NDOT Research Report

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Effectiveness of Wildlife Crossing Structures to Minimize Traffic Collisions with Mule Deer and Other wildlife in Nevada

April 2015

Nevada Department of Transportation
1263 South Stewart Street
Carson City, NV 89712

Disclaimer

EFFECTIVENESS OF WILDLIFE CROSSING STRUCTURES TO MINIMIZE TRAFFIC COLLISIONS WITH MULE DEER AND OTHER WILDLIFE IN NEVADA

FINAL REPORT

Prepared for

Nevada Department of Transportation

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Construction of the safety crossings and exclusionary fencing was provided by Nevada Department of Transportation, which was a combination of funds allocated by the Federal Highway Administration and matched by the state of Nevada. Additional funding for this research was provided by NDOW, State of Nevada Wildlife Heritage Trust Fund, Nevada Wildlife Record Book Foundation, NDOW Mining Assessment Fund, USFWS Federal Assistance Office, and the Animal Ark Wildlife Sanctuary and Education Center. We thank all of the employees involved at both NDOT and NDOW for their assistance with this project. We also appreciate assistance from H. Proctor, T. Sharp, K. Quinn, B. Regan, T.C. Allen, and M. Negron as well as numerous volunteers. Graduate students Nova O. Simpson and Ivy Attah completed Master's level graduate theses on this project. Dr. Zong Tian supervised Ivy Attah's thesis research. Nova Simpson conducted the data collection including setting cameras and collecting picture data as well as sorting, cataloging, and counting deer in over 1,000,000 photos.

ABSTRACT

Maintenance of movement corridors is a fundamental component of conservation of biological diversity, and is especially important for terrestrial species that migrate extended distances. Movement corridors for large-bodied species present unusual challenges, since body size is related to broad spatial needs. Highways and Interstate freeways not only fragment corridors, but result in increased mortality from collisions with vehicles. The observed level of mortalities of mule deer and other wildlife species on U.S. highways appears to have negative consequences on wildlife populations. Studies in other states indicate that more than 50% of the deer-vehicle collisions nationwide are not reported and there are no records for deer-vehicle collisions that occurred in remote areas although records for collisions within or near urban areas may be reported. Wildlife crossing structures are an important tool in multiple ecosystems to allow safe passage for wildlife across roadways. Indeed, crossing structures have been used extensively in Europe to reconnect fragmented habitats for numerous species. Few projects, however, have documented responses to more than one structure type simultaneously, and fewer have provided information on successful crossings versus retractions (retreat rather than cross). We used mule deer (*Odocoileus hemionus*), a widespread species across diverse bio-regions in western North America to test hypotheses about efficacy of different types of crossing structures in Eastern Nevada. The 6.6 km (4.1-mile) study section of highway is along the U.S. 93 Highway north of Wells, NV, with 3 miles of fencing on both sides of the highway. We documented responses and success of overpasses and underpasses at allowing safe passage across roadway for mule deer. Our metrics to evaluate success included the number of animals that crossed each structure, percentage of successful crossings versus retractions, and mortalities during multiple migrations. We employed an Empirical Bayes approach to compare the 'before' and 'after' changes in collisions between wildlife and vehicles. A benefit-cost analysis of the wildlife overpass is also included to identify its effectiveness considering factors like number of mortalities, deer-vehicle collisions threats to human injuries or fatalities, and the construction costs. Crossing structures were immediately successful and mortalities declined with each subsequent migration, independent of population size. Although all of the crossing structures were successful to some extent; we observed substantially more successful crossings at overpasses than underpasses. Relatively few retractions strongly indicated preference for overpasses by migratory ungulates. These wildlife crossing structures successfully enhanced connectivity by allowing safe passage across highway for mule deer. The benefit-cost analysis indicated that construction and maintenance of the overpass was economically supported. Importantly, those structures succeeded in making roadways safer for both wildlife and motorists.

EXECUTIVE SUMMARY

We evaluated the effectiveness of wildlife crossing structures on Hwy 93, between Wells and Contact, Nevada. We documented use of the crossing structures by mule deer as well as mortalities that occurred in that area associated with structures and exclusionary fencing. Finally we conducted a benefit-cost analysis of the overpass at 10-Mile Summitt.

This research supported education of 2 master's level graduate students and 2 theses were produced from this project. Nova Simpson, supervised by Dr. Kelley M. Stewart in the Department of Natural Resources and Environmental Science, documented use of the crossing structure by mule deer as well as documenting mortalities of mule deer following construction of the structures. Ivay Attah, Supervised by Dr. Zong Tian in the Engineering Department, conducted a benefit-cost analysis of the structures.

Construction of wildlife crossing structures, including overpasses and underpasses for mule deer and other species on US Hwy 93 was implemented to reduce deer-vehicle collisions in an area that appeared to be a 'hotspot' for animal-vehicle collisions. Data on animal-vehicle collisions collected by Nevada Department of Transportation (NDOT) and Nevada Department of Wildlife (NDOW) along a 20-mile stretch of US Hwy 93 between Wells and Contact, Nevada documented 75 - 150 known deer killed annually with an estimated total of approximately 300 deer killed per year (NDOT 2006). Deer-vehicle collisions were highest during the two migration periods and had resulted in human injury, damage to property, and increased mortality of mule deer (NDOT 2006). Those data indicated that this portion of US Hwy 93 is a 'hotspot' for deer-vehicle collisions particularly during spring and autumn migrations, when deer are forced to cross US Hwy 93 to reach seasonal ranges.

We documented use of the crossing structures by mule deer using remote cameras over 8 migrations at 10-Mile Summit (overpass and 2 underpasses). At HD Summit we began documenting use of structures as soon as they were completed, thus we documented 8 migrations at the underpass and 6 at the overpass because the overpass was completed a year later than the underpasses at that site. We used 26 cameras located at the entrance to each structure for each migration (e.g. autumn migration is west to east and cameras were located on the east side and vice versa for spring migration). Cameras also were located at the ends of exclusionary fencing. We documented mortalities of mule deer during the first 2 years the structures were available by driving the entire study area and locating sites of mule deer mortalities or evidence of collisions. Finally we conducted a benefit-cost analysis of the overpass at 10-Mile Summit and included costs of construction and maintenance as well as the costs of injuries, property damage, and the possibility of human fatalities.

We accrued > 1,000,000 photos between 8 migrations and 16 cameras located at the crossing structures and ends of the exclusionary fencing. Approximately 30% of the photos contained no wildlife, 20% contained various species of animals, and 50% contained mule deer.

The crossing structures were immediately used by mule deer and were successful at removing those deer from the roadway. We documented 35,369 mule deer that successfully crossed over or through 1 of the 5 crossing structures during 8 migratory periods (Table 4). During migratory periods, a total of 30,259 mule deer used a crossing structure at 10 Mile Summit and 5,110 mule deer used the safety crossings at HD Summit (Table 4). During autumn 2011 through spring 2014 migrations when both sites were available for use, 85.6% of the mule deer population that used a structure crossed at 10 Mile Summit and 14.4% crossed at HD Summit (Table 4). Throughout the duration of the study the percentage of approaches that resulted in successful crossings was highest at the overpasses compared with the underpasses (Figure 3).

We recorded 14 mortalities within 2.4 km of the north and south ends of the fencing, 5 mortalities outside of the exclusionary fencing, and 9 mortalities within the exclusionary fencing. The majority of mortalities were within 1.0 km of the fence ends (n = 10), 2 within 2.0 km, and 2 were located more than 2.5 km away from the fence ends but remained within the study area. We observed a 50% decrease in the number of mortalities of mule deer with each subsequent migration, although the total number of mule deer using the structures increased with each subsequent migration (Figure 6). Additionally, we observed 50% more mortalities than those reported in NDOT's Animal-Hit Database during the first 3 migrations that the crossings were available for use (Figure 6). We did not detect any mortalities during the fourth migration, but Nevada Highway Patrol reported a single mortality near the southern fence end.

The benefits and costs estimated over the analysis period were discounted to calculate the net present value of benefits and costs. The wildlife overpass has a Net Present Worth of approximately $3,972,269 million and a Benefit-Cost Ratio of 1.58. Benefit-cost ratios greater than one identify projects worth the investment. A benefit to cost ratio of 1.58 indicates that having wildlife crossing structures at locations of high wildlife vehicle collisions is economically justified.

We observed greater numbers of animals crossing the overpass at 10-Mile summit, where most of the migratory deer cross Hwy 93, however we also observed few retractions at overpasses compared with underpasses, the percentage of approaches that resulted in successful crossings was higher at overpasses in every migration. Nevertheless, underpasses remained a successful method for removing migratory ungulates from the roadway. In addition, crossing structures in our study were located in several locations because of multiple sites where migratory deer crossed those highways; and in a large stretch of highway, provision for multiple crossing structures rather than a single structure is certainly desirable (Sawyer et al. 2012).

Although the overpasses had a higher proportion of successful crossings, underpasses also are an important tool in restoring connectivity and reducing wildlife vehicle collisions, especially when the cost or construction of an overpass is not feasible (Clevenger et al. 2001,Sawyer et al. 2012). Although the cost of an overpass can be 2-3 times the cost of an underpass depending on location, materials, and construction methods (NDOT 2006), our benefit-cost ratio indicates the overpass is economically justified. Nevertheless, reduction in wildlife mortalities, vehicle damage, and reduction or elimination of human injuries or possible fatalities make the cost of crossing structures and increased cost of overpasses worthwhile. All of the crossing structures were very effective at reducing collisions between ungulates and vehicles, preserving migratory corridors, reducing fragmentation of habitats throughout human altered landscapes, and making roadways safer for both wildlife and motorists.

CHAPTER 1: Background

This research supported education of 2 master's level graduate students and 2 theses were produced from this project. Nova Simpson, supervised by Dr. Kelley M. Stewart in the Department of Natural Resources and Environmental Science, documented use of the crossing structure by mule deer as well as documenting mortalities of mule deer following construction of the structures. Ivay Attah, Supervised by Dr. Zong Tian in the Engineering Department, conducted a benefit-cost analysis of the structures.

Approximately 6.2 million km (~3.9 million miles) of public roads cover <1% of the United States, yet the "road effect zone" has been estimated to span approximately 20% of the country's land area (Foreman 2000, Litvaitis and Tash 2008). Roads directly influence animal and plant communities by removing habitat, functioning as movement corridors for some animals, increasing wildlife mortality from collisions with vehicles, and forming a barrier to the movement of individuals and eventually gene flow among populations (Litvaitis and Tash 2008). In general, the most conspicuous consequence of roads on animal populations is direct mortalities that result from collision with vehicles (Litvaitis and Tash 2008).

An estimated 1 million animals are killed on American roads each day often with substantial cost (Forman and Alexander 1998, Litvaitis and Tash 2008). Damages to vehicles that result from collisions with deer (*Odocoileus sp*.) alone can exceed $1 billion and result in more than 200 human fatalities each year (Conover et al. 1995). Every year in the United States approximately 1.5 million deer-vehicle collisions occur resulting in more than 29,000 human injuries, 200 human fatalities, 1.3 million deer fatalities, and over 1 billion dollars' worth of property damage. Deer–vehicle collisions are increasing in the United States and worldwide as traffic volume increases, more roads are constructed, and habitat for deer becomes more fragmented (Sullivan and Messmer 2003). Across the nation, traffic crashes involving wildlife cause an estimated $5 to $8 billion in damage each year. In 1980, Williamson reported that about 200,000 deer was killed on U.S. roadways in collisions with vehicles. In 1991, more than 538,000 deer were estimated to have been killed by vehicles in the U.S. (Romin and Bissonette 1996). This estimate was considered conservative since numerous hits were not recorded and the estimate only included 36 states (Lehnert and Bissonette 1997).

Numerous overpasses and underpasses, although not designed for wildlife, have been documented to be used by wildlife in the United States, and are suggested to reduce collisions between wildlife and vehicles (Romin and Bissonette 1996). Wild ungulates are assumed to readily use crossings, but only limited data has been collected in North America regarding design features and related animal responses and use of crossings. The only overpass structure specifically designed for wildlife in North America is near Banff, Canada and existing data on effectiveness of that crossing have not been reported. Nonetheless, Van Wieren and Worm (2001) documented extensive use of a vegetated overpass for wildlife in the Netherlands, Europe, by several species of large mammals including red deer (*Cervus elaphus*), roe deer (*Capreolus capreolus*), and wild boar (*Sus scrofa*). Van Wieren and Worm (2001) also reported minimum effective width of overpasses for deer species as 40 – 50m (131 – 164 feet); overpasses with smaller widths were used less or avoided by deer species altogether. In addition, there may be a lag-time in responses of mule deer to the crossing. Van Weiren and Worm (2001) reported greater use of an overpass by red deer 5 years after establishment compared with the year immediately following establishment of the crossing.

Construction of wildlife crossing structures, including overpasses and underpasses for mule deer and other species on US Hwy 93 was implemented to reduce deer-vehicle collisions in an area that appears to be a 'hotspot' for animal-vehicle collisions. Data on animal-vehicle collisions collected by Nevada Department of Transportation (NDOT) and Nevada Department of Wildlife (NDOW) along a 20-mile stretch of US Hwy 93 between Wells and Contact, Nevada has documented 75 - 150 known deer killed annually with an estimated total of approximately 300 deer killed per year (NDOT 2006). Deer-vehicle collisions are highest during the two migration periods and have resulted in human injury, damage to property, and increased mortality of mule deer (NDOT 2006). Those data indicate that this portion of US Hwy 93 is a 'hotspot' for deer-vehicle collisions particularly during spring and autumn migrations, when deer are forced to cross US Hwy 93 to reach seasonal ranges. The observed level of mortalities of mule deer on this section of road appears to be having negative consequences on the population of mule deer in Elko County. The ability of the mule deer herd in eastern Elko County to sustain current population levels is severely compromised by landscape changes including continual animal-vehicle collisions with high deer mortalities during migration to summer and winter ranges, and loss of habitat resulting from the accelerated wildfire/cheatgrass cycle.

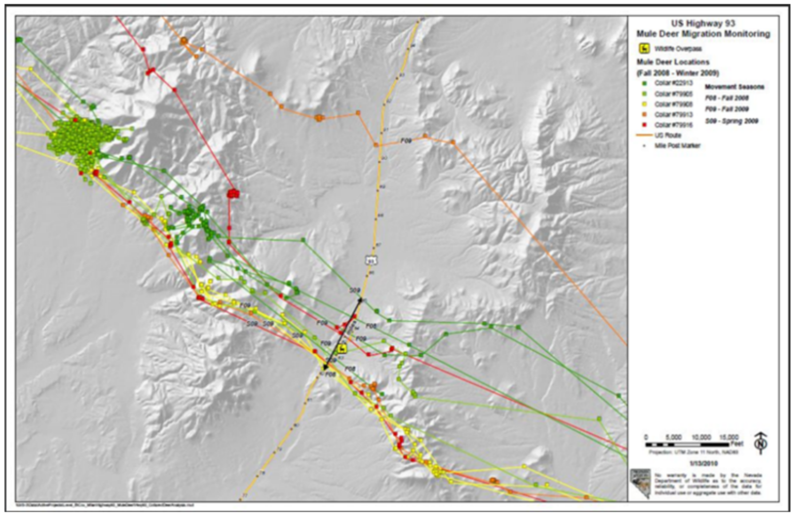

Figure 1 Deer Migration Routes across U.S. Highway 93
The black dots represent the mile posts along U.S. Highway 93 and the colors represent animal movements of GPS collars showing deer locations to track deer movements. Data from NDOW 2010.

Objectives

Our objectives were to document the use of crossing structures at 10-Mile Summit and HD Summit by mule deer and other species of wildlife and evaluate the effectiveness of overpasses versus underpasses, when both types of structures were simultaneously available to the same migratory population. We hypothesized that overpasses would be more effective for ungulates than underpasses, and that individuals that approached an overpass would successfully cross the structure, without retractions, more often than individuals that approached an underpass. Finally, we hypothesized that there would be an overall reduction in traffic-related mortalities with each subsequent migration independent of population size.

We also conducted a benefit – cost analysis specific to the overpass, the main objective of this analysis of the wildlife overpass was to identify its effect on mule deer population levels resulting from high levels of mortalities of mule deer in collisions with vehicles, and threats to human injuries or fatalities as well as to determine whether having wildlife crossings at high deer vehicle locations is economically justifiable. The analysis period selected was 10 years prior to the construction of the overpass and 2 years after the completion of the overpass.

CHAPTER 2: Research Approach

Study area (Simpson and Attah theses)

Our study area incorporates 2 sites located along U.S. Highway 93 in northeastern Nevada between the cities of Wells (41° 07' N, 114° 58' W) and Contact (41° 46' N, 114° 45' W). The wildlife crossing structures were located within the 4.1 mile segment, which starts from MP EL 81.6 to EL 85.7 in Wells, NV along the U.S. 93 Highway. Prior to the placement of the first crossing structures within Nevada, state records of vehicle collisions were consolidated by Nevada Department of Transportation (NDOT) with wildlife movement data from Nevada Department of Wildlife (NDOW) to determine the hotspots of mule deer mortalities caused by collisions with vehicles. The first site was located at 10-Mile Summit (41° 21' N, 114° 85' W), approximately 16 km north of Wells, and consists of 1 overpass and 2 underpasses (Fig. 1). Elevation at 10-Mile Summit is 1830 meters. The second site, HD Summit (41.35° N, 114.81'), is located approximately 32 km north of Wells, and consists of one underpass and one overpass (Figure 2). Elevation at HD Summit is 1920 meters. Average temperatures range from -11 during winter to 31 °C during summer and precipitation averages 260 mm annually (Pojar et al. 1975).

Construction of the first set of crossing structures at 10 Mile Summit, which consisted of 1 overpass and 2 underpasses, as well as the underpass as HD Summit were completed in August of 2010. The overpass located at HD Summit was completed during summer 2011. Both overpasses are made of concrete arches that cross over two lanes of U.S. Highway 93 (USDOT 2011). Each overpass is covered with soil, graded to match the natural elevation at the boundaries of the public right-of-way, and seeded with natural vegetation. The overpass at 10 Mile Summit is 49 m wide and 20 m long. The overpass at HD Summit is 30 m wide and 46 m long. Those 3 underpasses are large spheres made from corrugated metal that pass below the roadway. Each underpass is 8 m wide, 28 m long, and 6 m tall. After installation, soil was placed in the base of each sphere to create a natural pathway and was graded to match the natural elevation at the boundaries of the public right-of-way on both sides. All underpasses had a minimum 6 m x 4 m clearance opening after all grading was completed.

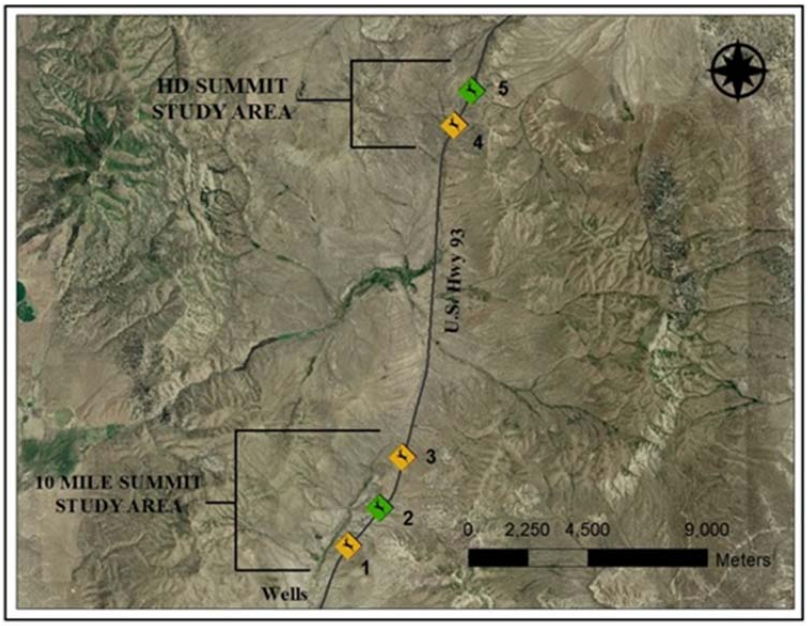

Figure 2. Map of the study area where safety crossings were located on migratory corridor for mule deer in Nevada. Crossing structures are indicated by deer crossing signs; for overpasses (green) and underpasses (yellow) at 10-Mile and HD Summits on Highway 93 between Wells and Contact, Nevada, 2010-2014. Each crossing is uniquely numbered and corresponds with Tables 1 and 2 (Simpson 2012).

Exclusionary fencing was included to funnel wildlife to the entrance of each structure. Exclusionary fencing is an important tool used in conjunction with crossing structures. This fencing is crucial to the effectiveness of the structure by reducing species movement onto the roadway, and funneling wildlife to the entrance of the structure (Sawyer et al. 2013, Beaudry et al. 2008, Dodd and Gagnon 2010, Sawyer et al. 2012). Escape ramps, known as jump-outs, were incorporated into the exclusionary fencing to allow individuals that get stuck within the fencing an opportunity to "jump out" and away from the roadway (Sawyer et al. 2012). This fencing spanned the entire length of each study site and was located between each structure to prevent wildlife from entering the roadway. The fencing is 2.4 m tall and is made of 12.5 gauge woven wire animal fencing. At 10 Mile Summit the exclusionary fencing starts approximately 0.8 km south of the most southern safety crossing and ends approximately 1.6 km north of the most northern safety crossing with about 6.4 km of fencing on both sides of the road. At HD Summit the exclusionary fencing starts approximately 1.6 km south of the underpass and ends approximately 1.6 km north of the overpass with a total of about 4.8 km of fencing on both sides of the road. From the north fence end of 10 Mile Summit to the south fence end of HD Summit there is a break in exclusionary fencing that is approximately 8.0 km, although there is standard cattle fencing present.

Ethics Statement (Simpson thesis)

All aspects of this research were approved by the Institutional Animal Care and Use Committee (Protocol #: 0500) at the University of Nevada Reno, which is accredited by the Association for Assessment and Accreditation of Laboratory Animal Care. All procedures for handling animals also were in keeping with protocols adopted by the American Society of Mammalogists for field research involving mammals (Sikes et al. 2011). The property in which our research was conducted was owned by NDOT. NDOT and NDOW are collaborators of the project and no additional permissions or permits were required.

Field Methods (Simpson thesis)

We collected data on responses of mule deer to the safety crossings from September 2010 through May 2014. We began data collection during the first migration that the structures and fencing at each study site were fully completed. At 10-Mile Summit, structures and fencing were completed in August 2010, therefore we collected data during a total of 8 migrations (autumn 2010-2013 and spring 2011- 2014). The Underpass at HD Summit were completed and monitoring of the underpass began in August 2010; and the overpass was completed August of 2011, one year later than 10-Mile Summit; therefore at that site we collected data on both sets of structures during 6 migrations (autumn 2011- 2013 and spring 2012- 2014) and for the underpass for 8 migrations, which also included autumn 2010 and spring 2011. We monitored the structures for 10 weeks during each migration; observations for autumn migrations ranged from 15 September through 1 December and spring migrations ranged from 1 March through 15 May.

We used Reconyx HyperFire Professional Cameras (hereafter cameras) with infrared technology to document use and response to each crossing structure by mule deer. Cameras were triggered when motion and a change in temperature gradient were detected, which reduced the likelihood of misfires resulting from wind driven movement of vegetation. We synchronized all wildlife cameras at the beginning of each migratory period, and used the rapid fire setting with 10 continuous pictures, fast shutter speed, and no delay period. Thus, a series of photographs could be as short as 10 or >100 when individuals or large groups were in the camera range for extended periods of time. We used a range of 12 m, which had the best performance at maximizing clarity and consistency of photos taken at night when infrared technology was required. We staggered cameras to capture all movement at locations where the width at the entrance to the structure exceeded 12m. We placed 5 cameras at the entrance of the overpass at 10 Mile Summit, 4 cameras at the overpass at HD Summit, 1 camera at each of the 3 underpasses, and 4 cameras at the fence ends. Cameras were operating 24 hours a day during migratory periods. After preliminary trials, we documented no camera failures during the study at any of the crossing structures during migratory periods. Because we were monitoring use of the structures by migratory mule deer, we placed cameras on the appropriate side of the structure to capture the approach of mule deer to the safety crossings based on the direction of seasonal migratory movements. We downloaded pictures every 2 weeks during migrations, and filed photographs based on structure location, date, and time. For locations with more than one camera, we grouped photographs in 5 minute increments. When files had more than one series of photos taken by multiple cameras, we carefully evaluated each series to avoid double-counting individuals that were captured by more than one camera.

We documented mule deer behaviors as approaches, successful crossings, and retractions. We defined approaches as the numbers of individuals that enter the frame of the camera. We described an approach that resulted in a successful crossing if the individual continued through the frame and used the crossing structure. We defined retractions as the number of individuals that turned around and returned in the direction from which they originated rather than crossing over or through the structure. We calculated the proportion success for each structure by dividing the number of successful crossings by the total number of approaches to each structure.

We conducted daily field observations, by driving the extent of the study area, during migratory periods between autumn 2010 and spring 2012, to determine the number of mortalities resulting from vehicle collisions. We used those data to determine if and to what extent the numbers of deer-vehicle collisions declined with each subsequent migration following completion of the structures and exclusionary fencing. We began observations for traffic related mortalities of deer approximately 2.4 km south of the southern fence end at 10 Mile Summit and continued until approximately 2.4 km north of the northern fence end at HD Summit. We monitored the entire study site by driving slowly along the shoulder of US Highway 93 for the full extent of fencing and structures. We used several cues to find locations where wildlife-vehicle collisions may have occurred, including the physical presence of animal carcasses, blood on the road or on the shoulder of the road, a congregation of predators or scavengers, or broken vehicle parts such as blinker casings. If one of those indicators was observed, we walked the vicinity until further evidence was located or we determined that no further evidence was available. If a carcass was located or obvious evidence of a wildlife-vehicle collision occurred, we identified the species (when possible) or documented the evidence, and recorded the global positioning system (GPS) coordinates of the location.

Statistical Analyses (Simpson thesis)

We used data obtained from cameras set at the entrances of all 5 crossing structures to analyze responses to the structures by mule deer. We included 3 structures at 10 Mile Summit from the autumn 2010 through the spring 2014, and we included the underpass at HD Summit starting in spring 2011 and the overpass at HD Summit starting autumn 2011. Because deer that cross in the opposite direction of the migration may have already crossed the structures, we excluded crossings in the opposite direction of that migratory period for all statistical analyses.

We used a model selection procedure using generalized linear models with maximum likelihood to compare total number of deer crossed or proportion of successful crossings (Proc Genmod, SAS institute 2010). We used a variable defined as subsequent migration to determine if use of a structure changed with familiarity (e.g. 1 = first migration that structure was used, 2= second migration that structure was used, etc). Fixed effects offered to models included site (10-mile or HD Summit), year, season, structure type (overpass or underpass), subsequent migration, structure*area interaction, or year*structure interaction. We used an information-theoretic approach for model selection, using Akaike's Information Criterion adjusted for small sample size (AICc), δAICc, and the Akaike weight (ω_i) (Burnam and Anderson 2010). Following selection of the most appropriate model, we examined parameter estimates and least squared means to determine significant differences in fixed effects.

We compared traffic-related mortalities detected during migratory periods with data recorded in the Animal Hit Database managed by NDOT (Deer Crash 2011). We began data collection of mortalities after construction was completed at 10 Mile Summit, and we used data for deer-vehicle collisions that occurred within the 2.4 meter south and north boundaries of 10 Mile Summit. We concentrated on 10-Mile Summit because we had 2 years of mortality data for that site. Some states have indicated that 50% of collisions with ungulates are reported, but only about 30% of those collisions are reported in rural areas (NDOT 2006, Foster and Humphrey 1995). We also compared the numbers of reported deer-vehicle collisions in the Animal-Hit Database with a reporting rate of 50%. Although a 30% reporting rate is assumed for rural areas, we used a 50% reporting rate since we believe the search effort by local agencies increased around the study area because of local interest about the project. Records that were not positively identified as mule deer were not included in our analyses. We plotted mortalities that we documented with those from the animal hit database and the estimated 50% reporting rate for comparison.

Benefit-Cost Analysis (Attah thesis)

Benefits (both monetary and safety aspect) of a transportation project are commonly defined as a combination of the effectiveness of the mitigation measure in reducing collisions and the costs associated with an average collision. Ideally, the level of effort allocated to quantifying benefits and costs in the benefit – cost analysis (BCA) is proportional to the expense and complexity of the project. The benefits derived from constructing wildlife crossings to extend wildlife migration corridors over and under major roads appear to outweigh the costs of construction and maintenance.

Costs are defined as the resources such as land, labor and material expended on the project by the entity providing it (Cambridge 2011). Also included are the design, implementation, maintenance and removal efforts. Deer-vehicle collisions (DVCs) can also impose a variety of costs which include property damage, traffic delays, emergency response services and medical care, rehabilitation expenses, lost productivity, suffering and grief. DVCs in which somebody is injured, disabled or killed, are less frequent but much more costly to society. These costs are generally easier to measure or quantify than benefits. In effect, costs are largely construction oriented in the present whereas benefits are distributed more uniformly over the life of the project (Table 1). Initial costs are those that are incurred during the design and construction process. These include the planning, preliminary engineering and project design; land acquisition and construction costs (Table 1). The bid amount of 1,862,862.00 was adjusted to 2011 dollars amounting to 2,329,598.00 based on Consumer Price Index. Maintenance costs are incurred after completion of the structure and while it is in use. It involves routine maintenance of the facility (sometimes referred to as preventive maintenance) as well as repair and cleanup required by crashes. The maintenance cost adjusted to 2011 dollars amounted to 134,520.00 based on Consumer Price Index.

Table 1: Construction and maintenance costs of wildlife crossing structures on Hwy93 at 10-Mile Summit between Wells and Contact, Nevada (Attah 2012).

CONSTRUCTION COST (CC)	
Approximate cost of overpass	$2,018,000.00
Backfill and Top Soil	$112,085.00
Fencing and Vegetation	$196,150.00
Maintenance Cost (annual)	$134,520.00(3,363*40)
Total Construction Cost	**$2,460,755.00**

Costs for an average deer-vehicle collision could be estimated based on property damage, human injuries, and human fatalities. Other parameters include: vehicle repair costs, costs associated with human injuries and fatalities, towing, incident attendance and investigation, the monetary value of deer per collision (substantially higher, thus driving up the cost of the average deer-vehicle collision) (Table 2). Although different studies have different cost estimates, cost estimates for this study will be based on the Utah data because the 2002 statewide Nevada cost of $3500 was the average for all property damage. In this analysis, 2006

USDOT estimates for motor vehicle crash costs would be used and adjusted to 2011 dollars based on Consumer Price Index. Costs that are not easily quantifiable and excluded from the analysis are the costs associated with emotional distress of deer-vehicle collision victims and expenses involved with conservation efforts for threatened or endangered species.

Table 2 Summary of Estimated Average Costs of a DVC adjusted to 2011 (Attah 2012).

Damage Cost (DC) (2011)	$7,625.20
2003 Utah data adjusted to 2011	$1,941.30
Value of deer in Nevada (2011)	$4,990.00
2011 value of hunters' travel, food, lodging, equipment, etc.	$693.80
Injury Cost (IC) (2011)	$91,091.70
Fatality Cost (FC) (2011)	$3,068,359.10
Total Collision Cost	**$3,174,701.00**
Total (Construction + Collision Cost)	**$5,635,456.00**

Following are the assumptions outlined and the procedures involved to perform the BCA. In this analysis, the cost for an average collision with a deer was estimated and all costs and benefits are in real terms (Table 3). The following list comprises the assumptions used in illustrating the Benefit-Cost estimate.

1) With exclusionary fencing (3 miles on each side), 90% of deer-vehicle collisions will be eliminated within the segment. (For actual B/C determination, reduction will be based on actual deer related crashes reduced over a minimum of two years).
2) Number of reported deer-vehicle collisions is 29% (**Error! Bookmark not defined.**), which was based on field data collected along a 10-mile segment of I-80 that included Pequop Summit by NDOW in the fall of 2005, which would factor the crashes to the analysis years. Again, this is reported data; therefore, the actual number of collisions is approximately 3.5 times greater.
3) All costs were adjusted to 2011 dollars based on Consumer Price Index.
4) The value of the wildlife overpass at the end of 40 years was zero.
5) The value of deer was based on the average of 2001-2005 (**Error! Bookmark not defined.**) data and included the cost of nonresident tags, license fees, travel, food, lodging, equipment, etc., incurred by hunters divided by the total number of deer killed by hunters. For this analysis, it was assumed that an AVC always resulted in the eventual death of the animal, regardless of the species.
6) The 2003 Utah vehicle damage cost ($1,574) was used because the 2002 statewide Nevada cost of $3500 was the average for all property damage. This categorizes the types of collisions and deer collisions that are probably less severe, implied by the 29% reporting rate.

7) For the injury cost the 2002 statewide Nevada data for ‘stuck animal’ collision cost was reduced since 35% of animal collisions were animals larger than deer. The rural cost of $144,400 was reduced by 50% to $72,200.
8) For the average deer carcass removal and disposal, there was no apparent cost involved.
9) The 2002 statewide Nevada data of $2,432,000 was used for fatal collisions.
10) The Upper Midwest data was used as the portion of fatal collisions. Nevada data had one fatal in five years giving a probability of 0.001, which was about 5 times higher than the published data. The Nevada sample was too small to be statistically reliable.
11) For towing, incident attendance and investigation, not all deer-vehicle collisions require the towing of a vehicle and attendance or investigation by medical personnel, fire department or police. The cost for the actual medical assistance is included in the cost estimates for human injuries. These assumptions result in an average cost for towing, incident attendance, and investigation of $125 for deer.

Table 3. Benefit-cost analysis of overpass crossing structure at 10-Mile summit completed in August 2010. Included are probability factors applied to each category of crash severities to account for the probability of each occurrence as well as calculations of Net Project Worth (NPW) and the ratio of benefits to costs (B/C ratio) (Attah 2012).

Variables	Value	Data
Probability of Damage (PD)	0.9591	
Probability of Injury (PI)	0.0407	Nevada
Probability of Fatality (PF)	0.00021	
Collision Data	10.3 / yr	10 years for 4.1 mile segment on Hwy 93, annual amount increased by 3.5 because of 29% reporting rate.
Interest rate (i)	4%	Approximate average over past 40 yrs
Life of Project (n)	40 years	
PWF (Present worth factor)	I=40%, 40 yrs	
Damage Cost (DC)	$ 7,625.20	2011 rates
Injury Cost (IC)	$ 91,091.70	2011 rates
Fatalist Cost (FC)	$ 3,068,359.10	2011 rates
Construction Cost (CC)	$2,460,755.00	From table 4-1.
N – number of collision reduced (90% reduction factor)		
PWF $=(1-\frac{1}{(1+i)^n})/\{\ln(1+i)\}$ $=(1-\frac{1}{(1+0.04)^{40}})/\{\ln(1+0.04)\}$ = 20.19		
NPW = {(DC) (PD) + (IC) (PI) + (FC) (PF)} (N) (PWF) – {CC + (MC) (PWF)}, =		
NPW = {7313.29+ 3707.43 + 613.67} (38.00) (20.19) – {2,326,235+ $2,715,958.80} = **$3,885,587**		
B/C ratio = 3,885,587/2,460,755.00 = **1.58**		

CHAPTER 3: Results and Discussion

Results

We accrued > 1,000,000 photos between 8 migrations and 16 cameras located at the crossing structures and ends of the exclusionary fencing. Approximately 30% of the photos contained no wildlife, and 20% contained various species of animals. Fifty percent of the photos we collected contained mule deer (Figure 3). Other mammal species that we observed in photos using the structure included: American badger (*Taxidea taxus*), American pronghorn (*Antilocapra americana*), bobcat (*Lynx rufus*), coyote (*Canis latrans*), North American elk (*Cervus elaphus)*, blacktailed jackrabbit (*Lepus californicus)*, desert cottontail (*Sylvilagus audubonii)*, red fox (*Vulpes vulpes*), domestic cattle (*Bos taurus*), domestic horses (*Equus caballas*), dogs (*Canis sp*.), and cats (*Felis sp*.). Avian species observed in photos included Great Horned Owl (*Bubo virginianus*), Common Raven (*Corvus corax*), Black-billed Magpie (*Pica hudsonia*), Mourning Dove (*Zenaida macroura*), and various species of small passerines.

Figure 3. Mule deer on overpass at 10-mile Summit during autumn migration 2010. Note remote camera mounted on t-post in foreground. (Simpson 2012).

We documented 35,369 mule deer that successfully crossed over or through 1 of the 5 crossing structures during 8 migratory periods (Table 4). During migratory periods, a total of

Table 4. Total number of successful crossings during migratory periods by mule deer on Highway 93 between Wells and Contact, Nevada, 2010-2014. Each crossing structure has a unique identifier (Structure #) consistent with Figure 2. Total number of deer that crossed the structures 35,369 (Simpson 2012).

		10 Mile Summit			HD Summit	
Year	Season	Underpass (1)	Overpass (2)	Underpass (3)	Underpass (4)	Overpass (5)
2010	Autumn	148	2,853	330	179	-
2011	Spring	215	2,716	476	38	-
2011	Autumn	116	3,043	253	418	477
2012	Spring	78	3,242	403	320	234
2012	Autumn	116	4,007	287	629	625
2013	Spring	207	3,442	348	185	318
2013	Autumn	96	3,769	215	425	682
2014	Spring	76	3,467	356	185	395
Total Crossings		1,052	26,539	2,668	2,379	2,731

30,259 mule deer used a crossing structure at 10 Mile Summit and 5,110 mule deer used the crossing structures at HD Summit (Table 4). During autumn 2011 through spring 2014 migrations when both sites were available for use, 85.6% of the mule deer population that used a structure crossed at 10 Mile Summit and 14.4% crossed at HD Summit (Table 4). Throughout the duration of the study the percentage of approaches that resulted in successful crossings was highest at the overpasses compared with the underpasses (Figure 4). We observed a high percentage (> 94%) of successful crossings at the overpasses the first migration they were open for use, and their success rate remained high (>94%) throughout the duration of the study (Figure 4). The percentage of successful crossings at the underpasses was low the first year they were available and increased with each subsequent migration or maintained the same level as the pervious migration, with the exception of the underpasses at 10 Mile Summit where we detected a decrease in the percentage of successful crossings during the fourth migration (Figure 4).

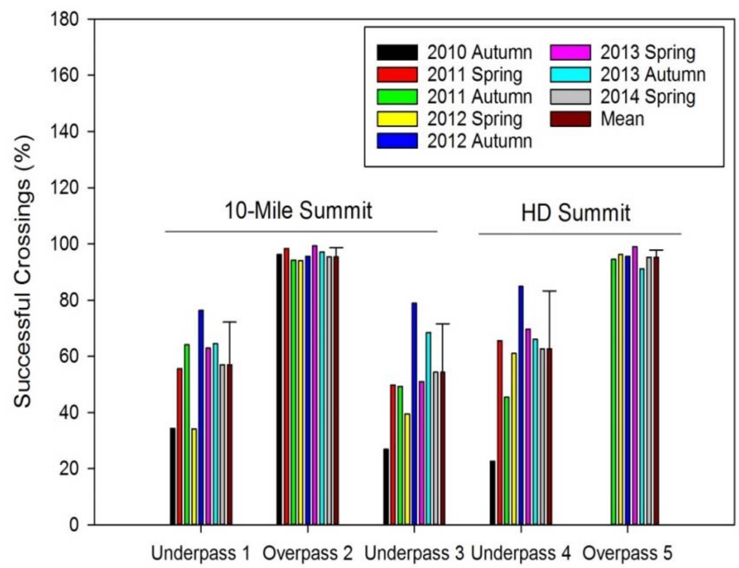

Figure 4. Percentage of successful crossings during migratory periods by mule deer on Highway 93 between Wells and Contact, Nevada, 2010-2014. Each crossing structure has a unique identifier (Structure #) consistent with Fig 2. Final bar in each group is mean ± SD of deer that used that structure during migrations (Simpson 2012).

Overall the majority of mule deer crossed the overpass at 10-Mile, which differed from all of the other structures and locations (Figure 5). Although season entered our models and a trend indicated more mule deer used the structures during autumn than spring (*Wald Chi Square* = 298.37, $P < 0.0598$); those confidence intervals included 0. We observed an interaction between study site and structure (*Wald Chi Square* = 907.92, $P < 0.0001$), because we observed greater number of crossings at the overpass at 10 Mile Summit but no differences between the structures at HD Summit (Figure 5).

Our top model for the proportion of successful crossings by mule deer only included year and structure type. We observed a higher percentage of successful crossings by mule deer at the overpasses when compared with the underpasses (*Wald Chi Square* = 72.25, $P < 0.0001$; Figure 6). At HD Summit, when both types of structures were available to mule deer, approximately 44.2% of the successful crossings occurred at the overpass and 55.8% occurred at the underpass (Figure 6).

We documented 820 mule deer that moved around the exclusionary fencing and onto U.S. Highway 93 rather than using the crossing structures during migrations at 10 Mile Summit. We recorded 14 mortalities within 2.4 km of the north and south ends of the fencing, 5 mortalities outside of the exclusionary fencing, and 9 mortalities within the exclusionary fencing. The majority of mortalities were within 1.0 km of the fence ends (n = 10), 2 within 2.0 km, and 2 were located more than 2.5 km away from the fence ends but remained within the study area. We observed a 50% decrease in the number of mortalities of mule deer with each subsequent migration, although the total number of mule deer using the structures increased with each subsequent migration (Figure 7). Additionally, we observed 50% more mortalities than those reported in NDOT's Animal-Hit Database during the first 3 migrations that the crossings were available for use (Figure 7). We did not detect any mortalities during the fourth migration, but Nevada Highway Patrol reported a single mortality near the southern fence end.

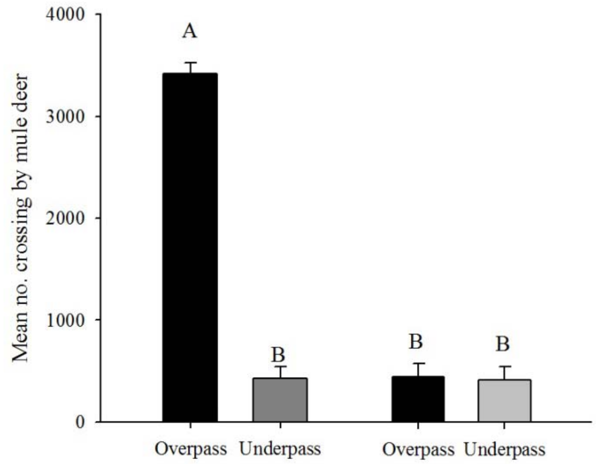

Figure 5. Least squared mean ± SE number of mule deer that crossed each structure. We observed an interaction between study site and structure (*Wald Chi Square=907.92*, $P < 0.0001$) at 10-Mile and HD Summits, Nevada, 2011-2014. Similar letters indicate means that were not significantly different.(Simpson 2012)

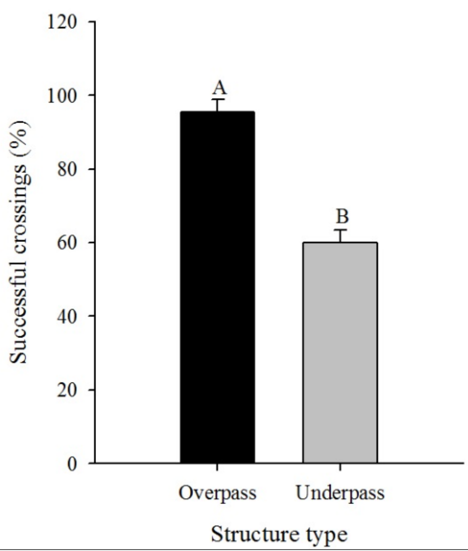

Figure 6. Least squared mean ± SE percent of approaches by mule deer that successfully crossed overpasses versus underpasses (*Wald Chi Square= 72.25*, $P < 0.0001$) at 10-Mile and HD Summits on Highway 93 between Wells and Contact, Nevada, 2011-2014. (Simpson 2012)

Cost-benefit analysis indicated a net present worth of $ 3,885,587 million for the overpass with a benefit to cost ratio of 1.58 (Table 3). The benefits and costs estimated over the analysis period were discounted to calculate the net present value of benefits and costs. The wildlife overpass has a Net Present Worth of approximately $3,972,269 million and a Benefit-Cost Ratio of 1.58. These results indicate the benefit of the project is substantially greater than the costs of the structure to build and maintain. Benefit-cost ratios greater than one identify projects worth the investment. A benefit to cost ratio of 1.58 indicates that having wildlife crossing structures at locations of high wildlife vehicle collisions is economically justified.

Moreover, costs that were difficult to quantify and thereby were excluded may still be substantial and likely would increase the benefits of the project by reducing not only injuries and possible fatalities associated with deer vehicle collisions but also the resulting emotional distress to persons involved in those collisions.

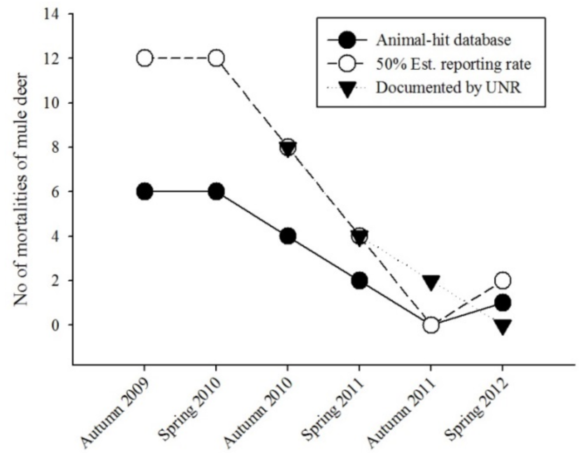

Figure 7. Documented and estimated mortalities of mule deer caused by vehicle collisions within the boundaries of the 10 Mile study site on U.S. Highway 93 between Wells and Contact, Nevada, 2010-2012. We documented 50% more mortalities than the numbers reported in the Animal-Hit Database maintained by NDOT during the first three migrations the crossings were available for use by mule deer and other wildlife. (Simpson 2012)

Discussion

Consistent with our hypothesis, we observed a greater number of mule deer that used overpasses to cross the highway when compared with the underpasses, although the difference was significant only at 10-Mile Summit. During the 8 migrations that we documented use of crossing structures, the total number of mule deer that approached and successfully crossed the overpass at 10 Mile Summit remained near 95% (Figure 3). The percentage of successful crossings was greater at both overpasses compared with all of the underpasses. Thus, most of the mule deer that approached an overpass continued over the structure, versus the greater number of individuals that hesitated and retreated from the underpasses.

Surprisingly, there was no significant difference in the number of mule deer that crossed the overpass and underpass at HD Summit. The underpass at HD Summit was available to mule deer 1 migration prior to completion of the overpass and the topography near the crossing structures varied between study sites. The overpass at 10 Mile Summit is located along a flat stretch of highway and is at a lower elevation than the surrounding hills on both sides of the entrances, which allowed mule deer approaching the overpass to view the structure and the land on the opposite side of the highway, creating a relatively flat bridge above the roadway. Moreover the overpass at 10-Mile Summit is wider (49m) and shorter (10m long) compared with the overpass at HD Summit, which is 30m wide and 46 m long. The differences in size of the structures may also have affected the numbers of animals that crossed the structure. The overpass at HD Summit is located at the peak of a summit, which was higher in elevation than the surrounding hills. Because of the location, the overpass at HD Summit has a steep grade which does not allow for full view of the structure or of the land on the opposite side of the highway until an animal reaches the middle of the structure. In addition, there is a natural spring located near the entrance of the underpass at HD Summit, which may attract deer to this structure within the study site at HD Summit and may somewhat confound our results at that site. Nevertheless, we observed substantially higher percentage of successful crossings at both overpasses, such that deer that approached the overpasses almost always crossed the structure successfully.

Consistent with our prediction, we documented a higher proportion of successful crossings at the overpasses (e.g. few to no retractions), and a much lower proportion of successful crossings at all of the underpasses immediately following their availability. We observed that the percentage of successful crossings at the underpasses increased with each subsequent migration to about 60% success, although they remained significantly lower than that of the overpasses with a much higher success rate, about 95%. Ungulates have been reported to habituate to use of underpasses, which has been described to occur after about 3 years (Forman et al. 2003, Clevenger et al. 2001,Clevenger and Waltho 2005,Clevenger 2005,McCollister and Van Manen 2010). Nonetheless, our data indicated that although some habituation occurred after 3 years of use, the proportion of successful crossings at the underpasses remained substantially lower than that of the overpasses. The proportion of successful crossings at the overpasses remained high from first encounter and over the entire duration of our study. Thus, overpasses were more effective crossing structures for mule deer and likely other large-bodied ungulates, than underpasses, and relatively few retractions at those structures strongly indicated preference for that type of structure by these ungulates.

We observed a decrease in the number of mortalities of mule deer caused by collisions with vehicles within the boundaries of our study site at 10 Mile Summit. We documented a 50% decrease in mortalities with each subsequent migration that the safety crossings were available for use, even though the total number of deer using the structures continued to increase throughout the study. Although we did not have intensive monitoring of the study site prior to construction of the safety crossings and exclusionary fencing, we detected 50% more mortalities than what were reported in the Animal-Hit Database maintained by NDOT. All of the reported mortalities in the database within the study boundary occurred in the same vicinity of our marked locations, and we detected 50% more than the state reports. Collisions between vehicles and wildlife often are not reported (Sawyer et al. 2012), but we are confident, that we detected the majority of the mortalities caused by collisions with vehicles in our study area. With this decrease in the number of mortalities from vehicle collisions with subsequent migrations, the cost of the construction should be recuperated with time, because of the decrease in infrastructure damage, and importantly decrease in human injuries or potential fatalities (McCollister and Van Manen 2010).

Our results are similar to other areas that have documented a concentration of vehicle collisions with wildlife near the ends of fencing and higher rates of mortalities within exclusionary fencing (McCollister and Van Manen 2010). The higher number of mortalities located inside the exclusionary fencing likely indicated that some of the mule deer that went around the ends of the fences, moved inside the fencing, and became trapped on the highway.

Those individuals either did not detect the ‘jump outs’ or did not identify them as an escape route. Nevertheless, following the addition of more fencing and painted cattle guards, no further mortalities occurred within the exclusionary fencing.

CHAPTER 4 Conclusions

Crossing structures for wildlife may be defined as successful when there is a reduction in collision rates between vehicles and wildlife, and restoration of animal movement corridors (Ford et al. 2009,Van Wieren and Worm 2001,Fortin and Agrawal 2005). Mule deer used crossing structures extensively during migrations; and the numbers of vehicle related mortalities decreased, independent of population size. Those crossing structures effectively enhanced connectivity of migratory corridors that were bisected by roads and allowed substantial numbers of individual animals to safely cross the highway. Nevertheless, crossing structures without associated exclusionary fencing tend to be much less successful (McCollister and Van Manen 2010). We observed greater numbers of animals crossing the overpass at 10-Mile summit, where most of the migratory deer cross Hwy 93, however we also observed few retractions at overpasses compared with underpasses. In addition, crossing structures in our study were located in several locations because of multiple sites where migratory deer crossed those highways; and in a large stretch of highway, provision for multiple crossing structures rather than a single structure is certainly desirable (Sawyer et al. 2012).

Although the overpasses had a higher proportion of successful crossings, underpasses are still an important tool in restoring connectivity and reducing wildlife vehicle collisions, especially when the cost or construction of an overpass is not feasible (Clevenger et al. 2001, Sawyer et al. 2012). Although the cost of an overpass can be 2-3 times the cost of an underpass depending on location, materials, and construction methods (NDOT 2006) our benefit-cost ratio indicates the overpass is economically justified. Nevertheless, reduction in wildlife mortalities, vehicle damage, and reduction or elimination of human injuries or possible fatalities make the cost of crossing structures and increased cost of overpasses worthwhile. All of the crossing structures were very effective at reducing collisions between ungulates and vehicles, preserving migratory corridors, enhancing connectivity among populations, reducing fragmentation of habitats throughout human altered landscapes, and making roadways safer for both wildlife and motorists.

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ABBREVIATIONS, ACRONYMS, INITIALISMS, AND SYMBOLS

Acronym	Meaning
AICc	Akaike Information Criterion adjusted for small sample sizes
BCA	Benefit cost analysis
B/C ratio	ratio of benefits to costs
CC	construction cost
DC	Damage cost
DVC	Deer vehicle collision
FC	Fatality cost
GPS	Global positioning system
Hwy	Highway
IC	Injury cost
MC	maintenance cost
NDOT	Nevada Department of Transportation
NDOW	Nevada Department of Wildlife
NPW	Net present worth
PD	Probability of damage
PF	Probability of fatality
PI	Probability of injury
Proc	procedure
PWF	Present worth factor
US	United States
USDOT	United States Department of Transportation

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