p < 0.01$ B: 2.5 C: 0.2
Fence	$p = 0.63$	$p = 0.98$	$p = 0.59$	$p = 0.45$	$p = 0.56$
Guard rail	$p = 0.04$ Slope = 0.004	$p = 0.02$ Slope = -0.004	$p = 0.04$ Slope = -0.004	$p = 0.21$	
Humans per day	$p = 0.80$	$p = 0.63$	$p = 0.84$	$p = 0.54$	$p = 0.10$ B: 0.15 C: 0.06
Grass	$p = 0.81$	$p = 0.39$	$p = 0.68$	$p = 0.37$	$p = 0.74$
Forbs	$p = 0.90$	$p = 0.95$	$p = 0.89$	$p = 0.15$	$p = 0.21$
Shrubs	$p = 0.10$ Slope= 0.13	$p = 0.04$ Slope = -0.07	$p = 0.12$	$p = 0.21$	$p = 0.53$
Trees	$p = 0.23$	$p = 0.38$	$p = 0.24$	$p = 0.99$	$p = 0.62$
Bare ground	$p = 0.84$	$p = 0.26$	$p = 0.96$	$p = 0.74$	$p = 0.89$
Water	$p = 0.27$	$p = 0.32$	$p = 0.28$	$p = 0.27$	$p = 0.83$
Pellets	$p = 0.33$	$p = 0.44$	$p = 0.33$	$p = 0.48$	$p = 0.60$

3.3.2. White-Tailed Deer Use Rates and Explanatory Variables

Results for simple regressions of white-tailed deer use rates on explanatory variables are presented in rows two through 14 and columns one through four in Table 5. Select graphs of these relationships are presented in Figures 21 through 25. The blue line depicts the regression of the response variable on the explanatory variable, back-transformed to the original scale; a 95% confidence interval for the regression is shown as a shaded band. Success rate increased with increasing openness (Figure 21), width (Figure 22), guardrail length, and shrub cover, and decreased with increasing length (Figure 23). Rate of repellency decreased with increasing height, width, openness (Figure 24), guardrail length, and shrub cover. Parallel rate decreased with increasing width, openness, and guardrail length, and increased with increasing length. Success per camera day increased with structure width and openness (Figure 25). There was little to no evidence that fence length, humans, grass, forbs, trees, bare ground, water, and pellets were related to white-tailed deer use rates of wildlife crossing structures.

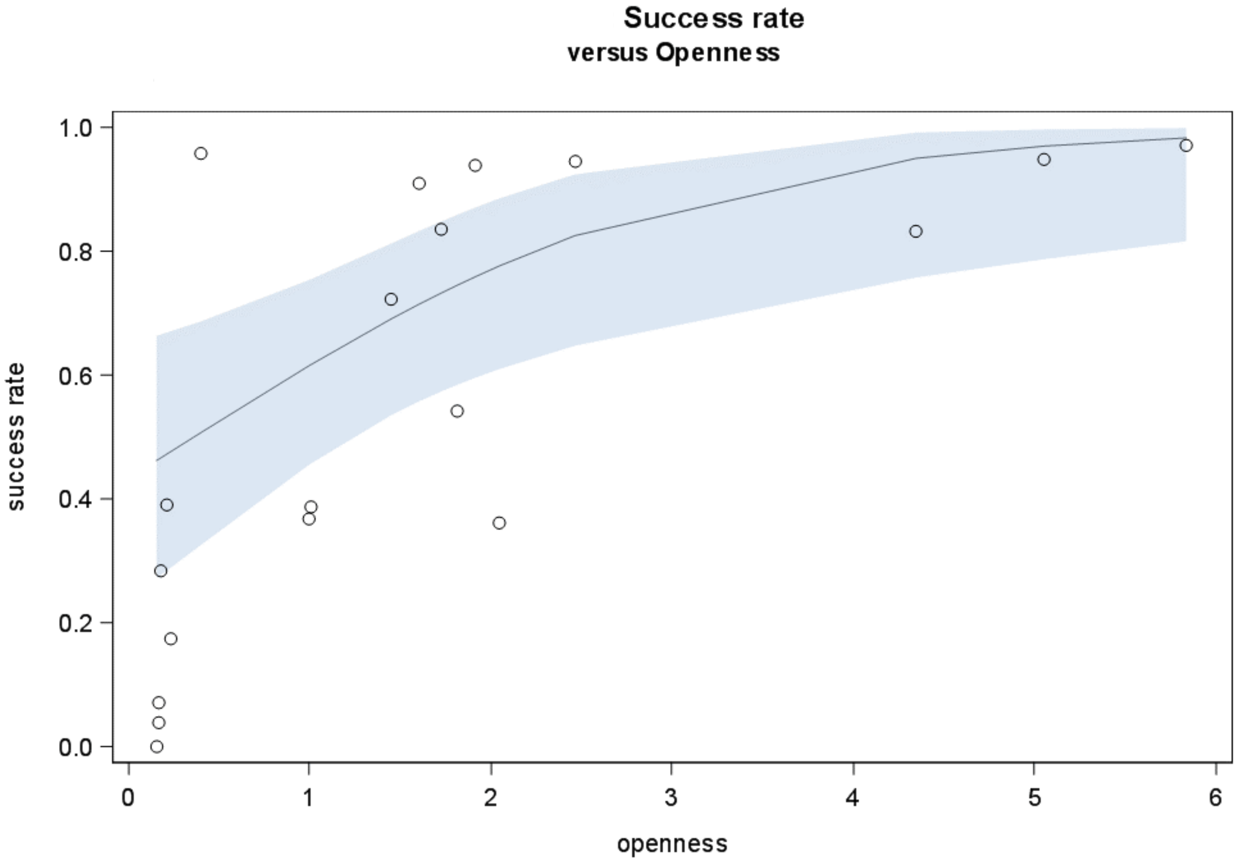

Figure 21. White-Tailed Deer Success Rate Plotted Against Openness.

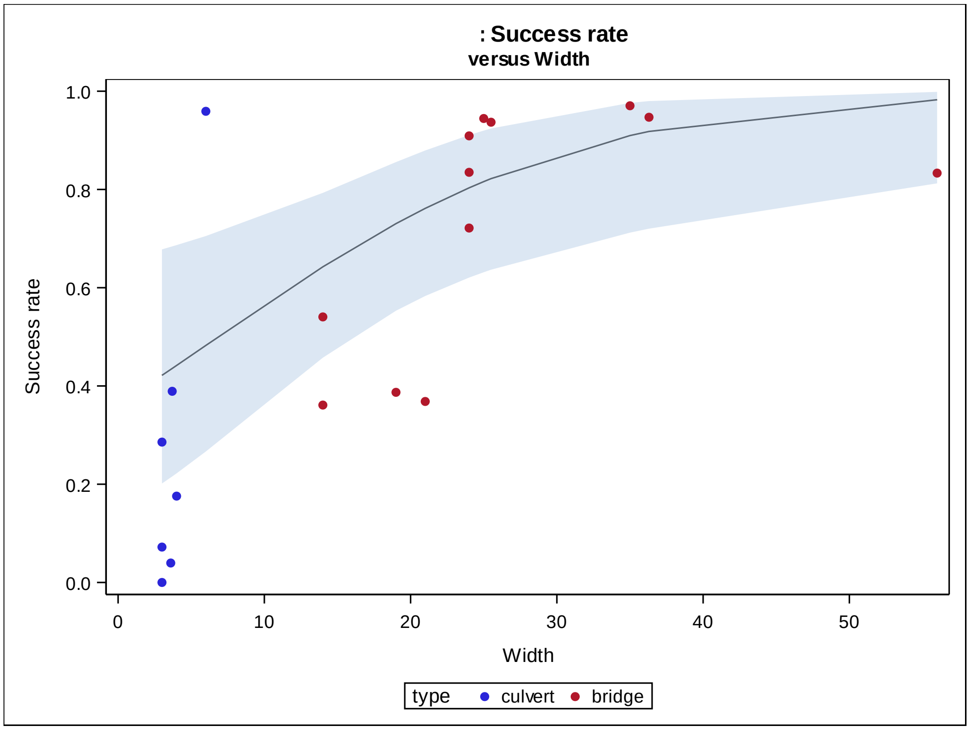

Figure 22. White-Tailed Deer Success Rate Plotted Against Width.

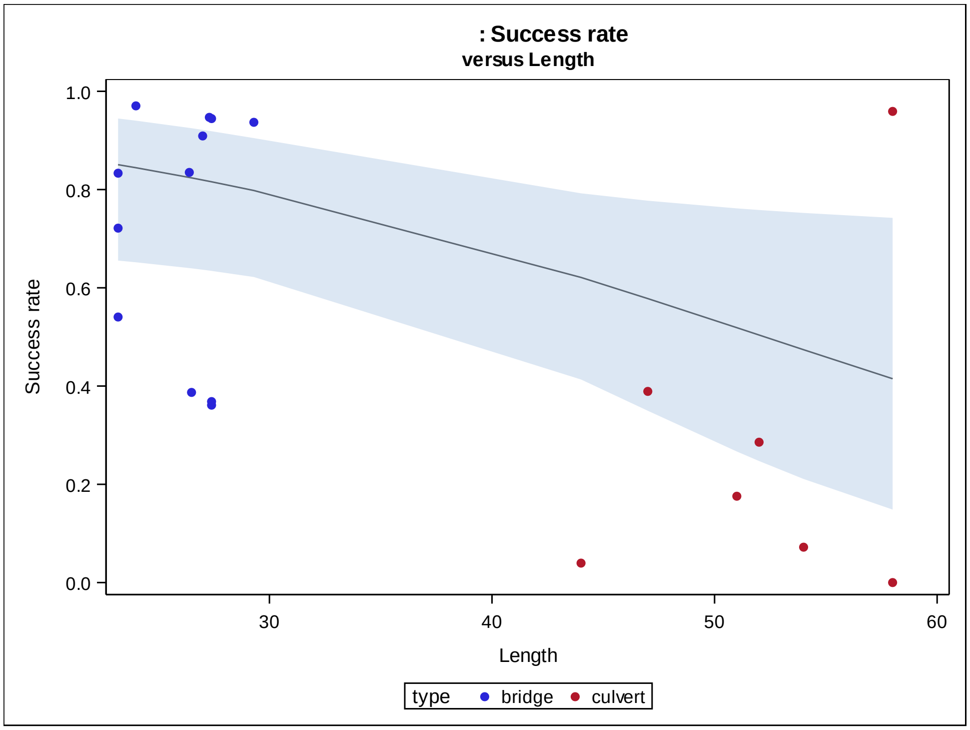

Figure 23. White-Tailed Deer Success Rate Plotted Against Length of Structure.

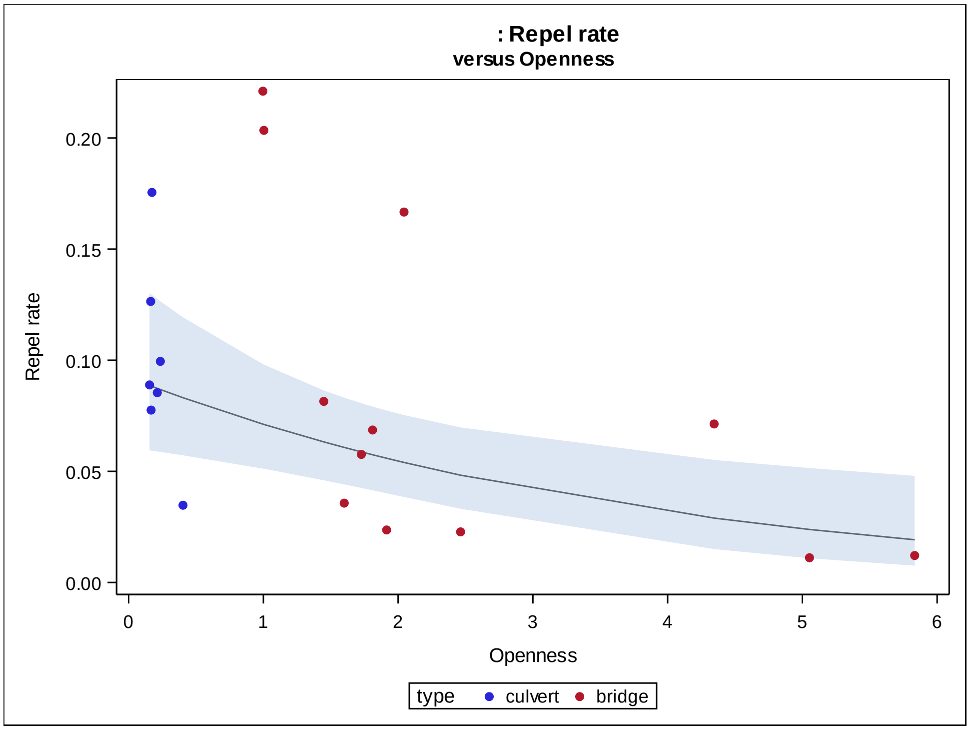

Figure 24. White-Tailed Deer Rate of Repellence Plotted Against Openness.

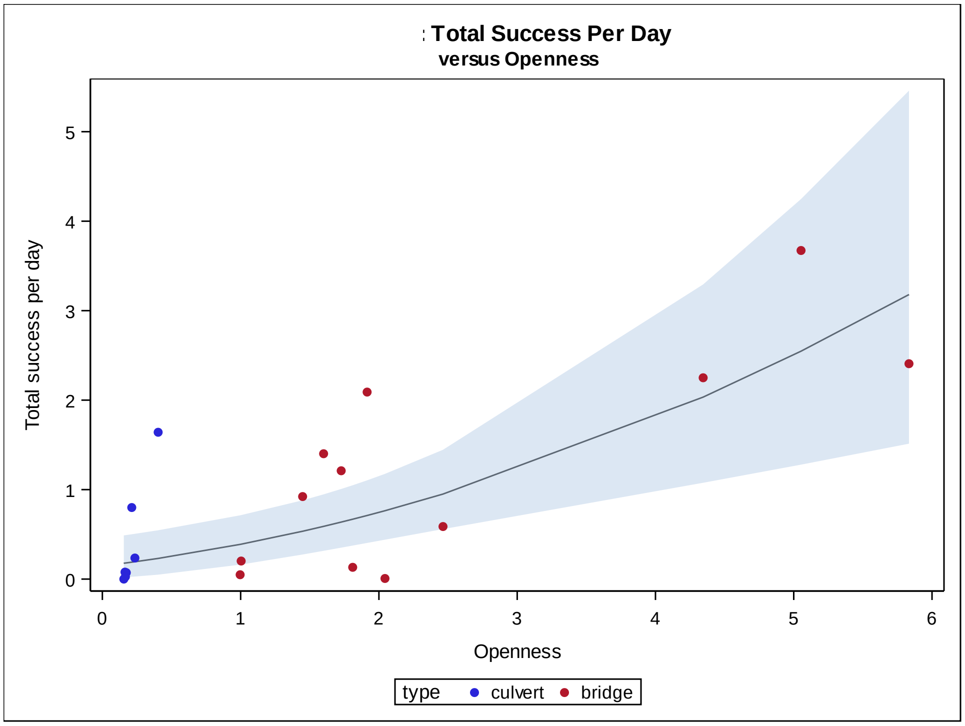

Figure 25. White-Tailed Deer Success Per Day Plotted Against Openness.

3.3.3. Test for Equal Means

Results for mean comparisons of explanatory variables between structure types are reported in the fifth column in Table 5. Means for each structure type are included when the difference was significant. Bridges and culverts differed in width, length (Figure 26), openness, and number of humans per day. Bridges were wider, shorter, more open, and had higher human use. There was no evidence of difference between bridges and culverts for any other explanatory variable.

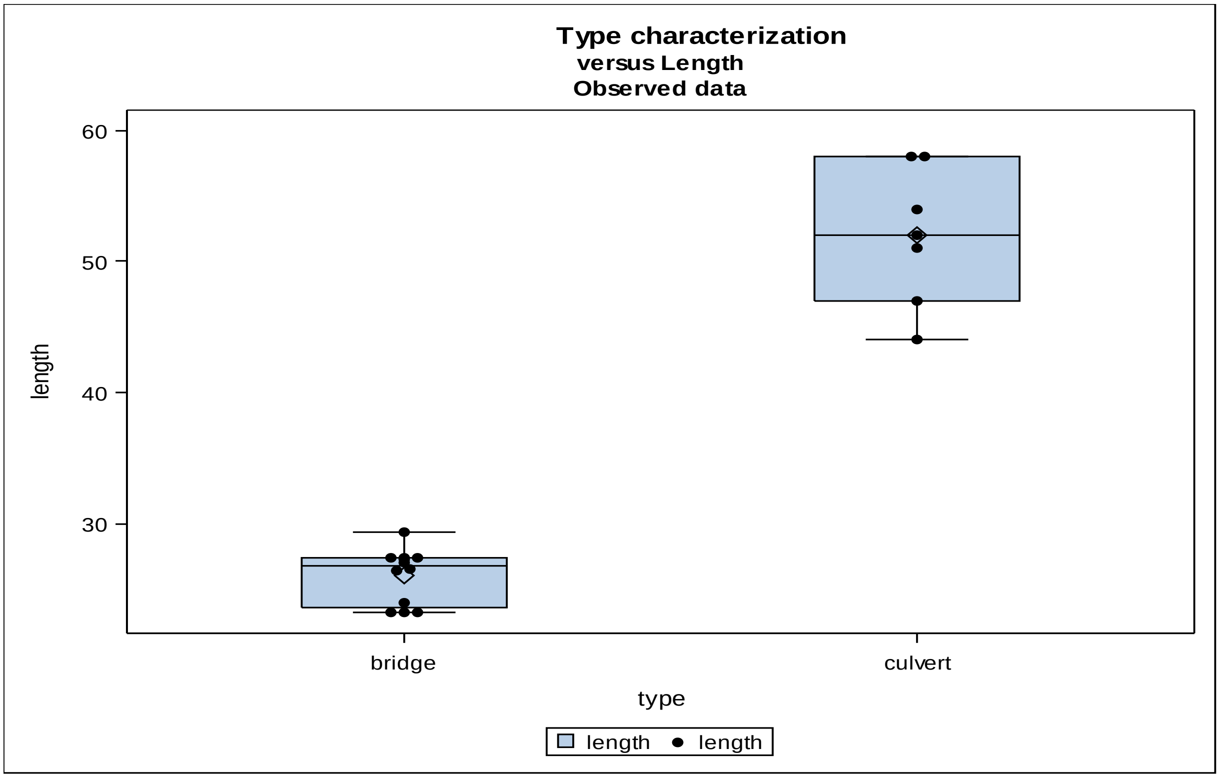

Figure 26. Wildlife Crossing Structure Type and Length of Structures.

3.3.4 Correlation Between Abundance and Number of Fecal Pellets

There was a very weak positive linear relationship between white-tailed deer abundance and number of fecal pellets: $r = 0.23$.

3.4 Discussion

3.4.1 White-Tailed Deer Use Rates for Bridges and Culverts

Success rate was higher for bridges than for culverts (Figure 27). Counterbalancing this difference in success rate, parallel rate was lower for bridges than for culverts, whereas no difference was observed in rate of repellency. A notable exception to this pattern was Bass Creek Fishing Access Culvert, which was as successful as the most successful bridges and appreciably more successful than any other culvert (Table 3, Section 2.3.3). Bass Creek Fishing Access Culvert had height, width, and openness nearly twice as large as other culverts. White-tailed deer success per camera day was higher for bridges than for culverts (Figure 28).

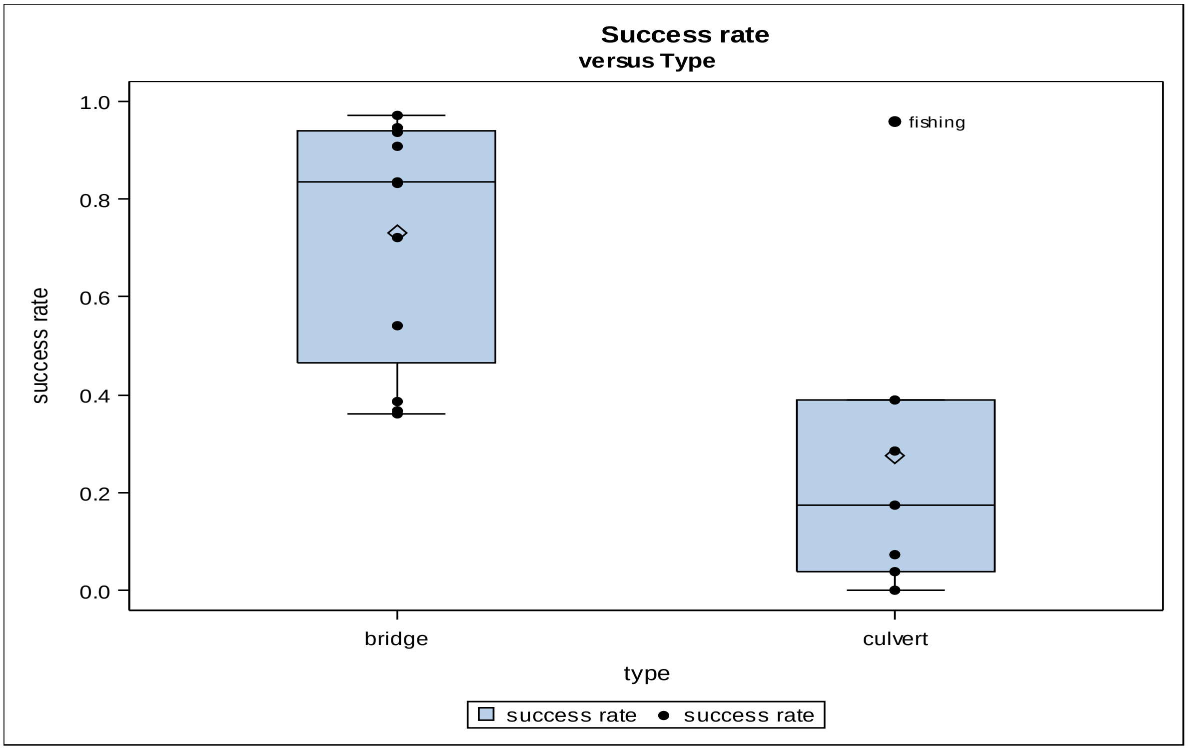

Figure 27. White-Tailed Deer Success Rate for Bridges and Culverts.

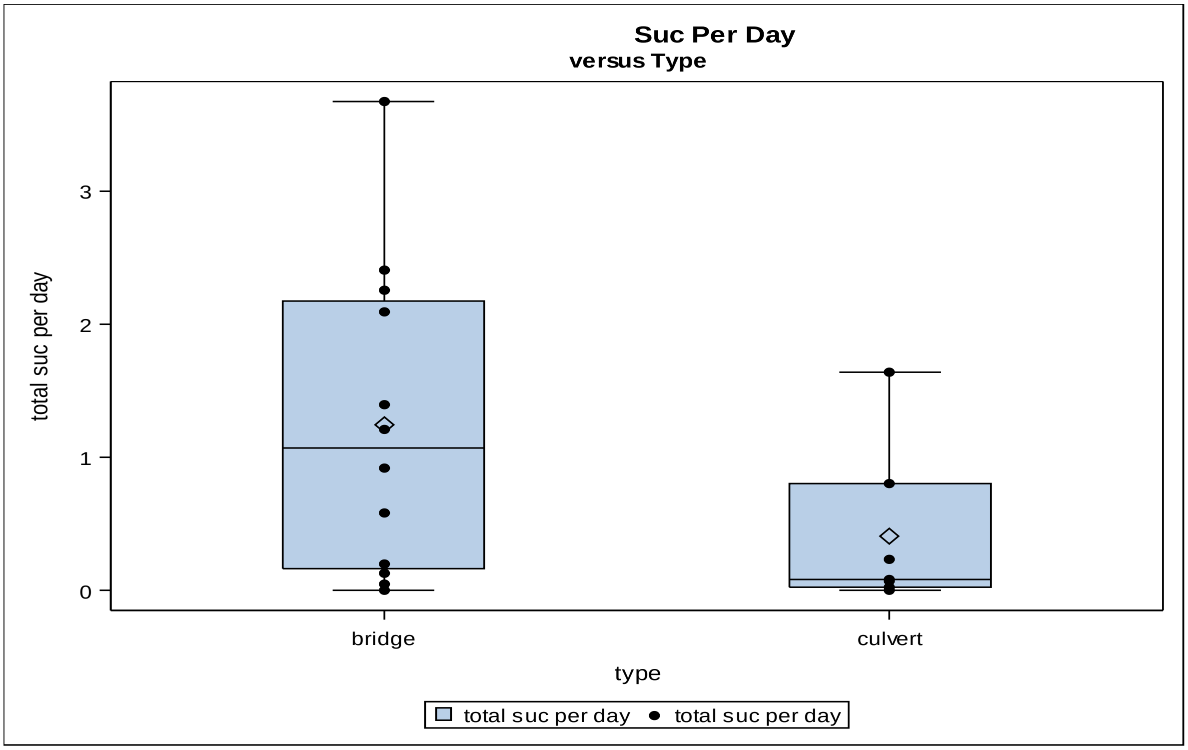

Figure 28. White-Tailed Deer Success per Day for Bridges and Culverts.

3.4.2 White-Tailed Deer Use Rates and Explanatory Variables

Design characteristics of wildlife crossing structures such as width, length, and openness strongly affected success rate, parallel rate, and, to a lesser extent, rate of repellency. Height strongly affected rate of repellency. Increased width, increased openness, and decreased length increased success rate while decreasing parallel rate and rate of repellency. Decreased height increased rate of repellency without affecting success rate or parallel rate. Increasing guardrail length on bridges improved success rate while decreasing both parallel rate and rate of repellency. There was no evidence that fence length, human use, or number of fecal pellets had an effect on use rates. We note that success rate, rate of repellency, and parallel rate are compositional data, in that their sum equals one, and hence, their tests are not independent. If there is evidence of a positive effect for a given explanatory variable for one rate, we expect to see counterbalancing negative effects in one or both of the other rates. We also note that openness is calculated from height, length, and width, and consequently results for analysis of these variables will be related.

It is well documented that white-tailed deer utilize shrubs for browse and cover. Consistent with this, we found that increased shrub percent cover increased success rate and decreased rate of repellency. There was no evidence that percent cover of grass, forbs, trees, bare ground, or water had an effect on use rates. The study area is quite homogeneous in terms of its vegetation and natural community type. Nearly all of the structures were constructed in riparian areas that convey water to the Bitterroot River by way of creeks, springs, or wetlands, and white-tailed deer abundance was high throughout the study area. Thus, the scale of vegetation sampling in these riparian areas may not have been pertinent to the scale that white-tailed deer perceive their riparian habitat.

3.4.3 Test for Equal Means

Bridges and culverts were distinctly different in their design characteristics of width, length, and openness. There was no overlap in width, length, and openness values between bridges and culverts. For example, the widest culvert was 6 meters (20 feet) and the narrowest bridge was 14 meters (46 feet). Consequently, the effects of width, length, and openness on use rates cannot be distinguished from the effect of structure type on use rates. Height values overlapped for bridges and culverts (Figure 29). There was no evidence of a difference between the bridge mean and the culvert mean for height. Bridges typically had more human use than culverts. The exception was Indian Prairie Culvert (Figure 30).

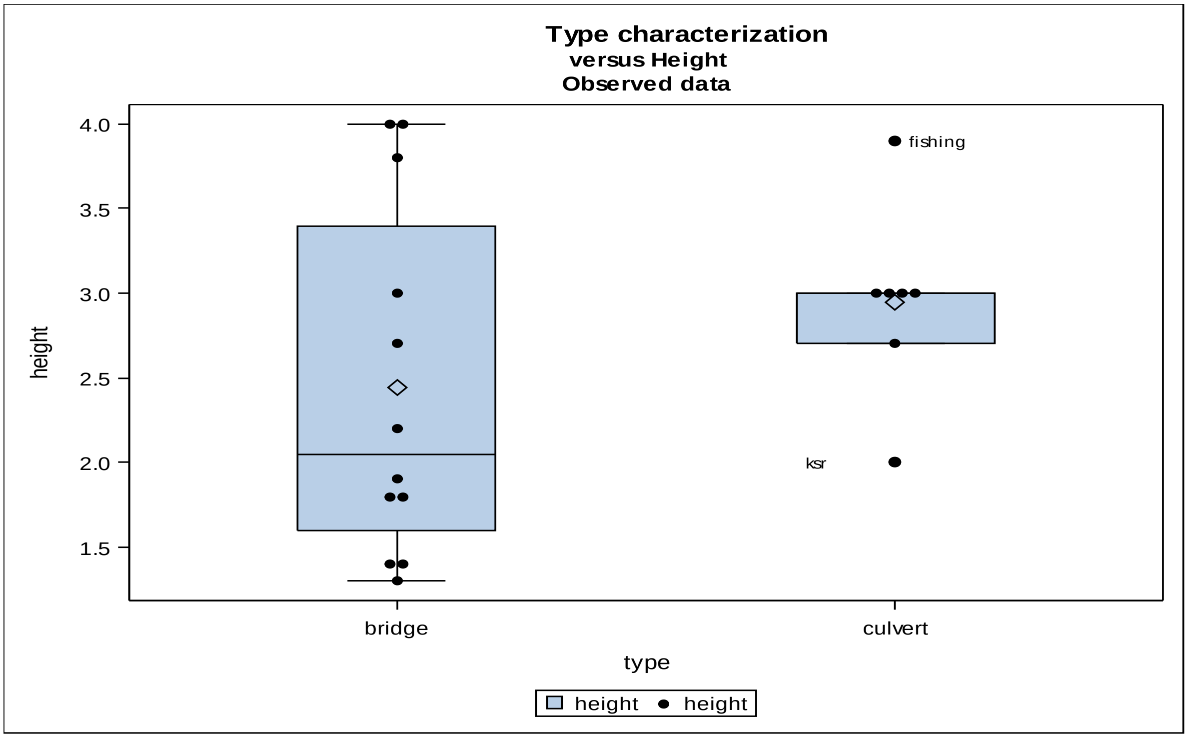

Figure 29. Heights of Bridges and Culverts.

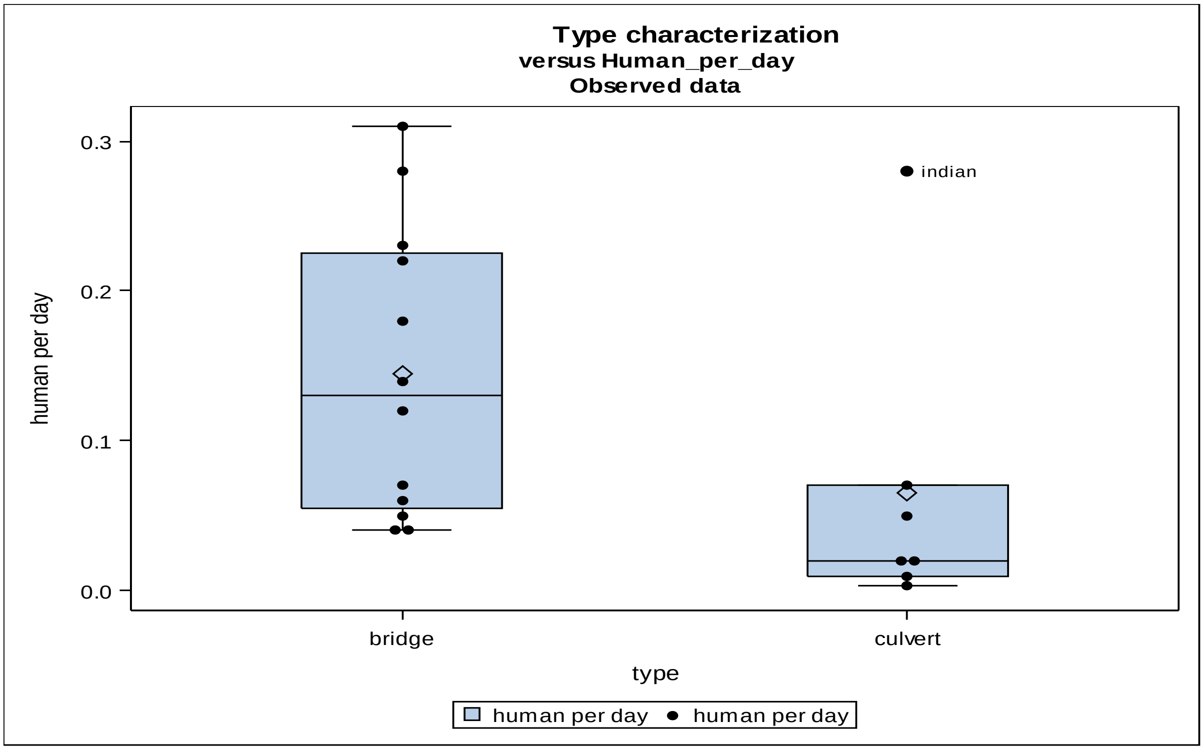

Figure 30. Human Use Per Day for Bridges and Culverts.

3.4.4 Correlation Between Abundance and Number of Fecal Pellets

Deer fecal pellet counts were conducted to help determine if there was a relationship between deer present on the landscape nearby, as indexed by fecal pellet counts, and the number of deer photographed at the structures, as indexed by deer abundance. There was evidence of a very weak relationship ($r = 0.23$). This result could help inform placement of wildlife crossings structures by conducting these pellet counts in the planning phase of mitigation. Areas with higher pellet counts could potentially be the best locations for future wildlife crossing structures. DeCalesta (2013) found that fecal pellet counts can be an accurate estimate of white-tailed deer abundance on large landscapes. Further investigations on identifying the relationship between the number of fecal pellets present and pre-construction crossing rates could yield alternative, fast, and inexpensive methods for determining the best location of wildlife crossing structures.

Chapter 4 Relationships Between Wildlife-Vehicle Collisions and Wildlife Crossing Structures

4.1 Introduction

The objectives of this chapter were to investigate changes in WVC rates between pre-construction and post-construction of wildlife fence and wildlife crossing structures, and to investigate relationships between WVC rates and wildlife crossing structures over space and time. Analyses in this chapter are divided into four sections. In the first section, WVC carcass and crash data are displayed and compared. The Kernel2d function in the Splancs package (Rowlingson and Diggle 2015) in R (R Core Team 2016) is used in the second section to display smooth representations of WVC intensity variations in two dimensions. The third section details the collection and analysis of white-tailed deer abundance estimates and traffic volume data. These variables were included in an attempt to create predictive statistical model. In the fourth section, Before-After-Control-Intervention (BACI) design statistical analysis is used to evaluate changes in WVC rates between pre-construction and post-construction of wildlife crossing structures. BACI analyses are robust and accurate methods to evaluate mitigation efficiency (Roedenbeck et al. 2007, van der Grift et al. 2013). BACI analyses isolate the influence of the intervention from the independent variables. In this study, wildlife crossing structures and wildlife exclusion fence were the intervention, while white-tailed deer abundance, traffic volume, highway configuration, and adjacent land use were the variables affecting changes in WVC.

4.2 Wildlife-Vehicle Collision Carcass and Crash Data

4.2.1 Methods

WVC carcass and crash data were obtained from MDT on several occasions during the study. A final carcass and crash data set was received from MDT Traffic and Safety Bureau in May of 2016. It included WVC carcass data from 1999 through October of 2015 and WVC crash data from 1999 through 2015. This final data set from the Traffic and Safety Bureau was used for analyses in this chapter. Carcass data were collected by MDT from the Hamilton maintenance section, mp 48 to mp 67, and the Lolo South maintenance section, mp 67 to mp 85. Carcasses were identified to species. Ninety-four percent of the carcasses were white-tailed deer. WVC crash data were collected by Montana Highway Patrol and Sheriffs' Departments for incidents that caused at least $1,000 damage to vehicles. The WVC crash data did not indicate the species of wildlife involved. White-tailed deer WVC carcasses and all WVC crashes were tallied for each year, and these annual counts from each WVC data source were plotted.

4.2.2 Results

The plot of annual white-tailed deer WVC carcasses and annual WVC crashes are presented in Figure 31. The annual number of WVC carcasses fluctuated greatly compared to the annual number of WVC crashes. The number of WVC carcasses decreased 59 percent from 2012 to

2013, and decreased 84 percent from 2012 to 2014. The lowest number of WVC carcasses (36) occurred in 2014 when WVC carcasses were less than WVC crashes (58). From 2000 through 2012, WVC crashes averaged 32 percent of WVC carcasses.

Figure 31. WVC Carcass and Crash Data Comparison, in the Study Area, mp 48 to mp 85, from 1999 through 2015.

4.2.3 Discussion

The WVC carcass data better demonstrated the magnitude of WVC compared to WVC crash data, however, WVC carcasses varied greatly from year to year and appear to be underreported in 2013. Carcasses were clearly underreported in 2014 and 2015 when the number of carcasses was less than the number of crashes. Additional carcass data in an alternate format were obtained from MDT in the Fall of 2015, but still appeared to underreport carcasses in 2014 and 2015. The additional data recorded 118 carcasses in 2014, which resulted in WVC crashes totaling 49 percent of WVC carcasses. In 2015, the additional data reported 68 carcasses, equal to the number of reported crashes. Again, the mean crash to carcass ratio from 2000 through 2012 was 32 percent. Overall, WVC carcass data in all forms appeared to be unreliable from 2013 through October 2015. WVC carcasses in the study area were collected in two separate maintenance sections by separate personnel, potentially with unequal effort. A supervisory personnel change occurred at the Hamilton maintenance section during the study. In addition to recording and reporting carcasses according to standard procedure, MDT began using aerial photographs in 2012 to assist in the determination of WVC carcass locations. Alternatively, crash data appeared to be collected with equal effort during the study period. WVC crash data were used exclusively in the final section of this chapter, section 4.5. Going forward, the collection of complete and accurate post-construction WVC carcass data will be important for measuring the future effectiveness of wildlife mitigation. The WVC carcass data from MDT Traffic and Safety Bureau and the additional WVC carcass data should be rectified. Complete and accurate carcass data could be used, in part, to create predictive statistical models that evaluate the efficacy of wildlife crossing structures and wildlife exclusion fence as highway configuration, wildlife abundance, traffic volume, and adjacent land use change over time. Incomplete WVC carcass data from 2013 through 2015 precluded predictive statistical models in this study (section 4.4.3).

4.3 Kernel2d

4.3.1 Methods

The Kernel2d function in the Splancs package in R was used to compute and map smooth representations of the spatial-temporal variations in intensities of WVC carcasses and WVC crashes relative to wildlife crossing structure locations within the study area. The kernel width parameter h_0 was set to 1.6 km (1 mile) which generated a visually appealing degree of smoothness and produced estimates of WVC intensity with units of number of carcasses or crashes per mile per year. Wildlife crossing structures were superimposed as blue squares (not to scale).

4.3.2 Results

Kernel2d representations of white-tailed deer WVC carcass and WVC crash intensities are presented in Figure 32 and Figure 33. The figures visually demonstrate the discrepancy between WVC carcass and crash intensities from 2013 through 2015. Figure 32 reveals a general increase in WVC carcass intensity from 2011 to early 2013 following the construction of wildlife crossing structures between mp 55 and mp 65. WVC carcass intensity decreased from mp 55 to mp 65 in the second half of 2013 and remained low through 2015. A temporary increase in WVC carcass intensity also occurred in 2005 and 2006 between mp 69 and mp 72 following the construction of wildlife crossing structures. A similar pattern of temporary increases in WVC crash intensities near mp 54 through 57, mp 61, mp 63, mp 65, and mp 70 through mp 72 following construction of wildlife crossing structures was also observed in Figure 33.

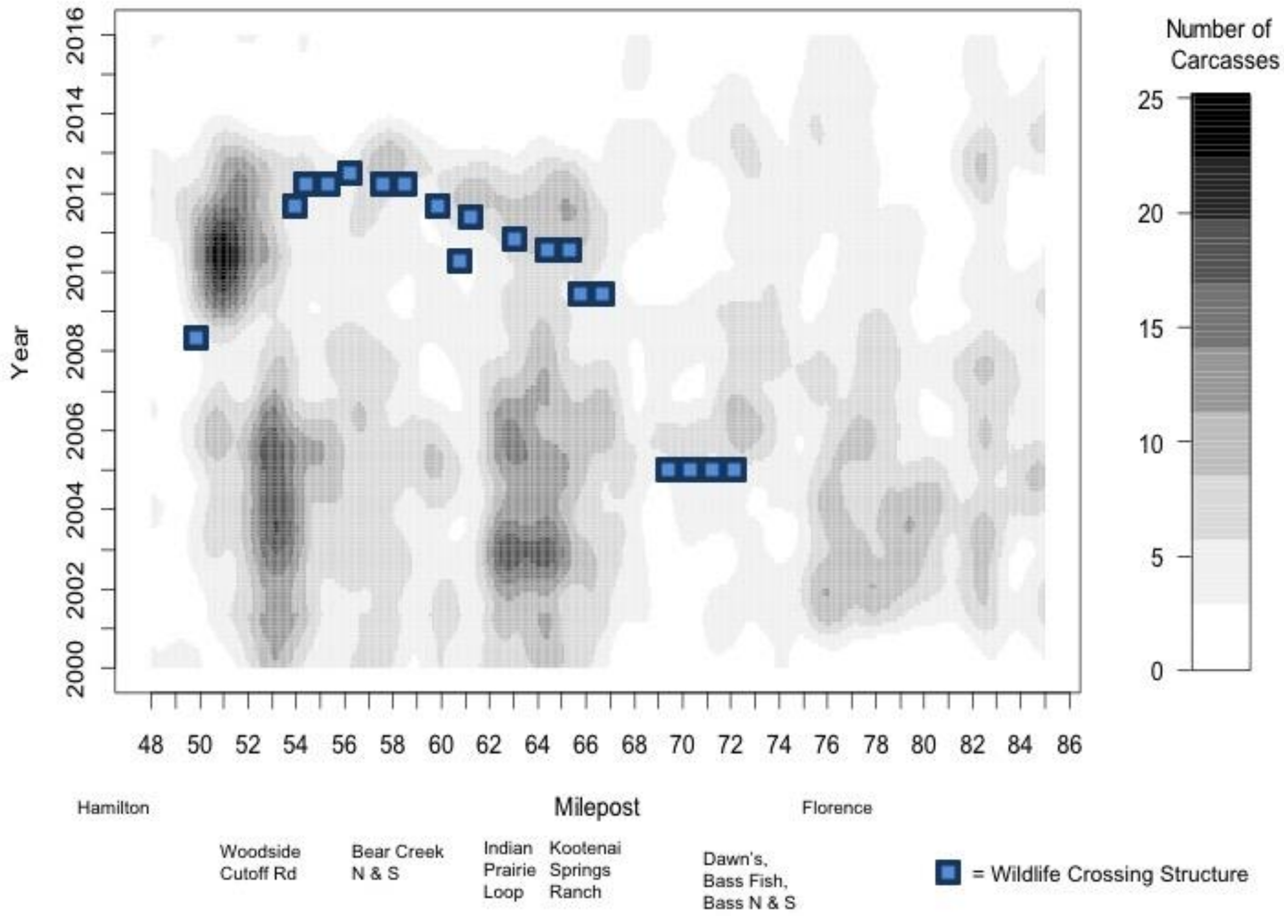

Figure 32. Kernel2d Representation of WVC Carcass Intensity, US 93, mp 48 to 85, 2000 Through October 2015.

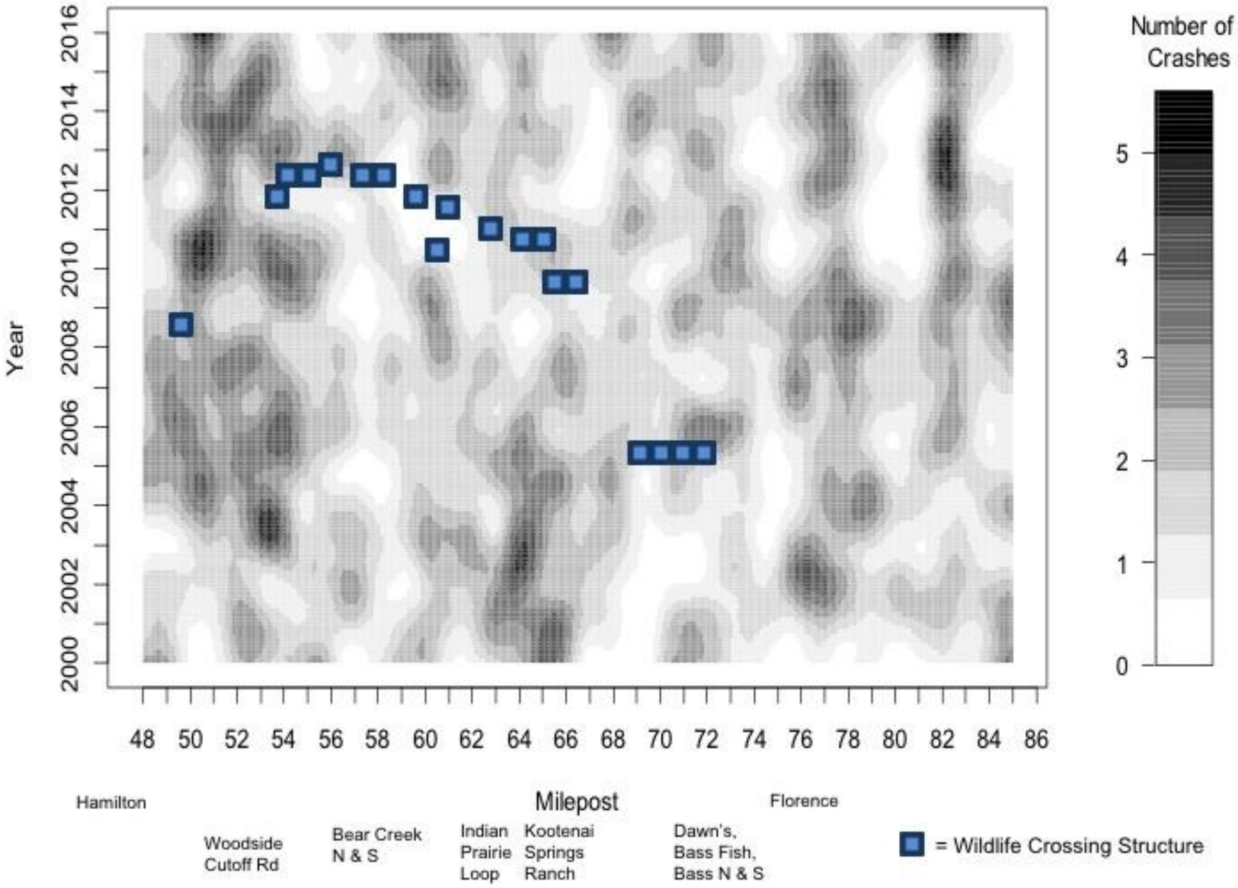

Figure 33. Kernel2d Representation of WVC Crash Intensity, US 93, mp 48 to 85, 2000 Through 2015.

4.3.3 Discussion

Kernel2d representations provided powerful displays of the variation in WVC intensities within the entire study area during the past 16 years. The observed discrepancy between WVC carcass and crash intensities from 2013 through 2015 was discussed in section, 4.2.3. The temporary increases in WVC carcass and crash intensities following the construction of most of the wildlife crossing structures have several potential explanations. The temporary increases may represent white-tailed deer adaptations to the structures, four lanes rather than two, and increases in traffic speed following an entire season of construction. It is also possible that the temporary increases were not related to the construction of wildlife crossing structures. Figure 32 and Figure 33 clearly display fluctuations in WVC intensities over time at any given location. These fluctuations over time may be normal. For example, WVC carcass and crash intensities near mp 64 were high from 2000 through 2007, lower in 2008 and 2009, then higher in 2012 and 2013. WVC intensities at hot spots appear to increase and decrease over time, before and after the construction of wildlife crossing structures. Kernel2d representations do not provide statistical evidence for or against a relationship between WVC rates and wildlife crossing structures. They simply display variations in WVC intensities over space and time relative to wildlife crossing structure locations. However, Kernel2d representations become more powerful for observing WVC patterns over the long term, and should be continued in the future to assist in the monitoring and evaluation of wildlife crossing structures.

4.4 White-tailed Deer Abundance, Traffic Volume, and a Predictive Statistical Model

4.4.1 Methods

White-tailed deer annual hunter harvest rates (all harvested deer/hunter effort days/year) in Hunting District 260 (HD 260) were used as an estimate of white-tailed deer abundance in this study (Seiler 2004). Data from 1981 through 2013 were obtained from Montana Fish Wildlife and Parks (Montana Fish Wildlife and Parks 2014). Rates for 2012 and 2014 were not available. Harvest rates from Hunting District 240 (HD 240) were also obtained from Montana Fish Wildlife and Parks (MFWP). A Pearson product-moment correlation coefficient was computed to assess the relationship between harvest rates from HD 260 and harvest rates from HD 240.

Annual aerial survey counts of white-tailed deer from 1988 through 2005 were obtained from MTFWP. Counts were not available in 1990, 1994 to 2000, 2002, and after 2005, thus were not used as an estimate of abundance in this study. A Pearson product-moment correlation coefficient was computed to assess the relationship between harvest rates from HD 260 and aerial survey counts.

Monthly traffic volume data from 2000 through 2014 were obtained from MDT. Data were collected from two MDT traffic counters: A-047 at mp 72.5 and A-056 at mp 50.8. Data were missing from counter A-047 for all of 2000, 2004, 2005, and 2008 because of construction. Data were missing from counter A-056 for all of 2009, and parts of 2000, 2008, and 2010 because of construction.

WVC carcass and crash data were described previously in section 4.2.1. Attempts were made to program a fine-scale predictive statistical model to measure changes in WVC rates and determine the effectiveness of wildlife crossing structures. The model was to measure and control for the influence of white-tailed deer abundance, traffic volume, and potentially other independent variables on WVC rates during pre-construction and post-construction of wildlife crossing structures.

4.4.2 Results

There was a moderate positive linear relationship ($r = 0.56$) between white-tailed deer harvest rates from HD 260 and harvest rates from HD 240.

There was a strong positive linear relationship ($r = 0.86$) between harvest rates from HD 260 and aerial survey counts.

Attempts to program a fine-scale predictive statistical model were unsuccessful.

4.4.3 Discussion

Pearson product-moment correlation coefficients and inspection of the meta-data presented in Appendix C indicated that total white-tailed deer harvest rates from HD 260 were the best estimate of white-tailed deer abundance.

Attempts to program a fine-scale predictive statistical model were unsuccessful for multiple reasons:

- The model required white-tailed deer abundance values at a fine scale, ideally monthly values within the vicinity of each of the 19 wildlife crossing structures. We know that abundance varies greatly between wildlife crossing structure locations (Table 3). Harvest rates from HD 260 provided annual values for the entire study area, with no spatial or monthly variation. Harvest rates from 2012 and 2014 were unavailable which limited analysis during post-construction years.
- The model required traffic volumes at a fine-scale, ideally monthly values near each wildlife crossing structure. Monthly traffic volumes were only available from two traffic counters. Values from counter A-047 at mp 72.5 were used for the nine wildlife crossing structures from mp 63 to mp 71. Values from counter A-056 at mp 50.8 were used for the 10 wildlife crossing structures at mp 50 to mp 61. Traffic volume from both counters was unavailable for multiple years during the study.
- The model did not account for other independent variables such as highway configuration, speed limits, and adjacent land use.
- The construction of wildlife crossing structures occurred over a long span of time, beginning in 2005 and ending in 2011. Comparisons of pre-construction and post-construction WVC rates would have been more powerful and simpler if all of the wildlife crossing structures had been completed at the same time (Appendix D).
- Post-construction WVC data for structures completed in 2011 were only available for four years.
- WVC carcasses and crash data comparisons and their limitations were discussed in section 4.2.3. The model required accurate and complete WVC carcass rates, ideally with a scale of carcasses per month per 0.1 mile. WVC crash rates used at this scale resulted in multiple data points with a value of zero. WVC crash rates at the scale of crashes per year per mile were in the single digits.

4.5 Before-After-Control-Intervention to Evaluate Wildlife-Vehicle Collision Crash Rate Changes Between Pre-construction and Post-construction of Wildlife Crossing Structures

4.5.1 Methods

Before-After-Control-Intervention design analysis was used to evaluate changes in WVC crash rates between pre-construction and post-construction of wildlife crossing structures. The effect of wildlife crossing structures on crash density (number of crashes per year per mile) was assessed using a generalized linear mixed model for a BACI design. The model was a two-way factorial in a split-plot design. Phase (pre-construction and post-construction), site (control and wildlife crossing), and the interaction of phase and site were incorporated as fixed effects factors. Total variance was partitioned into variance among years within a phase (such that year was a replicate, nested within phase) and residual variance (the variance among the two observations within each year associated with the control and the wildlife crossing). A Poisson distribution was assumed with a log link for the response variable (number of crashes each year), and the log transformation of section length was incorporated as an offset to implement an analysis of density (number of crashes per year per mile). Computations were made using the GLIMMIX procedure in SAS/STAT Version 14.3 in the SAS System for Windows 9.4 (TS1M3).

In simple terms, WVC crash rates at pre-construction wildlife crossing sites were compared to WVC crash rates at post-construction wildlife crossing structures. The difference between these rates was calculated. WVC crash rates at pre-construction control sections were compared to WVC crash rates at post-construction control sections, and the difference between these rates was calculated. The two differences were then statistically compared. The null hypothesis stated that the two differences were equal. Small *p*-values would indicate that the differences were not equal, and that there would be good evidence that individual wildlife crossing structures had an effect on the WVC crash rate at those locations. Large *p*-values would indicate that individual structures did not have an effect on the WVC crash rate at those locations. The non-statistical changes in WVC crash rates at crossing structures relative their control sections were calculated.

WVC crash data used in the analyses were described in section 4.2.1. Wildlife crossing structures were buffered 0.1 to 0.3 mile beyond the ends of structures and their associated wildlife fence. Wildlife crossing structures with continuous wildlife fence between them were analyzed together. These included Bass Fishing Access Culvert and Dawns Crossing Bridge (mp 70.4 to mp 69.0), Kootenai Creek Bridge and McCalla Creek North Bridge (mp 66.4 to mp 65.9), and McCalla Creek South Bridge and Kootenai Springs Ranch Culvert (mp 65.3 to mp 63.8). One control was located at mp 69.0 to mp 66.5 and was under construction in 2008 and 2009. A second control section was located at mp 54.2 to mp 50.5 and was under construction in 2007 and 2008. Each wildlife crossing structure and its control section were appropriately paired in space and time.

4.5.2 Results

The BACI design analysis is presented in Table 6. Wildlife crossing structures had no statistically significant effect of WVC crash rates. The smallest *p*-value (0.11) was computed for Kootenai Creek Bridge and McCalla Creek North Bridge (mp 66.4 to mp 65.9). This location had the largest WVC crash rate reduction relative to a control section (-2.6 crashes per year per mile), and is clearly observed in Figure 34. The BACI analysis computed a *p*-value of 0.22, not statistically significant, for McCalla Creek South Bridge and Kootenai Springs Ranch Culvert (mp 65.3 to mp 63.8). The relative WVC crash rate reduction at this location was -1.2 crashes per year per mile; and this reduction is shown in Figure 35. Other statistically insignificant but notable relative reductions in WVC crash rates (-1.8 crashes per year per mile) occurred at Big Creek Bridge (mp 61.8 to mp 61.4), Bear Creek South Bridge (mp 57.3 to 56.9), and Fun Park Culvert (mp 55.7 to mp 55.3). These relative reductions are apparent in Figure 36 through Figure 38. The largest relative increases in WVC crash rates occurred at Blodgett Creek Bridge (1.4 crashes per year per mile, mp 50.5 to 50.1) and at Bass Creek Fishing Access Culvert and Dawns

Crossing Bridge (1.2 crashes per year per mile, mp 70.4 to mp 69.0). These changes can be observed in Figure 39 and Figure 40.

Table 6. BACI Design Analysis to Assess the Effect of Wildlife Crossing Structures on WVC Crash Rates.

Structure	**Construction**	**Crossing Space Time**	**Control Space Time**	**Crossing Difference**	**Control Difference**	***p*-value**	**Relative Difference**
	(Year)	(mp, pre yrs, post yrs)	(mp, pre yrs, post yrs)	(Crashes/yr/mi)	(Crashes/yr/mi)		(Crashes/yr/mi)
Bass North, mp 71.1	2004-2005	71.3-70.9, 99-03, 10-15	69.0-66.5, 99-03, 10-15	1.0	0.3	0.77	0.7
Bass South, mp 70.5	2004-2005	70.7-70.3, 99-03, 10-15	69.0-66.5, 99-03, 10-15	-0.4	0.3	0.55	-0.7
Fishing, mp 70.1 and Dawns, mp 69.7	2004-2005	70.4-69.0, 99-03, 10-15	69.0-66.5, 99-03, 10-15	1.5	0.3	0.35	1.2
Kootenai, mp 66.2 and McCalla North, mp 66.1	2008-2009	66.4-65.9, 99-07, 10-15	69.0-66.5, 99-07, 10-15	-2.5	0.1	0.11	-2.6
McCalla South, mp 65.1 and Kootenai Springs, mp 64.6	2009-2010	65.3-63.8, 99-06, 11-15	54.2-50.5, 99-06, 11-15	-1.3	-0.1	0.22	-1.2
Indian, mp 63.4	2010	63.7-63.1, 99-06, 11-15	54.2-50.5, 99-06, 11-15	-1.0	-0.1	0.42	-0.9
Big, mp 61.6	2010-2011	61.8-61.4, 99-06, 12-15	54.2-50.5, 99-06, 12-15	-1.6	0.2	0.3	-1.8
Axmen, mp 60.7	2010	60.9-60.5, 99-06, 11-15	54.2-50.5, 99-06, 11-15	0.2	-0.1	0.88	0.3
Sweathouse, mp 59.7	2011	59.9-59.5, 99-06, 12-15	54.2-50.5, 99-06, 12-15	-0.6	0.2	0.58	-0.8
Bear North, mp 58.3	2011	58.5-58.1, 99-06, 12-15	54.2-50.5, 99-06, 12-15	0.3	0.2	0.95	0.1
Bear South, mp 57.1	2011	57.3-56.9, 99-06, 12-15	54.2-50.5, 99-06, 12-15	-1.6	0.2	0.3	-1.8
Lupine, mp 56.7	2011	56.9-56.5, 99-06, 12-15	54.2-50.5, 99-06, 12-15	0.0	0.2	0.91	-0.2
Gallery, mp 56.2	2011	56.4-56.0, 99-06, 12-15	54.2-50.5, 99-06, 12-15	0.6	0.2	0.8	0.4
Fun Park, mp 55.5	2011	55.7-55.3, 99-06, 12-15	54.2-50.5, 99-06, 12-15	-1.6	0.2	0.34	-1.8
Mill Creek, mp 54.6	2011	54.8-54.4, 99-06, 12-15	54.2-50.5, 99-06, 12-15	0.3	0.2	0.93	0.1
Blodgett, mp 50.3	2008	50.5-50.1, 99-06, 09-15	54.2-50.5, 99-06, 09-15	1.6	0.2	0.49	1.4

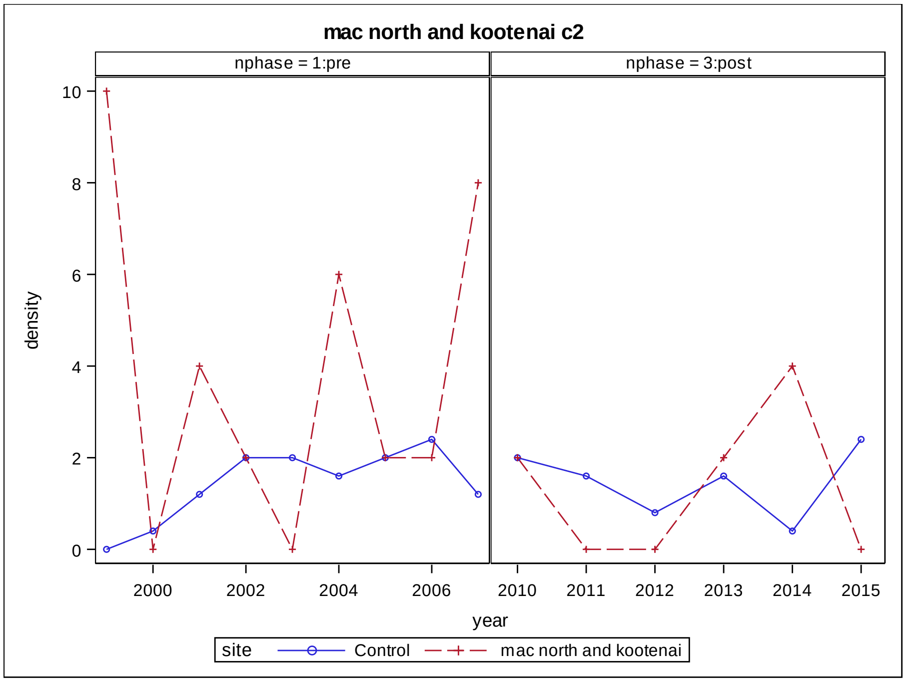

Figure 34. Changes in WVC Crash Rate at Kootenai Creek Bridge and McCalla Creek North Bridge Wildlife Crossing Structures between Pre-construction and Post-Construction Relative to a Control Section.

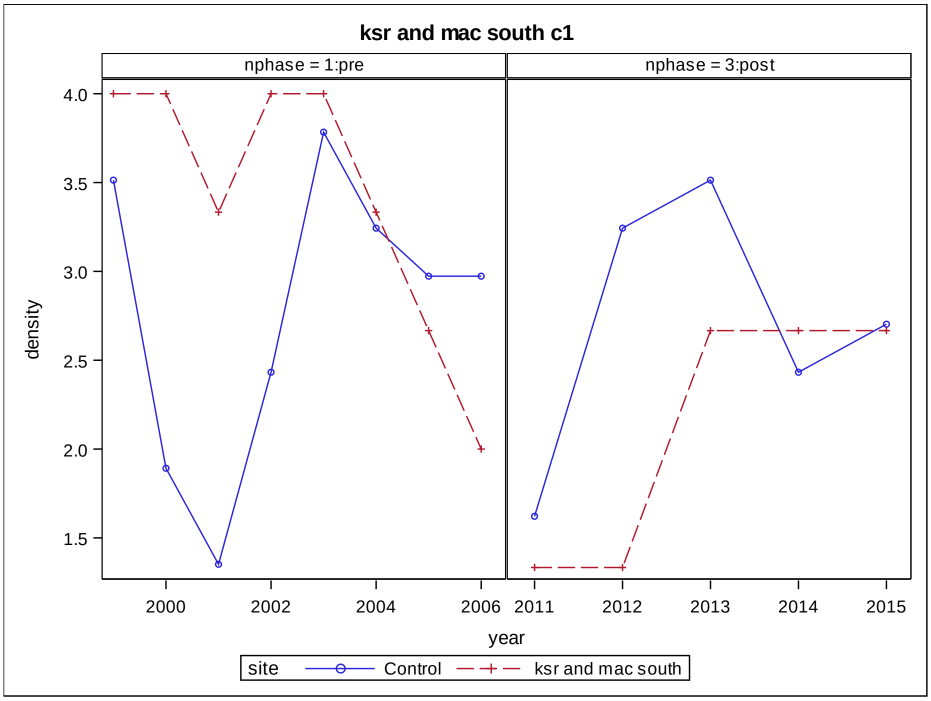

Figure 35. Changes in WVC Crash Rate at McCalla Creek South Bridge and Kootenai Springs Ranch Culvert Wildlife Crossing Structures between Pre-construction and Post-Construction Relative to a Control Section.

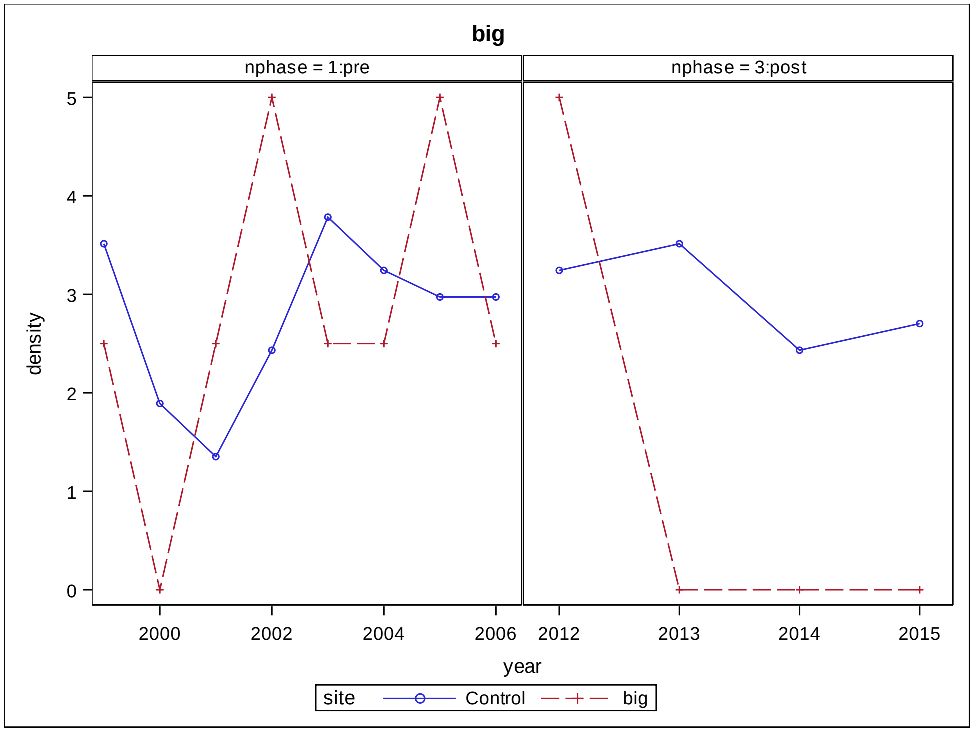

Figure 36. Changes in WVC Crash Rate at Big Creek Bridge Wildlife Crossing Structure between Pre-construction and Post-Construction Relative to a Control Section.

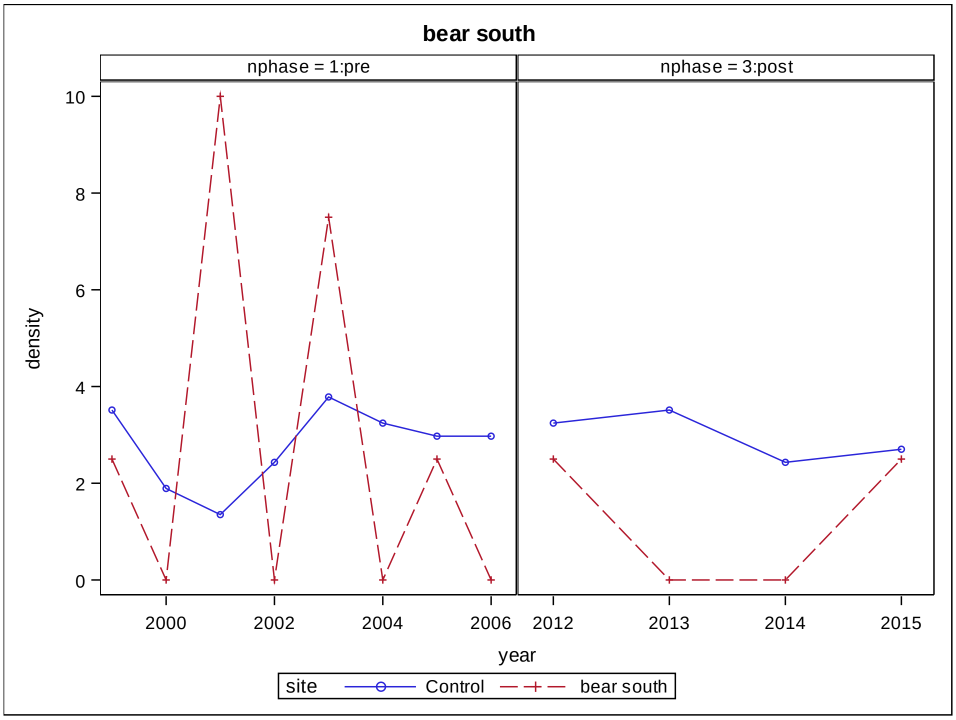

Figure 37. Changes in WVC Crash Rate at Bear Creek South Bridge Wildlife Crossing Structure between Pre-construction and Post-Construction Relative to a Control Section.

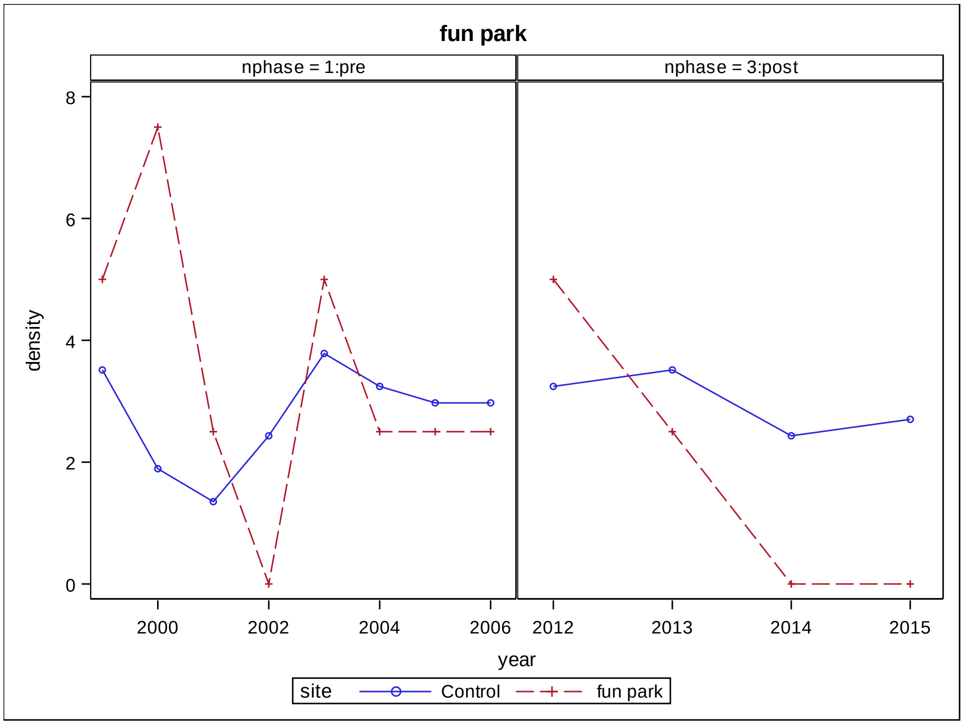

Figure 38. Changes in WVC Crash Rate at Fun Park Culvert Wildlife Crossing Structure between Pre-construction and Post-Construction Relative to a Control Section.

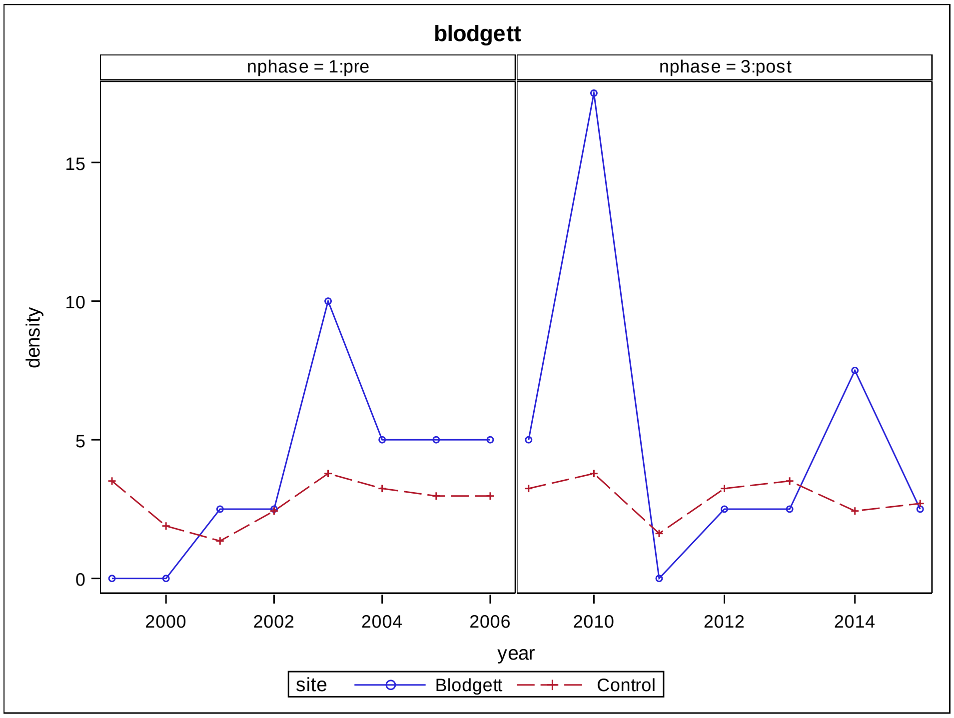

Figure 39. Changes in WVC Crash Rate at Blodgett Creek Bridge Wildlife Crossing Structure between Pre-Construction and Post-Construction Relative to a Control Section.

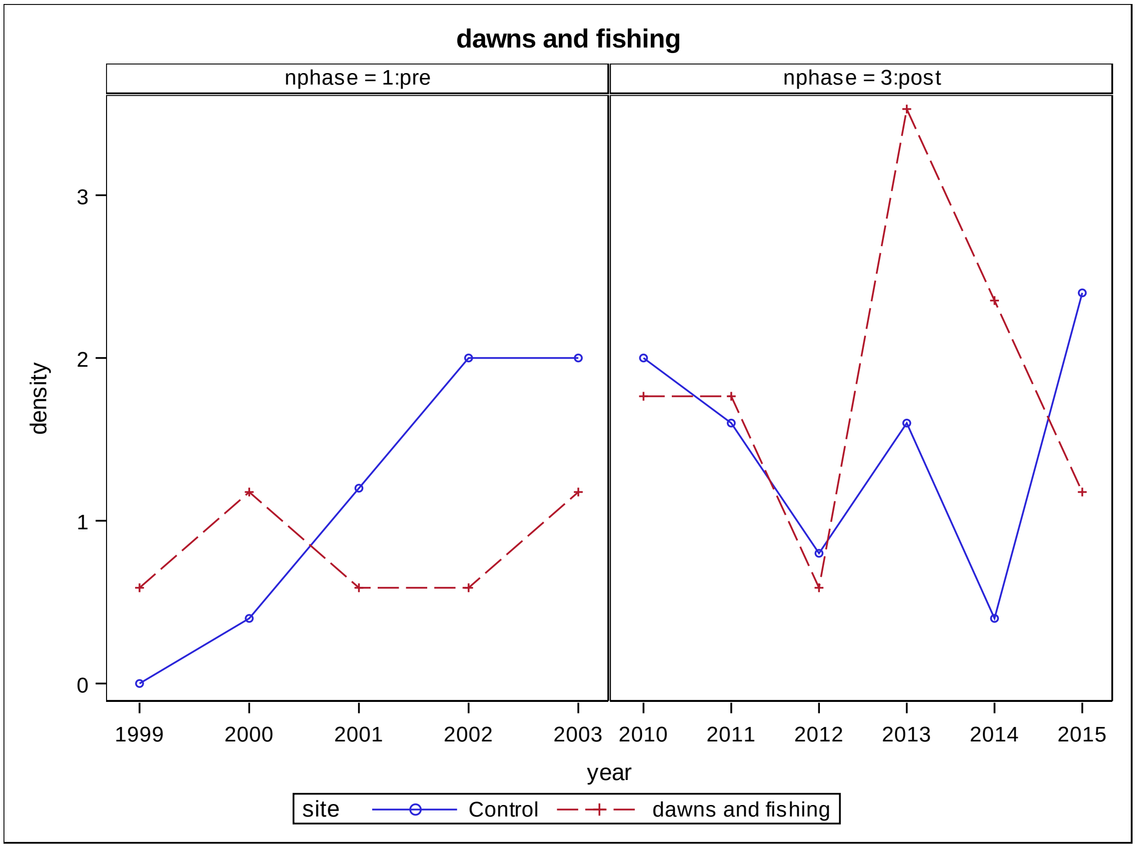

Figure 40. Changes in WVC Crash Rate at Bass Creek Fishing Access Culvert and Dawns Crossing Bridge Wildlife Crossing Structures between Pre-construction and Post-Construction Relative to a Control Section.

4.5.3 Discussion

The high *p*-values computed in the BACI analysis showed that wildlife crossing structures did not have a statistically significant effect on WVC crash rates. However, substantial relative reductions and increases in WVC crash rates did occur at wildlife crossing structures. These relative rate changes were measured, and not statistically computed. Utilizing complete and accurate WVC carcass data may have improved the statistical power of the BACI analysis, and may have resulted in statistically significant results. Carcass data would have decreased the variability in annual WVC rates and removed many of the data points with values of zero (Figure 34 through Figure 40). Future BACI analysis that includes additional years of WVC data will also improve statistical power.

The two lowest *p*-values were computed for structures with continuous wildlife fence between them, Kootenai Creek-McCalla Creek North and McCalla Creek South-Kootenai Springs Ranch. The first pair of structures had moderate wildlife fence but were both rated “positive” in terms of deer successfully moving through the structures. White-tailed deer abundance decreased at Kootenai Creek during post-construction monitoring (Figure 6). The second pair of structures had extensive wildlife fence between them, but were rated “slightly negative” and “highly negative” in terms of deer successfully moving though the structures (section 2.3.3.2). McCalla

Creek south had a very large decrease in white-tailed deer abundance during post-construction (Table 4). Fence length was not related to structure use rates (section 3.3.1), however, extensive wildlife fence and continuous fence between structures may be associated with reduced crash rates. One example that contradicts this hypothesis was observed at Bass Creek Fishing Access-Dawns Crossing. This pair of structures had extensive wildlife fence and continuous fence between them. Both structures were rated “highly positive” yet the relative WVC crash rate increased at these structures (Figure 40). One explanation is that white-tailed deer abundance greatly increased at Bass Creek Fishing Access and Dawns Crossing during post-construction monitoring (Figure 4 and Figure 5).

Another notable result from the BACI analysis was the relative reduction in WVC crash rate at the Fun Park Culvert wildlife crossing structure (Figure 38). This structure had only a small amount of wildlife fence. No white-tailed deer were observed moving through the structure during post-construction monitoring. The success rate and the success per camera day and were zero (Table 3). The explanation, once again, may be the substantial change in white-tailed deer abundance documented during pre-construction and post-construction monitoring (Figure 18). White-tailed deer were observed successfully moving across US 93 at the site on 663 occasions during pre-construction monitoring.

The BACI analysis assumed that all independent variables were controlled. Specifically, it assumed that changes in white-tailed deer abundance at individual wildlife crossing structures were equal to changes in abundance at the control sites. Figure 2 through Figure 20 in section 2.3.2.2 demonstrate that this assumption was invalid. Abundance changes at individual structures were highly independent relative to abundance changes at other structures. Overall, it appears that white-tailed deer abundance is the most dynamic and important variable affecting WVC crash rates. Other independent variables such as traffic volume, highway configuration, and adjacent land use appear to have been well controlled in the BACI analysis. Adjacent land use may be an important variable in determining WVC location rather than WVC rate.

4.6 Summary

Statistical analyses were used to assess differences and relationships among post-construction white-tailed deer use rates of wildlife crossing structures, structural characteristics of crossing structures, and environmental characteristics associated with crossing structures. Explanatory variables included: height, width, length, and openness of structures, fence lengths, guardrail lengths, humans per camera day, and average site values for percent cover of grass, forbs, shrubs, trees, bare ground, water, and number of deer fecal pellets.

The difference in white-tailed deer success rate, rate of repellency, and parallel rate between structure types was assessed using a generalized linear mixed model with a binomial response and a logit link. White-tailed deer success rate was higher for bridges than for culverts (model predicted values, 81 percent and 16 percent, respectively), counter-balanced by a lower parallel rate for bridges than for culverts (model predicted values, 12 percent and 57 percent, respectively). There was no significant difference in rate of repellency for structure type. The difference in success per camera day between structure types was assessed using a one-way ANOVA in a completely randomized design. White-tailed deer success per camera day was higher for bridges than for culverts (ANOVA predicted values, 0.9 and 0.2, respectively).

Assessment of the relationships between success rate, rate of repellency, or parallel rate and each explanatory variable used a generalized linear mixed model with a binomial response and a logit link. Success rate increased with increasing width, openness, guardrail length, and shrub cover, and decreased with increasing length. Rate of repellency decreased with increasing height, width, openness, guardrail length, and shrub cover. Parallel rate decreased with increasing width, openness, and guardrail length, and increased with increasing length. The relationships between each of the explanatory variables and white-tailed deer success per camera day were assessed using a simple linear regression. Success per camera day increased with structure width and openness. There was little to no evidence that fence length, humans, grass, forbs, trees, bare ground, water, and fecal pellets were related to white-tailed deer use rates of wildlife crossing structures.

A two-sample test was used to test for equal means of bridges and culverts for each explanatory variable. Bridges and culverts differed in width, length, openness, and number of humans per day. Bridges were wider, shorter, more open, and had higher human use. A Pearson product-moment correlation coefficient was computed to assess the relationship between white-tailed deer abundance and number of fecal pellets. There was a very weak positive linear relationship between white-tailed deer abundance and number of fecal pellets: $r = 0.23$.

WVC carcass and crash data were obtained from Montana Department of Transportation (MDT). The number of WVC carcasses decreased 59 percent from 2012 to 2013, and decreased 84 percent from 2012 to 2014. WVC carcass data in all forms appeared to be unreliable from 2013 through October 2015.

The Kernel2d function in the Splancs package in R was used to compute and map smooth representations of the spatial-temporal variations in intensities of WVC carcasses and WVC crashes relative to wildlife crossing structure locations within the study area. Kernel2d representations provided displays of the variation in WVC intensities within the entire study area during the past 16 years. Temporary increases in WVC carcass and crash intensities were observed after the construction of most of the wildlife crossing structures. These temporary increases have two possible explanations. They may represent white-tailed deer adaptations to the structures, four lanes rather than two, and increases in traffic speed following an entire season of construction. It is also possible that the temporary increases were not related to the construction of wildlife crossing structures. WVC intensities at many given locations appear to increase and decrease over time, before and after the construction of wildlife crossing structures. Kernel2d representations do not provide statistical evidence for or against a relationship between WVC rates and wildlife crossing structures. They simply display variations in WVC intensities over space and time relative to wildlife crossing structure locations. However, Kernel2d representations become more powerful for observing WVC patterns over the long term.

White-tailed deer annual hunter harvest rates from Hunting District 260, obtained from Montana Fish Wildlife and Parks (MTFWP), were used as an estimate of white-tailed deer abundance for the entire study area. Monthly traffic volume data from two traffic counters were obtained from MDT. Attempts were made to program a fine-scale predictive statistical model to measure changes in WVC rates and determine the effectiveness of wildlife crossing structures. The model was to measure and control for the influence of white-tailed deer abundance, traffic volume, and potentially other independent variables on WVC rates during pre-construction and post-construction of wildlife crossing structures. Attempts to program a fine-scale predictive statistical model were unsuccessful for several reasons: it required white-tailed deer abundance and traffic volume data at a fine scale, ideally at the 19 wildlife crossing structure locations, and required accurate and complete WVC carcass data.

Before-After-Control-Intervention (BACI) design analysis was used to evaluate changes in WVC crash rates between pre-construction and post-construction of wildlife crossing structures. The high *p*-values computed in the BACI analysis showed that wildlife crossing structures did not have a statistically significant effect on WVC crash rates. However, substantial relative reductions and increases in WVC crash rates did occur at wildlife crossing structures. These rate changes were measured, and not statistically computed. The largest reduction in WVC crash rate (-2.6 crashes per mile per year), relative to the change in WVC crash rate at a control section, occurred at Kootenai Creek Bridge and McCalla Creek North Bridge (mp 66.4 to mp 65.9). Other substantial relative WVC crash rate reductions occurred at McCalla Creek South Bridge and Kootenai Springs Ranch Culvert (mp 65.3 to mp 63.8), Big Creek Bridge (mp 61.8 to mp 61.4), Bear Creek South Bridge (mp 57.3 to 56.9), and Fun Park Culvert (mp 55.7 to mp 55.3). The largest relative increases in WVC crash rates occurred at Blodgett Creek Bridge (1.4 crashes per year per mile, mp 50.5 to 50.1) and at Bass Creek Fishing Access Culvert and Dawns Crossing Bridge (0.9 crashes per year per mile, mp 70.7 to mp 69.0).

The relative changes in WVC crash rates appear to be related to changes in white-tailed deer abundance. Abundance does not appear to be well controlled in the BACI analysis. In two examples, relative crash rate changes may be related to extended sections of wildlife exclusion fence. Overall, it appears that white-tailed deer abundance is the most dynamic and important variable affecting WVC crash rates. Other independent variables such as traffic volume, highway configuration, and adjacent land use appear to have been well controlled in the BACI analysis. Adjacent land use may be an important variable in determining WVC location rather than WVC rate.

Chapter 5 Recommendations

Recommendations based on the results of this research and the observations of the authors are grouped into the following categories:

- WVC Carcass Data;
- Wildlife Crossing Structure Openness, Type, and Structural Dimensions;
- Wildlife Exclusion Fence and Suburban-Wildland Settings;
- Transportation Planning and Wildlife Considerations;
- Pre-construction monitoring;
- Adaptive management.

5.1 WVC Carcass Data

- Complete and accurate WVC carcass data are required to determine the effect of wildlife crossing structures on WVC rates.
- The WVC carcass data maintained by MDT Traffic and Safety Bureau and any additional WVC carcass data should be rectified.
- Carcass data should be located, input, and managed in a smart phone application or other Global Positioning System (GPS) based format that uploads carcass locations to an on-line user-interfaced map. A smart phone application is successfully used in another state (Olson et al. 2014). The application and web-based mapping software is free and can be adapted for any state.
- The location of carcasses in real-time may be used to quickly indicate the presence of WVC hot spots, short-term seasonal migration areas, or holes in wildlife fence. These situations can be revealed in a matter of days using a smart phone application. Under the current carcass reporting procedure, these situations may require six to 12 months to recognize.
- Web-based maps of WVC carcass locations, hot spots, and seasonal migration areas can be used to plan future transportation projects, wildlife crossing structures, and highway safety measures.
- Current WVC carcass collection methods and data management should be consistent within MDT.

5.2 Wildlife Crossing Structure Openness, Type, and Structural Dimensions

- There were very strong relationships between openness ratio (height multiplied by width (span) divided by length, in meters) and use rates in this study. Wildlife crossing structures should be designed to maximize openness ratio. We choose not to recommend a minimum openness ratio for wildlife crossing structures. High openness ratios are easier to achieve with bridges than with culverts. In this study, the culvert with the least length (44 meters, 144 feet) was more than 14 meters (46 feet) longer than the bridge with the greatest length (29.3 meters, 96 feet).

- The Bass Creek Fishing Access Culvert greatly exceeded performance measures. Its openness ratio was approximately 50 percent greater than the openness ratios of the other culverts in this study. Variables other than its dimensions and those analyzed in Chapter 3 may have played an important role at Bass Creek Fishing Access Culvert. This culvert could not be statistically compared to other culverts because it was the only large culvert in the study.
- Width (span) was the most important structural dimension in this study. Width should be maximized for wildlife crossing structures. Length was the second most important dimension. Length, the distance an animal moves under a highway through a structure, should be minimized. Height was the least important dimension in this study; there was no significant relationship between height and success rate or between height and success per camera day. However, height of wildlife crossing structures should be maximized.

5.3 Wildlife Exclusion Fence and Suburban-Wildland Settings

- Extended sections of wildlife exclusion fence are not recommended as a means to improve the use of wildlife crossing structures by white-tailed deer. Length was not related to wildlife crossing use rates in this study. However, WVC crash rates, relative to crash rates at control sections, were reduced at wildlife crossing structures in two locations with extended sections of wildlife exclusion fence.
- Wildlife crossing structures are recommended in suburban-wildland settings (Nielsen et. al 2003). In this study, several highly successful structures were located in close proximity to humans and their infrastructure. Examples included Bear Creek South Bridge, Sweathouse Creek Bridge, Kootenai Creek Bridge, and McCalla Creek North Bridge. In addition to white-tailed deer, puma, wolf, and black bear were observed successfully utilizing these structures.

5.4 Transportation Planning and Wildlife Considerations

- Future transportation planning should include consultation with MTFWP to consider multiple wildlife species in the area under consideration. Species such as moose and elk require specifically designed wildlife crossing structures.

5.5 Pre-construction Monitoring

- Pre-construction monitoring of future wildlife crossing structure sites, and monitoring of control sites are recommended. In this study, monitoring of sites and control locations provided performance measures used to evaluate post-construction use rates and effectiveness of wildlife crossing structures. The Transportation Act of 2012, MAP-21, required performance-based transportation. Section 150 of the Act mandated that performance measures should be increasingly used in transportation research to evaluate the effectiveness of transportation projects in meeting their stated goals.

- Pre-construction monitoring of sites should occur for at least one year, and longer if possible.
- Right of way cameras should be installed whenever possible during pre-construction monitoring. In this study they provided success rates, repel rates, and quantified the permeability of US 93 across two lanes of traffic for white-tailed deer and elk.

5.6 Adaptive Management

- In addition to post-construction monitoring, wildlife crossing structures and wildlife exclusion fence should be regularly inspected and adaptively managed. Monitoring and inspection during this study provided many opportunities for adaptive management. These included: repeated human activities inside structures, right of way fence placed too close to structure entrances, damaged fence from vehicle collisions, and excessive growth of vegetation at entrances of culverts.

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Appendix A Wildlife Crossing Structures Monitored in Study

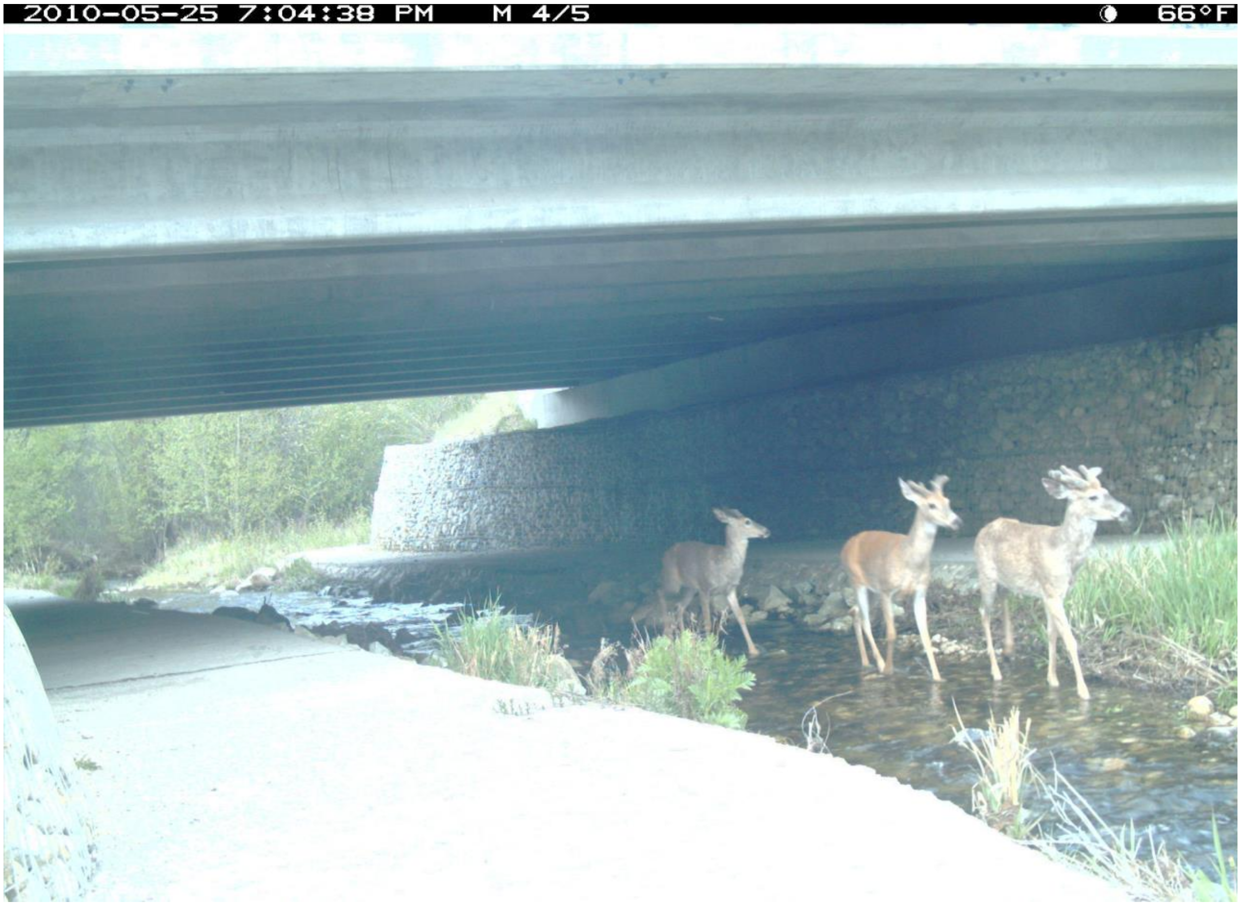

Figure 41. US 93 mp 71.1 Bass North Bridge, 3 (H) x 14 (W) x 23.2 (L) meters, 9.8 x 46 x 76 feet, Openness Ratio (meters) 1.8.

Figure 42. US 93 mp 70.5 Bass South Bridge, 4 (H) x 14 (W) x 27.4 (L) meters, 13 x 46 x 76 feet, Openness ratio (meters) 2.0.

Figure 43. US 93 mp 70.1 Bass Fishing Access Culvert, 3.9 (H) x 6 (W) x 58 (L) meters, 12.7 x 20 x 190 feet, Openness Ratio (meters) 0.40.

Figure 44. US 93 mp 69.7 Dawn's Crossing Bridge, 4 (H) x 135 (W) x 24 (L) meters, 13 x 115 x 79 feet, Openness Ratio (meters) 5.8.

Figure 45. US 93 mp 66.2 Kootenai Creek Bridge, 1.8 (H) x 24 (W) x 27 (L) meters, 5.9 x 79 x 88.6 feet, Openness Ratio (meters) 1.6.

Figure 46.US 93 mp 66.1 McCalla North Bridge, 1.9 (H) x 24 (W) x 26.4 (L) meters, 6 x 79 x 86 feet, Openness Ratio (meters) 1.7.

Figure 47. US 93 mp 65.1 McCalla South Bridge, 1.4 (H) x 19 (W) x 26.5 (L) meters, 4.5 x 62 x 87 feet, Openness Ratio (meters) 1.0.

Figure 48. US 93 mp 64.6 Kootenai Springs Ranch Culvert, 2 (H) x 3.6 (W) x 44 (L) meters, 6.5 x 11.8 x 144 feet, Openness Ratio (meters) 0.16.

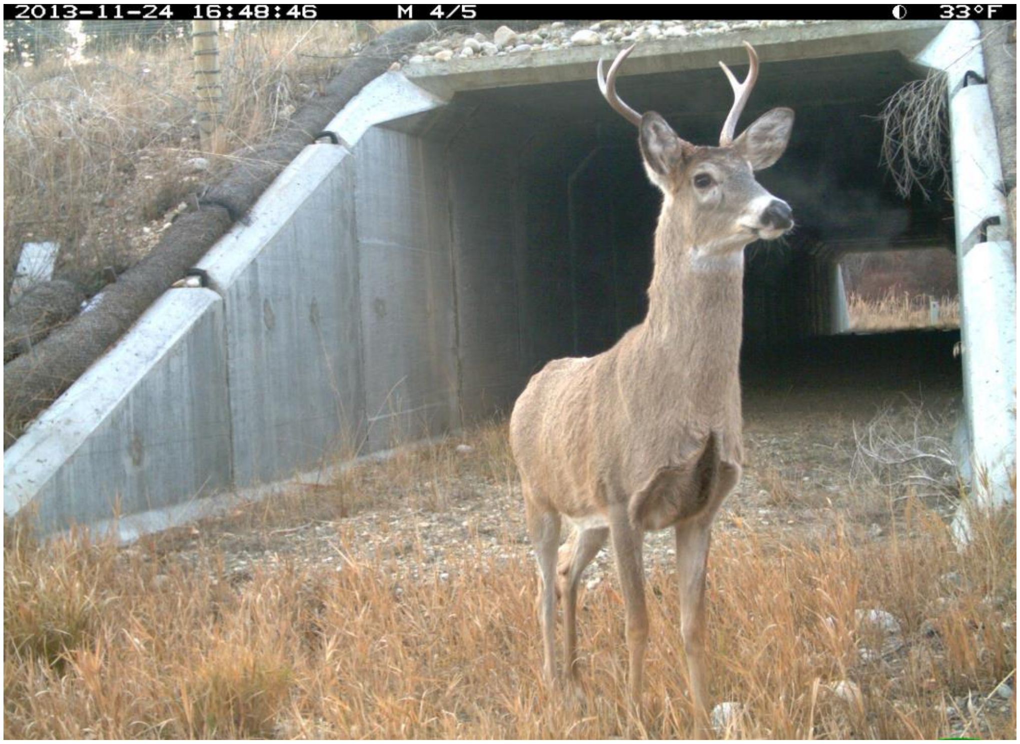

Figure 49. US 93 mp 63.4 Indian Prairie Culvert, 2.7 (H) x 3.7 (W) x 47 (L) meters, 8.8 x 12 x 154 feet, Openness Ratio (meters) 0.21.

Figure 50. US mp 61.6 Big Creek Bridge, 1.4 (H) x 19 (W) x 26.5 (L) meters, 4.5 x 62 x 87 feet, Openness Ratio (meters) 4.3. View from Northeast Corner. Note Researcher Bent Over Camera Box in Foreground for Height Comparison.

Figure 51. US 93 mp 61.6 Big Creek Bridge, Southeast Side.

Figure 52. US 93 mp 60.7 Axmen Propane Culvert, 3 (H) x 4 (W) x 51 (L) meters, 9.8 x 13 x 161 feet, Openness Ratio (meters) 0.24.

Figure 53. US 93 mp 59.7 Sweathouse Creek Bridge, 2.2 (H) x 25.5 (W) x 29.3 (L) meters, 7.2 x 84 x 96 feet, Openness Ratio (meters) 1.9.

Figure 54. US 93 mp 58.3 Bear Creek North Bridge, 1.3 (H) x 21 (W) x 27.4 (L) meters, 4.3 x 69 x 90 feet, Openness Ratio (meters) 1.0.

Figure 55. US 93 mp 57.1 Bear Creek South Bridge, 3.8 (H) x 36.3 (W) x 27.3 (L) meters, 12.5 x 119 x 89.5 feet, Openness Ratio (meters) 5.0.

Figure 56. US 93 mp 56.7 Lupine Culvert, 2.7 (H) x 2.7 (W) x 52 (L) meters, 9 x 9 x 170 feet, Openness Ratio (meters) 0.14.

Figure 57. US 93 mp 56.2 Mountain Gallery Culvert, 2.7 (H) x 2.7 (W) x 54 (L) meters, 9 x 9 x 177 feet, Openness Ratio (meters) 0.14.

Figure 58. US 93 mp 55.5 Fun Park Culvert, 2.7 (H) x 2.7 (W) x 58 (L) meters, 9 x 9 x 190 feet, Openness Ratio (meters) 0.13.

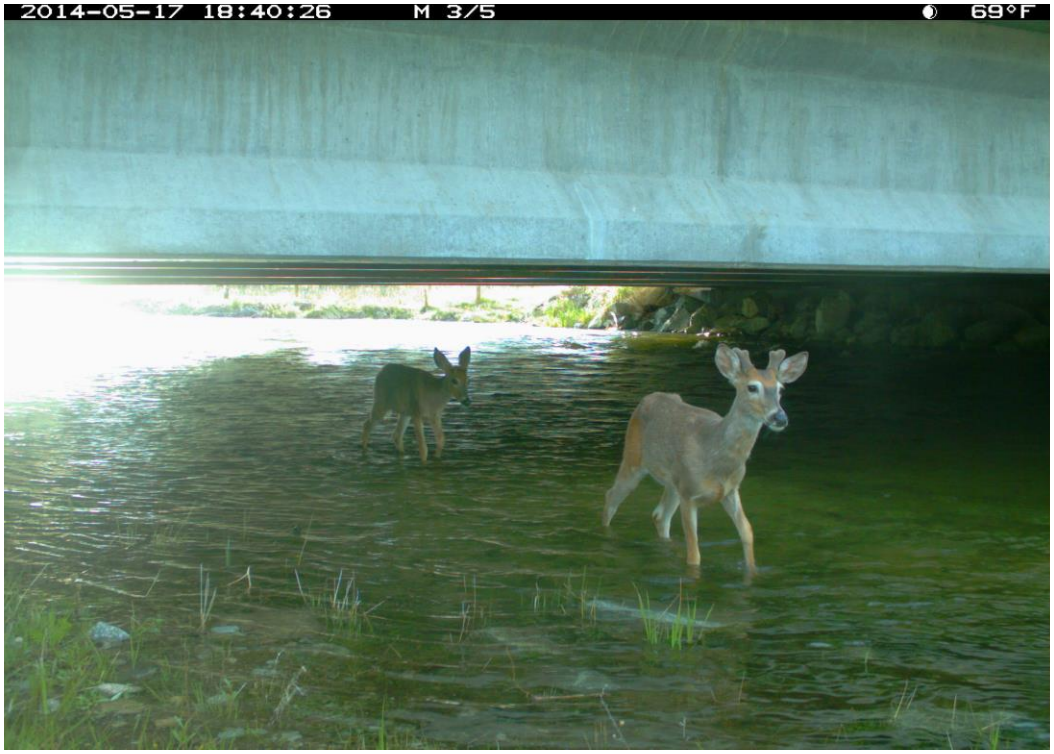

Figure 59. US 93 mp 54.6 Mill Creek Bridge, 1.4 (H) x 24 (W) x 23.2 (L) meters, 4.6 x 78.7 x 76 feet, Openness Ratio (meters) 1.4.

Figure 60. US 93 mp 50.3 Blodgett Creek Bridge, 2.7 (H) x 25 (W) x 27.4 (L) meters, 9 x 82 x 90 feet, Openness Ratio (meters) 2.4.

Appendix B Wildlife and Domestic Species Photographed at Structures

Wildlife Species Other Than White-Tailed Deer

Forty-three other species of animals were photographed at the wildlife crossing structures during the study. These included mammals, birds, and fish. Specific use rates of wildlife crossing structures for many of these other species were not tallied or calculated. Successful crossings through structures were documented for wolf (*Canis lupus*), fisher (*Martes pennanti*), sandhill crane (*Gurs canadensis*), and trout (*Salmonid sp*.). These species are rarely photographed using wildlife crossing structures in North America. Complete details for the number of occasions each of the other species were photographed at each wildlife crossing structure are presented in tables below.

Table 7. Wild and Domestic Animal Species Photographed at Wildlife Crossing Structures.

Species	Species
Mammals - Ungulates	**Birds**
Elk (*Cervus Canadensis*)	Cowbird (*Molothrus ater*)
Moose (*Alces alces*)	Northern Flicker (*Colaptes auratus*)
Mule Deer (*Odocoileus hemionus*)	Mourning Dove (*Zenaida macroura*)
Mammals - Carnivores	Grackle (*Quiscalus quiscula*)
Black Bear (*Ursus americanus*)	Robin (*Turdus migratorius*)
Puma – Mountain Lion (*Puma concolor*)	American Dipper (*Cinclus mexicanus*)
Bobcat (*Lynx rufus*)	Magpie (*Pica hudsonia*)
Coyote (*Canis latrans*)	Wild Turkey (*Meleagris gallopavo*)
Wolf (*Canis lupus*)	Ring Neck Pheasant (*Phasianus colchicus*)
Red Fox (*Vulpes vulpes*)	Great Blue Heron (*Ardea herodias*)
Badger (*Taxidea taxus*)	Sandhill Crane (*Gurs canadensis*)
Otter (*Lutra canadensis*)	Canada Goose (*Branta canadensis*)
Raccoon (*Procyon lotor*)	Grebe (*Podicipedidae* family)
Striped Skunk (*Mephitis mephitis*)	Ducks (*Anas* spp.)
Erimine (*Mustela frenata*)	Merganser (*Mergus* spp.)
Fisher (*Martes pennanti*)	Great Horned Owl (*Buba virginianus*)
Domestic Dog (*Canis lupus familiarus*)	Red Tailed Hawk (*Buteo jamaicensis*)
Domestic Cat (*Felis catus*)	Quail (*Odontophoridae* family)
Mammals – Humans – (*Homo sapien*)	
Mammals – Humans on Motorized Vehicles	**Fish**
Mammals – Rodents and Lagamorphs	Trout (*Salmonid* spp.)
Beaver (*Castor canadensis*)	
Marmot (*Marmota flaviventris*)	
Muskrat (*Ondatra zibethicus*)	
Porcupine (*Erythrizon dorsatum*)	
Rabbit (*Sylvilagis nuttali*)	
Squirrels (*Sciurus* spp. and *Tamiasciurus* spp.)	

Table 8. Number of Occasions Wild and Domestic Carnivores, Ungulates, Humans, and All-Terrain-Vehicles Were Photographed At Each Structure.

Structures	BB	Ba	Bc	Ca	Co	Do	Er	Fx	Fi	Ot	Pu	Ra	Sk	Wo	El	Mo	Mu	Hu	AT
Bass Creek North Bridge MP71	1		4	109	2	61		30	8			127	20				3	446	2
Bass Creek South Bridge MP 70	4	2	4	52		60		10	1			237	12					607	
Bass Creek Fishing Access Culvert MP 70	10			28	17	32		170			2	78	38	2				131	
Dawns Crossing Bridge MP 70	5		2	29	26	40		37			3	52	11	7	1		16	148	2
Kootenai Creek Bridge MP 66	20			193		32	1	7				130	69					72	
McCalla Creek North Bridge MP 66	7			640	11	98	2	9			3	261	196	1			1	76	
McCalla Creek South Bridge MP 65				114	2	28	2	1				134	12				1	59	
Kootenai Springs Ranch Culvert MP 65	12		1	158	10	11	1				5	51	2		207			56	8
Indian Prairie Loop Culvert MP 63	17			207	5	171	1	4				72	18					311	1
Big Creek Bridge MP 61	9			144	5	128	1	1			1	134						275	
Axmen Propane Culvert MP 61				442	17	115		236		3		459	15					20	2
Sweathouse Creek Bridge MP 60			1	978	3	34						149	1					74	
Bear Creek North Bridge MP 58				82	1	23		2				66	1				1	85	
Bear Creek South Bridge MP 57				175		49		21				78	73				20	188	14
Lupine Culvert MP 56				107		9		53				29	2				2	11	
Mountain Gallery Culvert MP 56				684		8		106				52	2					3	
Fun Park Culvert MP 55				22	7	12		6				268						14	
Mill Creek Bridge MP 55				345	3	44	1	1				148	2			3		192	
Blodgett Creek Bridge MP 50	1		1	370		41	4				1	98	25			1	7	387	
Totals	86	2	13	4879	109	996	13	694	9	3	15	2623	499	10	208	4	51	3155	29

BB = Black Bear, Ba= Badger, BC=Bobcat, Ca=Domestic cat, Co=Coyote, Do=domestic dog, Er=Ermine or mink, Fx=Fox, Fi=Fisher, Ot=Otter, Pu=Puma, Ra= Raccoon, Sk=Skunk, Wo=Wolf, El=Elk, Mo=Moose, Mu= Mule deer, Hu=Humans, AT=All Terrain Vehicle

Table 9. Number of Occasions Small to Meso Sized Mammals, Birds, and Trout Were Photographed At Each Structure.

Structures	Be	Ma	Mr	Po	Sq	Bi	AD	MD	UD	NF	Gr	GB	Ge	CG	Do	Ph	Qu	Tu	Tr
Bass Creek North Bridge MP71		22		3	7													69	
Bass Creek South Bridge MP 70		107		1	7							5			5	1		3	
Bass Creek Fishing Access Culvert MP 70		40	2	11	5	30												4	
Dawns Crossing Bridge MP 70		5		8	1													32	
Kootenai Creek Bridge MP 66		7		18	17	20								6			21	32	
McCalla Creek North Bridge MP 66	9	20	2	5	1	24			50			16		112	16	1	22	49	
McCalla Creek South Bridge MP 65	1		5	10		5	8		63			30	12	18	30	1		37	
Kootenai Springs Ranch Culvert MP 65		42		4		7								75		1	11	162	
Indian Prairie Loop Culvert MP 63		3				28		23	3		7			3		3	2	59	
Big Creek Bridge MP 61						9			11			1		2	1			787	
Axmen Propane Culvert MP 61		26		3	1	70		5		7							86	1	
Sweathouse Creek Bridge MP 60						17						11			11	2	13		2
Bear Creek North Bridge MP 58				1	1		1							8			41		
Bear Creek South Bridge MP 57		1			7	7											87	1103	
Lupine Culvert MP 56		2				21			11									21	
Mountain Gallery Culvert MP 56			1											9		28	175	3	
Fun Park Culvert MP 55		2	2		1	42		1	3							108	36	38	
Mill Creek Bridge MP 55		8					5		94			15		20	15	2	223	5	
Blodgett Creek Bridge MP 50		33		7	6							1			1	3	79	7	
Totals	10	318	12	71	54	280	14	29	235	7	7	79	12	253	29	150	796	2412	2

Be=Beaver, Ma = Marmot, MR = Muskrat, Po=Porcupine, Sq = Squirrel spp., Bi = Unidentified Bird, AD = American Dipper, MD = Mourning Dove, UD = Unidentified Duck, NF = Northern Flicker, Gr = Grackle, GB = Great Blue Heron, Ge = Grebe spp., CG = Canada Goose, Do = Dove spp., Ph = Ring Necked Pheasant. Qu = Quail spp., Tu = Wild Turkey, Tr = Trout spp.

Appendix C White-Tailed Deer Bitterroot Valley Abundance Estimates Based on Aerial Surveys and Hunter Harvest Survey Estimates for Hunting District 240 and 260

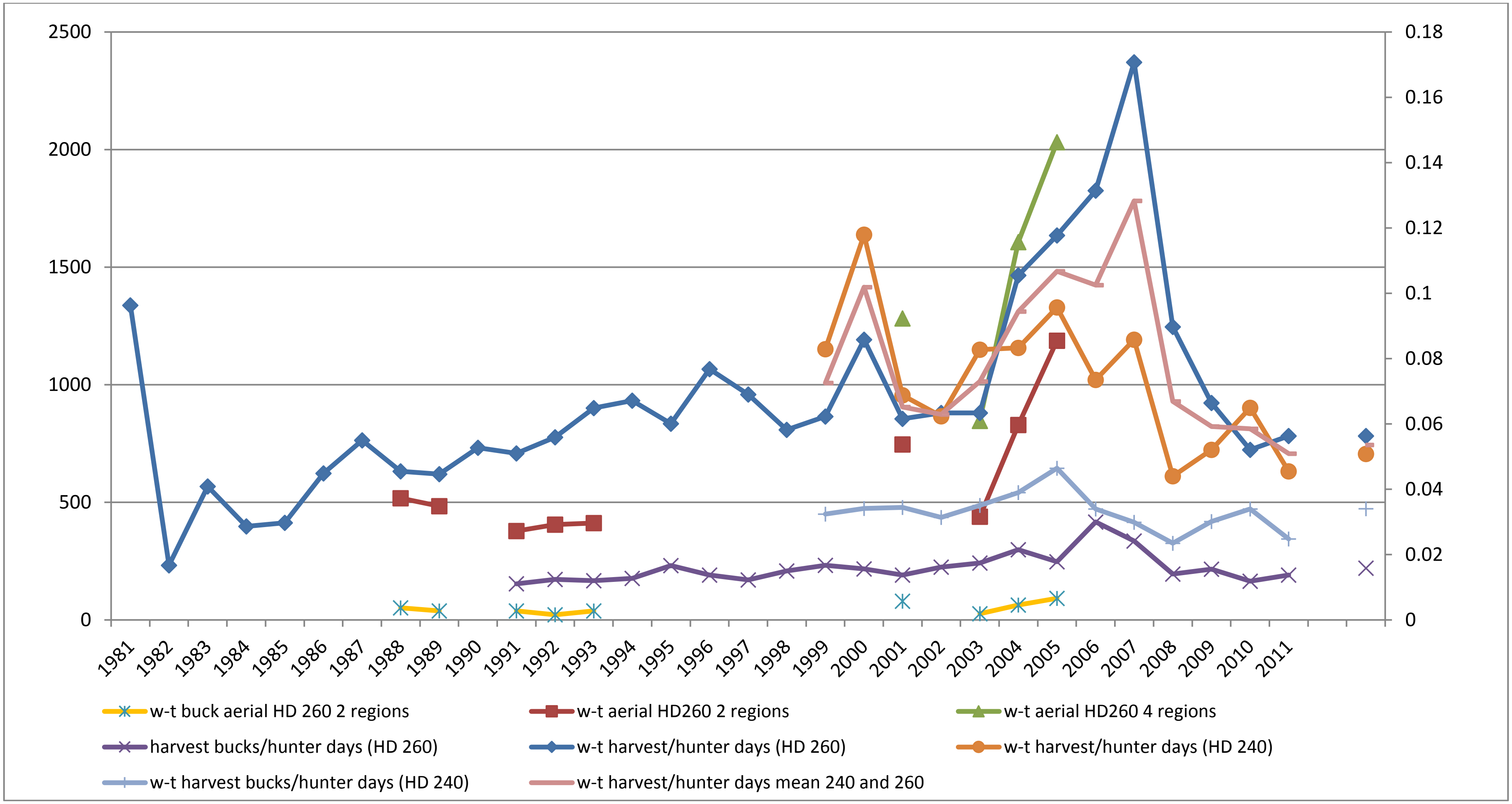

Figure 61. Figure of Plots of White-tailed Deer Population Estimates Based on Aerial Surveys on HD 260, 240 Regions, and Hunter Harvest Surveys.

Appendix D Wildlife-Vehicle Collision Crash Rate Before and After Mitigation, For Construction Sections of US 93 Compared with Two Control Sections

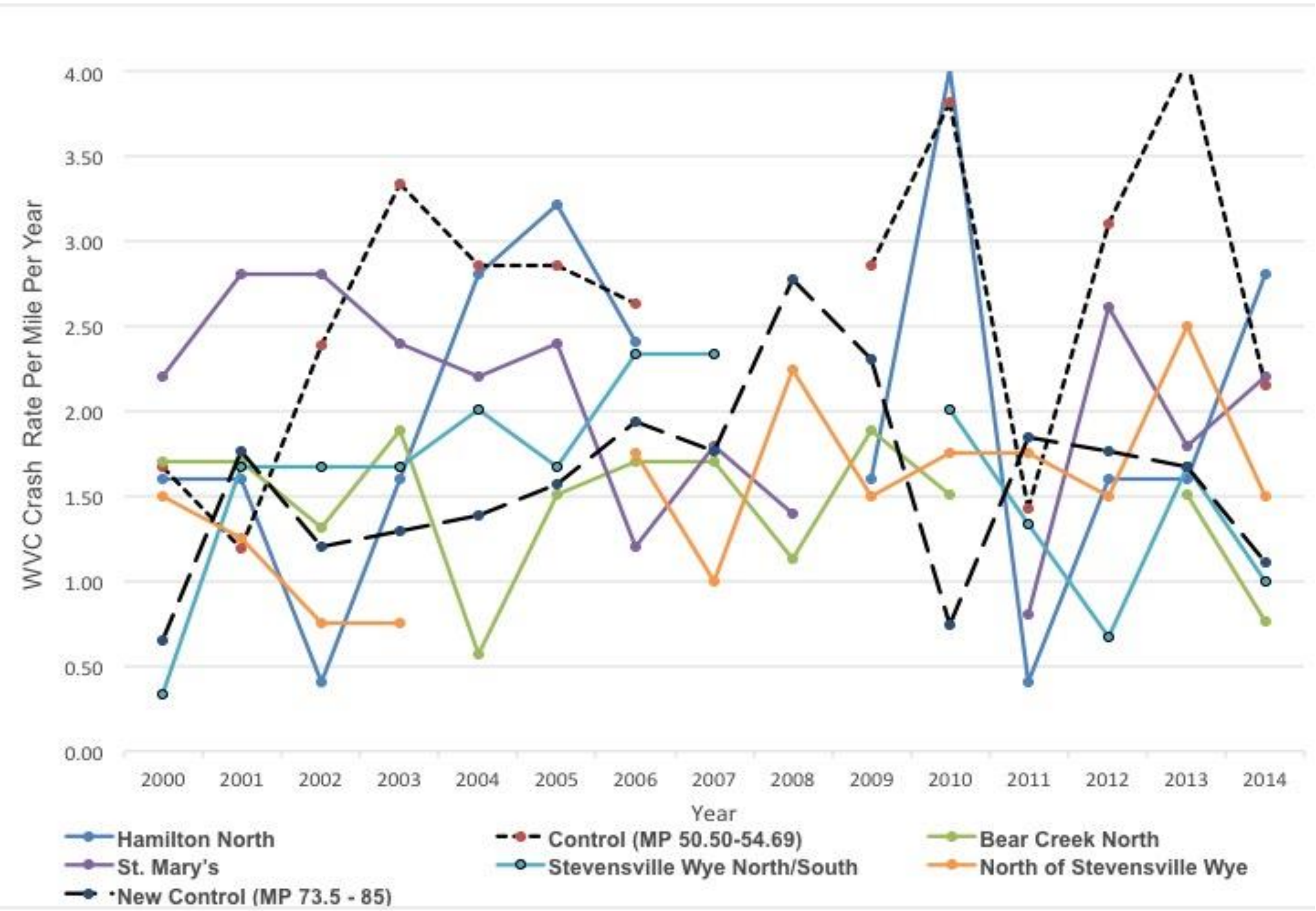

Figure 62. WVC Crash Rates per Mile Per Year for Each US 93 Highway Construction Section and Two Control Sections.