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Evaluation of Desert Bighorn Sheep Overpass Effectiveness: U.S. Route 93 Long-Term Monitoring

Arizona Department of Transportation Research Center

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16. Abstract

During the planning stage of upgrading U.S. Route (U.S.) 93 from a two-lane highway to a four-lane divided highway, there were concerns for the local desert bighorn sheep (DBS) population. Vehicle collisions with DBS were estimated at 11 per year prior to reconstruction and would likely increase after reconstruction. To overcome collision concerns, the Arizona Department of Transportation (ADOT) integrated three overpass (OP) structures—two 50 feet wide and one 100 feet wide. They are Arizona's first wildlife OPs and North America's first OPs for DBS. These OPs, along with three culverts and the dry washes under two bridges, were linked with fencing to limit DBS access to U.S. 93 and guide DBS to the safe crossings. From March 2011 through March 2015, researchers evaluated the success of these mitigation measures with video and still cameras, Global Positioning System collars on DBS, and DBS-vehicle collision monitoring. DBS used the OPs (5862 crossings) more than the dry washes under the bridges (474 crossings) and more than the culverts (195 crossings). Passage rate (crossings/approaches) at the OPs increased by 210 percent from years one to four of the study. Collared DBS crossings and passage rates increased by 100 percent and 1367 percent, respectively, from years one to four. DBS shifted their distribution of crossings more evenly across the study area and crossings became focused at crossing structures. Vehicular collisions with DBS were reduced by 68 percent in the first two years of monitoring until ADOT maintenance personnel addressed DBS breach points, after which only one vehicle-killed DBS was documented during 2011-2015, accounting for an 86 percent reduction overall and a 97 percent reduction in the years following repair of the fence breaches. These findings indicate that appropriately located 50-foot-wide overpasses connected with 7- to 8-foot ungulate-proof fencing, along with animal escape ramps, can reduce DBS-vehicle collisions and promote habitat connectivity. Post-construction monitoring can document effectiveness of mitigation measures and quickly identify areas of DBS access for modification or maintenance, to ensure long-term success of the measures.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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LIST OF ACRONYMS AND ABBREVIATIONS

AADT	average annual daily traffic
ADOT	Arizona Department of Transportation
AGFD	Arizona Game and Fish Department
BLM	Bureau of Land Management
BOR	Bureau of Reclamation
DBS	desert bighorn sheep
DW	Devils Wash
EIS	Environmental Impact Statement
FHWA	Federal Highway Administration
GIS	geographic information system
GPS	Global Positioning System
ln	natural logarithm
MP	milepost
NPS	National Park Service
OP	wildlife overpass
ROW	right-of-way
SDI	Shannon Diversity Indices
SE	standard error
SR	State Route
TI	traffic interchange
UP	wildlife underpass
U.S. 93	U.S. Route 93
WCS	wildlife crossing structure
WRC	White Rock Canyon
WVC	wildlife-vehicle collision

LIST OF SPECIES

Animals	**Scientific Name**
American pronghorn	*Antilocapra americana*
bobcat	*Lynx rufus*
burro (feral)	*Equus asinus*
coyote	*Canis latrans*
desert bighorn sheep	*Ovis Canadensis nelsoni*
elk	*Cervus canadensis*
gray fox	*Urocyon cineroargenteus*
kit fox	*Vulpes macrotis*
mule deer	*Odocoileus hemionus*
white-tailed deer	*Odocoileus virginianus*

Plants	
bursage	*Ambrosia dumosa*
catclaw acacia	*Acacia greggii*
cheesebush	*Hymenoclea salsola*
creosote bush	*Larrea tridentata*
galleta grass	*Hilaria rigida*
honey mesquite	*Prospois grandulosa*
Mormon tea	*Ephedra nevadensis*
range ratany	*Krameria parvifolia*

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EXECUTIVE SUMMARY

During the planning stage of upgrading U.S. Route (U.S.) 93 from a two-lane highway to a four-lane divided highway, there were concerns regarding the local desert bighorn sheep (DBS) population. Vehicle collisions with DBS were estimated at 11 per year prior to reconstruction and would likely increase after reconstruction. To overcome safety and habitat fragmentation concerns, the Arizona Department of Transportation (ADOT) integrated mitigation measures to limit DBS access to U.S. 93 and to guide DBS to the safe crossings. From March 2011 through March 2015, this study monitored the DBS population to evaluate the success of these mitigation measures on U.S. 93 from mileposts (MP) 2 to 17.

The research team assessed the effectiveness of ADOT's mitigation measures. These measures included three wildlife overpasses (OP) with exclusionary fencing (7- to 8-foot high exclusion fence) to guide DBS to the OPs and to additional drainage structures (three culverts and the dry washes under two bridges). The project included escape ramps to provide exits for DBS in the right-of-way (ROW), and double-wide cattle guards to minimize sheep ROW access at lateral roads and at on- and off-ramps.

The research team's analyses for portions of this study (2011 through 2015) also considered information collected during the previously completed construction (2010) of the Hoover Dam Bypass roadway section (MP 0-2) and information for the MP 2-17 segment before reconstruction (2004 to 2009) and during reconstruction (2009 to 2010).

This research project had three specific U.S. 93 reconstruction analysis objectives:

1. Assess DBS movement and roadway permeability (passage rates)
2. Assess DBS use and adaptation to mitigation measures
3. Assess DBS-vehicle collision patterns

DESERT BIGHORN SHEEP MOVEMENTS AND ROADWAY PERMEABILITY

The research team captured 70 DBS during four capture events and fitted each sheep with satellite-uplink Global Positioning System (GPS) collars that received relocations every two hours, whether they involved highway crossings or not. The team recovered adequate data from 53 sheep collars (25 rams and 28 ewes) that provided a combined 167,300 relocations—an average of 3157 relocations per animal. The data documented a 100 percent increase (888 crossings) in daily DBS crossings; crossing patterns also shifted from a concentration in the MP 0-2 highway segment (where older construction was completed) to a more even distribution throughout the study area, with concentrations at the OPs and the dry washes under the two bridges. Roadway permeability (susceptibility to crossings, as measured by actual DBS activity) increased 1367 percent from post-construction year 1 to year 4, was not affected by traffic volume, and was consistently higher on a monthly, daily, and hourly basis.

DESERT BIGHORN SHEEP USE AND ADAPTATION TO MITIGATION MEASURES

From March 15, 2011, to March 15, 2015, the research team logged 11,680 days of video surveillance and still camera monitoring at eight structures. The camera systems recorded 15,134 crossings by nine species. DBS accounted for 94 percent of all animals documented at the structures, while coyote and fox accounted for a combined 4 percent. When evaluating DBS use, 5894 (89.8 percent of the DBS) of DBS crossings occurred at the OPs, while 474 (7.2 percent) and 195 (3 percent) crossings occurred at the dry washes under the bridges and at the culverts, respectively. OP passage rates (the percentage of sheep that crossed the OP after approaching the structure) significantly increased from 28 percent in year 1 to 90 percent in year 4. Eventually, DBS adapted equally to the one 100-foot–wide OP and two 50-foot–wide OPs. Most DBS (90 percent) that approached the OPs then actually completed crossings of U.S. 93.

DBS use of the dry washes under the White Rock Canyon (WRC) and Devils Wash (DW) bridges was limited. The research team documented 474 DBS under-bridge crossings (84 at WRC and 390 at DW); while WRC use was consistently low (20 DBS under-bridge crossings per year), DW use increased (35 DBS under-bridge crossings in year 1; 153 in year 4.) Culverts similarly had limited use. The team documented 195 culvert crossings, 193 of which occurred at two of the three culverts.

Of the 150 sheep that used the escape ramps, 90 percent used them to exit the ROW and 10 percent to access the ROW. At the Kingman Wash Traffic Interchange (TI) single-wide cattle guards, the team documented 840 DBS approaches from the non-ROW side. Of these sheep, 124 (15 percent) crossed the guards to enter the ROW. From the ROW side, 54 sheep approached the guards and 44 (81 percent) used them to exit the ROW.

DESERT BIGHORN SHEEP-VEHICLE COLLISION PATTERNS

After reconstruction of U.S. 93 in 2011, reported DBS-vehicle collisions declined from the pre-construction (2001) figure by approximately 85 percent (the road was closed on September 11, 2001, until November 2010). All collisions (with two rams and six ewes) occurred between MP 0 and MP 4; seven happened in 2011 to 2012. From 2013 through 2015, one DBS-vehicle collision was documented, which amounts to a 97 percent reduction from the baseline of 11 collisions per year (Cunningham and Hanna 1992). The reduction from seven collisions (2011-2012) to one collision (2013-2015) can be attributed to addressing exclusion fence breach points by the Arizona Game and Fish Department (AGFD) and ADOT during the study's first two years.

CONCLUSIONS AND RECOMMENDATIONS

ADOT integrated three OP structures—two 50 feet wide and one 100 feet wide. They are Arizona's first wildlife OPs and North America's first DBS OPs. The data already given indicate that, after U.S. 93 reconstruction mitigation measures were added, the DBS population continued to access essential resources like water, while DBS-vehicle collisions fell. To cross U.S. 93, DBS used OP structures much more than dry washes under bridges or culverts; the OP width (100 feet or 50 feet) made little difference. Structures were linked with fencing to limit DBS access to U.S. 93 and to guide them to the structures. ADOT included cattle guards to reduce DBS access to the ROW while facilitating egress via escape ramps.

This monitoring study demonstrates possibilities for reducing DBS-vehicle collisions without jeopardizing habitat connectivity. To put to use the information gained, some key recommendations for future action include:

- For roadway construction in DBS habitat, adding 50-foot–wide OP structures and 7- or 8-foot–high woven-wire exclusion fencing with escape ramps and double-wide cattle guards.
- Using GPS telemetry data and analysis as the primary data-driven approach to determine placement of wildlife mitigation measures (crossing structures and fencing).
- Building escape ramps using 6-foot–high retaining walls to effectively retain soil, with a crossbar 16 inches above the ramp's edge. This retaining wall will reduce long-term maintenance and the crossbar allows DBS to exit the ROW while precluding access to the ROW.
- As a safety measure, continuing to monitor DBS-vehicle collisions on U.S. 93 between MP 0 and MP 17 as a means of detecting nearby fence breach points, which could be addressed quickly.
- Repairing escape ramps by adding metal mesh to their leading edge to prevent erosion of cinders, and designing future escape ramp projects to address soil retention.
- When roadway projects include wildlife mitigation measures, monitoring the performance after construction to evaluate the efficacy of the measures. This monitoring can also provide the timely data needed to make appropriate modifications and maximize mitigation success.

CHAPTER 1: INTRODUCTION

BACKGROUND

Wildlife-vehicle collisions (WVC) are a serious and growing threat to wildlife populations and contribute to human injuries, deaths, and property loss (Conover et al. 1995, Groot Bruinderink and Hazebroek 1996, Schwabe and Schuhmann 2002). An estimated 26,000 injuries and 200 human deaths attributable to WVC occur in the United States every year, and the economic impacts of these collisions exceed $8 billion per year (Huijser et al. 2007).

However, the most pervasive roadway impacts to wildlife species are the barrier and fragmentation effects that results in diminished permeability and reduced habitat connectivity (Noss and Cooperrider 1994, Forman et al. 2003). Roadways constitute wildlife movement barriers that fragment populations and habitats and limit juvenile (lamb) dispersal (Beier 1995, Proctor et al. 2012). The population fragmentation effects have resulted in documented limitations to genetic interchange and isolated wildlife subpopulations (Ng et al. 2004, Epps et al. 2005, Riley et al. 2006). These effects vary by wildlife species, roadway type, design standard, and traffic volume (Seiler 2003, Jaeger et al. 2005a).

To minimize or negate these barrier effects, wildlife crossing structures (WCS), combined with properly constructed and maintained wildlife exclusion fencing, have permitted safe wildlife passage for a variety of wildlife species (Groot Bruinderink and Hazebroek 1996, Clevenger and Waltho 2000;2005, Dodd et al. 2007a, Gagnon et al. 2011, Bissonette and Rosa 2012, Dodd et al. 2012a, Sawyer et al. 2012, Gagnon et al. 2015, Sawyer et al. 2016). In so doing, WCS enable wildlife populations to remain connected, maintain resource access, and safely cross under or over roadways, thus reducing the number of WVC. In addition, as roadway traffic volumes increase, wildlife's use of WCS does not diminish as it does for at-grade crossings (Gagnon et al. 2007a, Gagnon et al. 2007b, Dodd and Gagnon 2011).

During the past decade, the success of WCS has led to the incorporation of such structures into the design and construction phases of transportation. Designers have learned from earlier WCS studies that wildlife species appear to react differently to structure design. For example, American pronghorn (*Antilocapra americana*) require an overpass (OP) structure to cross over roadways (Sawyer et al. 2016), while deer (*Odocoileus spp*.) and elk (*Cervus canadensis*) will cross under roadways via underpasses (UP) (Dodd et al. 2007d, Dodd and Gagnon 2011, Gagnon et al. 2011, Bissonette and Rosa 2012, Sawyer et al. 2012). Deer and elk appear to have use tolerance thresholds related to UP structure size (Gagnon et al. 2011, Cramer 2013, Clevenger and Barrueto 2014). In addition to structure design characteristics, the proper location and placement of WCS influence wildlife use (Bissonette and Adair 2008, Gagnon et al. 2011). To effectively locate WCS and fencing, designers rely on species-specific movement, along with roadway crossing and WVC research, to appropriately place passage structures and exclusionary fencing that will simultaneously promote highway safety and permeability to wildlife (Dodd et al. 2007b, McKinney and Smith 2007, Gunson et al. 2009, Dodd et al. 2011, Dodd et al. 2012a, Dodd et al. 2012b, Gagnon et al. 2013, Sawyer et al. 2016). To further this pursuit, long-term monitoring—particularly for species like desert bighorn sheep or DBS (*Ovis canadensis nelsoni*) where information is lacking—is essential to determine current structure effectiveness and inform future WCS design, placement, and implementation (Gagnon et al. 2011).

DESERT BIGHORN SHEEP AND ROADWAYS

DBS (Figure 1) are adapted to the arid, mountainous desert habitats that occur throughout much of northern Mexico and the southwestern United States. Sheep are distributed in naturally fragmented populations occupying isolated mountain ranges separated by relatively flat, unsuitable habitats (Krausman and Leopold 1986, Bleich et al. 1990, Bleich et al. 1996, Andrew et al. 1999, Epps et al. 2007). In the 19th century, approximately 1,000,000 DBS were estimated to inhabit the western United States, with 35,000 in Arizona (Buechner 1960). However, following European settlement, the western United States sheep populations declined precipitously due to overhunting and the introduction of domestic livestock, which exposed DBS to exotic diseases and competition for limited desert forage (Russo 1956). Today, throughout the Southwest, including Arizona where DBS management practices have increased populations (Cunningham et al. 1993), most DBS populations remain small (less than 100) and isolated (Krausman and Leopold 1986). Reduced viability of individuals with restricted gene flow is expected to occur for a local population size of less than 100 individuals (Couvet 2002). The persistence of these remaining populations is a controversial topic (Berger 1990, Krausman et al. 1993, Krausman et al. 1996, Berger 1999, Wehausen 1999), because no specific population size ensures that a given population will survive (Thomas 1990). To ensure long-term persistence, small DBS populations that occupy marginal or comparatively poor habitat, or small suitable habitat patches, may require management intervention (Berger 1990, Gross et al. 1997, McKinney et al. 2003). Researchers agree that habitat patch size may be the primary correlate between DBS population numbers and persistence (Gross et al. 1997, Singer et al. 2001, McKinney et al. 2003); populations with fewer than 50 individuals tend to go extinct for reasons not related to food shortages, weather, predation, or interspecific competition (Berger 1990). Researchers also recognize that other factors such as preventing habitat fragmentation and loss and restoring habitat connectivity may influence DBS population extinction and colonization (Fahrig 1997, Fleishman et al. 2002).

A related factor is the retention of traditional DBS movement corridors that maintain connectivity between areas that exhibit adequately steep and broken escape terrain (Cunningham and Hanna 1992, McKinney et al. 2003, Epps et al. 2007). Corridors can help offset the deleterious effects of restricted gene flow caused by fragmentation (Couvet 2002). These corridors are especially important for males that are more likely than females to make long-distance movements between mountain ranges (Epps et al. 2007). The loss or obstruction of such traditional corridors and the fragmentation of habitats can have important implications for the long-term persistence and genetic viability of DBS populations (Epps et al. 2005, Epps et al. 2007). Epps et al. (2005) found that roadways reduced the genetic diversity of 27 DBS populations and that this genetic diversity reduction was tied to years of isolation attributable to roadways. He further suggested that continued isolation would pose a severe threat to the persistence of naturally fragmented DBS populations (Epps et al. 2005).

Figure 1. Desert Bighorn Ram

Ongoing challenges are presented by anthropogenic DBS habitat fragmentation and population isolation tied to human growth and development (Leslie and Douglas 1979). The rapid human population growth in the Southwest, exemplified by Arizona, has increased the number and size of barrier threats from new and improved roadways, canals, fences, widespread housing developments, and off-highway vehicles (Gionfriddo and Krausman 1986, Epps et al. 2007). To lessen the effects of these threats, traditional management techniques such as habitat protection and improvement and dispersal corridor maintenance, are important for fostering DBS population conservation (Schwartz et al. 1986). Dispersal corridor preservation or maintenance and new corridor creation may not preserve connectivity if corridor location is not determined scientifically, however (Beier and Loe 1992). Support for this suggestion has been found in North America, where a number of scientifically determined wildlife passage structures have been effective, but limited information exists on the usefulness of structures specifically designed and placed to promote DBS connectivity. A purpose of this study along U.S. Route (U.S.) 93 was to gain additional information on this topic.

Some information has been provided by Bristow and Crabb (2008), who evaluated the efficacy of three DBS UPs incorporated into the reconstruction of a 14-mile section of State Route (SR) 68 at the southern end of the Black Mountains in northeastern Arizona. They used global positioning system (GPS) telemetry and UP camera monitoring data to determine DBS use of the three structures (Bristow and Crabb 2008). They found that 12 percent of the GPS-collared sheep (rams) used the UPs and recorded 25 instances where the rams crossed under SR 68 in a 20-month span (Bristow and Crabb 2008). They stressed that DBS passage structures must be placed along existing travel corridors and exclusion fencing should guide animals to these structures (Bristow and Crabb 2008). Their findings and recommendations led the U.S. 93 reconstruction team to place three OP structures at locations defined by telemetered DBS movements identified by McKinney and Smith (2007).

U.S. 93 AND DESERT BIGHORN SHEEP

As the primary surface transportation route between Phoenix, Arizona, and Las Vegas, Nevada, U.S. 93 was congressionally designated as part of the CANAMEX (Canada to Mexico) Trade Corridor. In 2015, the CANAMEX was redesignated as Interstate 11 (I-11) in accordance with Fixing America's Surface Transportation Act.

In the 1960s, the U.S. 93 Hoover Dam Bypass planning efforts began. These efforts included constructing a bridge over the Colorado River at milepost (MP) 0 and widening the existing two-lane, undivided roadway to a four-lane divided roadway from MP 0 to 17. This long-term planning culminated with the Bureau of Reclamation's (BOR) 1990 formal initiation of an Environmental Impact Statement (EIS) and public scoping. During this period, the Arizona Game and Fish Department (AGFD) and other entities (see Acknowledgements) expressed concerns centering on the reconstructed roadways' likely impact on traditional DBS travel corridors and long-term population viability, as well as habitat fragmentation and probable DBS-vehicle collision increases.

The Black Mountain population is one of 32 identified Arizona DBS populations and a subunit of the state's largest. In the past, this population has been estimated at 2000 sheep and to account for nearly 30 percent of the state's total. The same population also functions as a "source" herd for sheep reintroductions into historic habitat throughout northern Arizona and Utah. The herds' ability to serve as a source is vulnerable to unpredictable events like disease and drought—a 2001 to 2004 drought resulted in a 54 percent population reduction for this herd (McKinney and Smith 2007)—and habitat fragmentation. The U.S. 93 Hoover Dam Bypass project further divided the herds' historic habitat (Figure 2), which had already been partitioned by Lake Mead, the Colorado River, State Route (SR) 68, Interstate 40 (I-40), and U.S. 93. AGFD's expressed concerns resulted in the establishment of DBS (Figure 3) as a focal species during U.S. 93 reconstruction planning and construction efforts.

The U.S. 93 reconstruction EIS evaluated the impacts of roadway alignments and proposed three routing alternatives, all of which crossed DBS habitat. Simultaneously, Cunningham and Hanna (1992) conducted a two-year DBS movement and habitat use assessment adjacent to the three proposed alignments. The researchers outfitted 49 sheep with very high frequency telemetry collars and determined sheep movement corridors, habitat use, and roadway behavioral responses. They documented approximately 600 DBS roadway crossings, with the majority occurring between MP 2.1 and 3.0 (Cunningham and Hanna 1992). Their findings, which were considered during the EIS process, supported the Sugarloaf Mountain alternative. In 2001, the final EIS and Record of Decision selected this alternative for the bypass alignment and bridge crossing of the Colorado River. Arizona's portion of the U.S. 93 Hoover Dam Bypass (MP 0 to 2.2) construction extended from 2003 to 2010 (FHWA 2001).

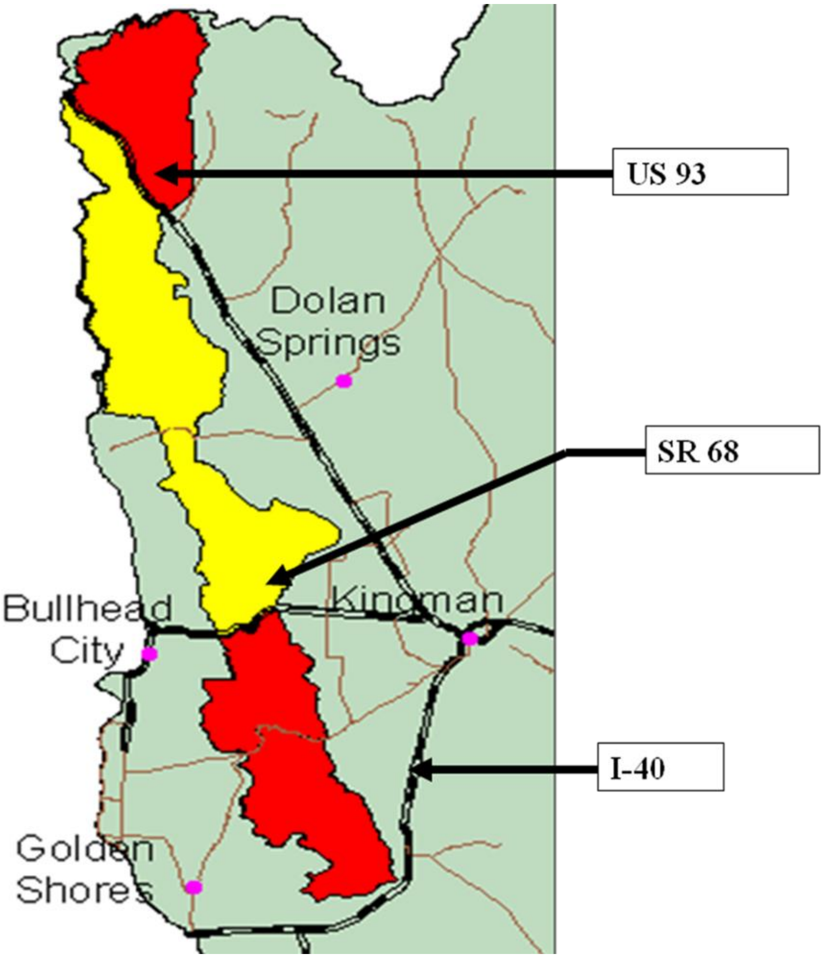

Figure 2. U.S. 93, SR 68, and I-40 Are Barriers to Desert Bighorn Sheep that Divide the Black Mountain Herd into Three Subpopulations (red and yellow shaded areas on the map)

Figure 3. Desert Bighorn Rams Crossing Two-Lane U.S. 93 before Reconstruction
(Stan Cunningham 1989)

Concurrent with Arizona’s Hoover Dam Bypass construction (MP 0 to MP 2.2) and U.S. 93 Reconstruction planning in Arizona (MP 2.3 to MP 17), McKinney and Smith (2007) conducted a DBS assessment that focused on sheep movements relative to the proposed reconstruction alignment. They instrumented 36 DBS with GPS collars that collected more than 73,000 locations from 2004 to 2006 (McKinney and Smith 2007). These locations identified five continuous, linear, elevated ridgelines where sheep concentrated their movements and crossings. McKinney and Smith (2007) recommended three of these locations that corresponded to elevated ridgelines between MP 2.3 and MP 17 where sheep made 82 percent of their crossings of this highway segment.

The recommendations by McKinney and Smith (2007), combined with the knowledge that DBS were unlikely to use UPs (Bristow and Crabb 2008), supported three new OP locations for DBS. The OPs were ultimately constructed at:

- MP 3.3
- MP 5.2
- MP 12.2

RESEARCH JUSTIFICATION AND OBJECTIVES

Over the last two decades, ADOT, BOR, AGFD, National Park Service (NPS), the Bureau of Land Management (BLM), and the have committed to mitigating U.S. 93 Hoover Dam Bypass and Reconstruction impacts on the Black Mountain DBS population. This included funding research and monitoring (Cunningham and Hanna 1992, McKinney and Smith 2007, Gagnon et al. 2014), implementing connectivity measures (FHWA 2001), and constructing three DBS OPs and exclusion fencing.

The research funding, implemented measures, and constructed OPs are one of the most aggressive North American efforts to ensure DBS connectivity and reduce DBS-vehicle collisions. To evaluate the effort’s effectiveness, this study included three objectives:

- Assess DBS movement and permeability (passage rates) across U.S. 93 following completion of OPs, bridges, and wildlife fencing. Compare results to previous U.S. 93 studies.
- Use camera surveilling (video and still cameras) to assess wildlife use of OPs, dry washes at bridges, selected culverts, selected escape ramps, and selected cattle guards.
- Investigate DBS-vehicle collision patterns along U.S. 93.

CHAPTER 2: STUDY AREA

U.S. 93 STRUCTURES

The research team expanded the initial research scope from focusing on U.S. 93, MP 2.3 to MP 17, to include the entire upgraded portion of U.S. 93 that had all ADOT mitigation measures implemented. The study area lay along U.S. 93 between MP 0 and MP 17 (approximate latitude 35 degrees 50 minutes north, longitude 114 degrees 34 minutes west, Figure 1), located 70 miles northwest of Kingman, Arizona. The land in the study area is owned and managed by three United States Department of the Interior agencies: BLM, BOR, and the NPS (Figure 1). The study area has seven large structures (four bridges and three OPs) that could provide DBS passage, either over — via the wildlife OPs — or under U.S. 93 — via the dry washes at the roadway bridges (Table 1, Figure 4).

Reconstruction in the study area — when U.S. 93 was upgraded from a two-lane undivided highway to a four-lane divided highway — occurred in two phases. Phase One (MP 0-2; completed in 2004), included building two new roadway bridges — Sugarloaf Mountain Bridge and Mike O'Callaghan-Pat Tillman Memorial Bridge, which spans the Colorado River — and the Kingman Wash Transportation Interchange (TI) Bridge (Table 1, figures 4 and 5). The Sugarloaf Mountain Bridge and Kingman Wash TI Bridge were connected to 7-foot-high exclusion fencing to guide DBS under them. Phase Two (MP 2-17; 2008-2010) included building three OPs (OP #1, OP #2, and OP #3) for DBS to cross over (Figure 6) and the large White Rock Canyon (WRC) and Devils Wash (DW) roadway bridges, which the DBS could cross under (Table 1; Figure 7). All structures were anticipated to increase roadway permeability for DBS and were connected to 5-foot- and 7-foot-high fencing. Lateral access roads within the exclusion fencing area included single-wide or double-wide cattle guards to limit DBS access to the right-of-way (ROW). ADOT installed 19 escape ramps to allow egress for DBS within the fenced corridor (Figure 8).

Table 1. U.S. 93 Bridge and Wildlife Crossing Structures Built during Roadway Reconstruction,MP 0-17, 2004-2010

Structure Name	Milepost	Length (feet)[1]	Width (feet)[2]
Sugarloaf Mountain Bridge	0.5	903	84
Kingman Wash TI Bridge	1.2	140	84
Wildlife OP #3	3.3	203	100
White Rock Canyon Bridge[3]	4.2	216	84
Wildlife OP #2	5.2	203	50
Devils Wash Bridge[3]	8.0	213	84
Wildlife OP #1	12.2	203	50

[1] Measured as linear highway distance. Average length of both directions.

[2] Measured as highway road width between ROW boundaries.

[3] Length equals average of northbound and southbound; width equals northbound and southbound combined.

Source: ADOT Bridge Inventory

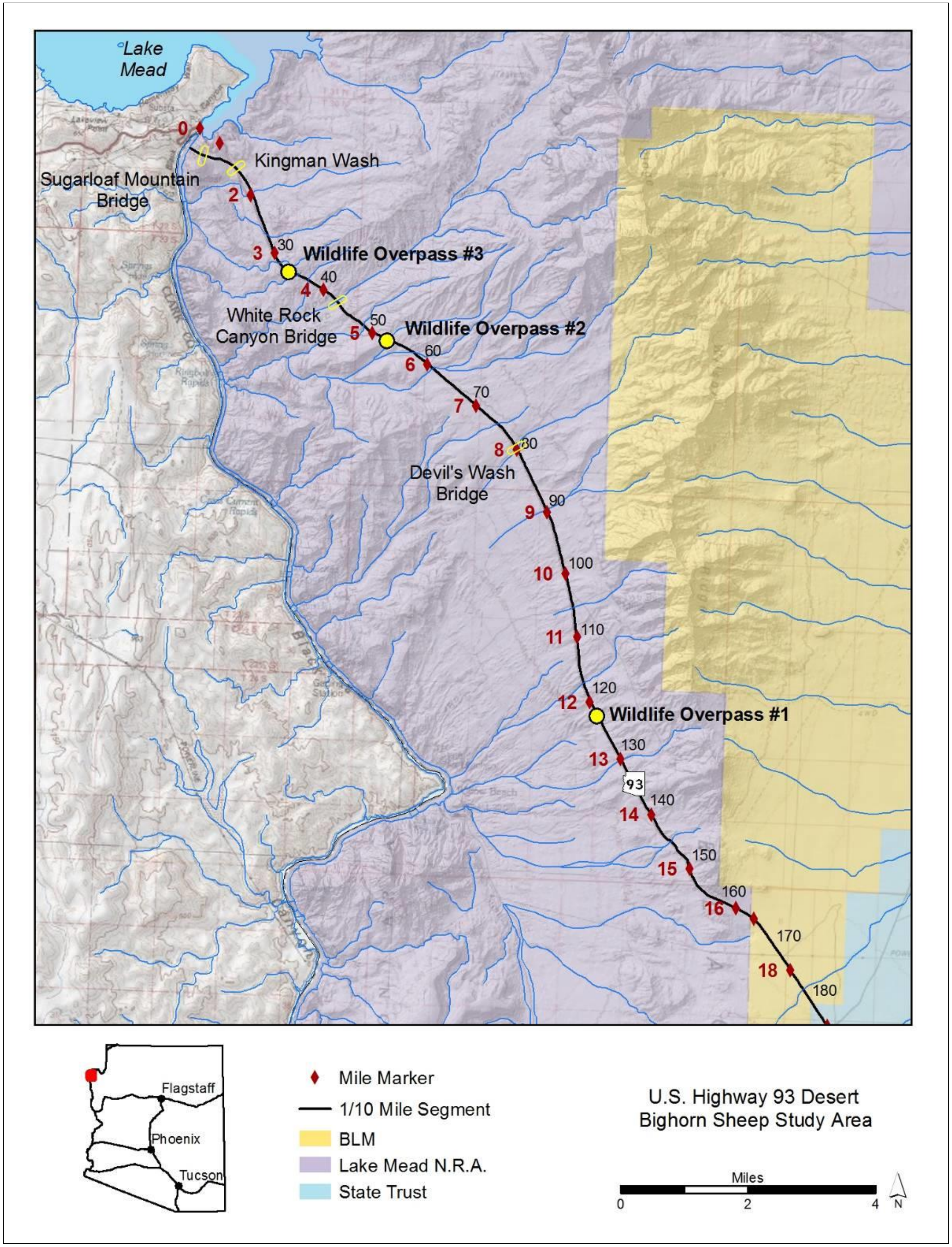

Figure 4. U.S. 93 Study Area Map Showing Land Ownership in Color
MP (red numbers), 0.1 mi segments (black numbers), and
location of wildlife overpasses (yellow dots)and bridges with dry washes (small yellow outline).

Figure 5. Sugarloaf Mountain Bridge (top) **and Kingman Wash Traffic Interchange Bridge** (bottom)**, Both Built as Part of Hoover Dam Bypass Project**.
The structures provided options for accommodating desert bighorn sheep movements under U.S. 93

Figure 6. Aerial Views (left column) **and Ground Views** (right column) **of Wildlife Overpasses Built along U.S. 93 at MP 3.3** (top)**, MP 5.2** (middle)**, and MP 12.2** (bottom)

Figure 7. Ground View with Aerial Inset of White Rock Canyon Bridge at MP 4.0 (top) **and Devils Wash Bridge at MP 8.0** (bottom) **along U.S. 93 near Hoover Dam**

Figure 8. Additional Mitigation Measures that Work with Wildlife Overpasses and Other Structures. Exclusion fencing prevents desert bighorn sheep from entering the roadway corridor and guides them to wildlife OP and under bridges (left); escape ramps allow sheep to exit the ROW (upper right); and double-wide cattle guards limit bighorn access at lateral access roads and still allow motorists entry to recreation opportunities (lower right).

NATURAL SETTING AND U.S. 93 TRAFFIC CHARACTERISTICS

Study area elevations range from 637 feet at the Colorado River to 4957 feet atop Mount Wilson. The topography includes rugged, mountainous terrain, steep talus slopes, cliffs, dry washes, and rolling hills (Figure 9, Cunningham and Hanna 1992). The annual average daily high and low temperatures are 86.8 degrees and 58.5 degrees Fahrenheit. However, the climate during the summer months (June–August) can have high temperature averages exceeding 105 degrees (Figure 10). Precipitation, which is almost entirely rainfall, averages 5.6 inches per year with nearly half of that falling from winter (January through March) frontal storms that emanate from the Pacific Ocean (Figure 10). The majority of the remaining precipitation occurs in the form of scattered thunderstorms during summer (Figure 10). Vegetation across the study area is characteristic of the arid and sparse Mohave Desert Scrub Biotic Community and is dominated by the creosote-bursage association (Figure 4). Along washes, where more moisture collects, catclaw, cheese bush, and mesquite are prevalent (Cunningham et al. 1993, McKinney and Smith 2007), while range ratany, Mormon tea, and galleta grass occur at the higher elevations. The area is frequented by the public to hike, recreate on the Colorado River, hunt, and watch wildlife, all of which may involve direct or indirect interactions with the local DBS population.

The 2011 to 2015 average annual daily traffic (AADT), as measured by the Automatic Traffic Recorder at MP 5.3, was 13,635 vehicles per day (Figure 11). This represents a 75 percent increase over the 2005 to 2010 AADT of 7793. The traffic volume increase reflects the October 2010 opening of the reconstructed and modernized U.S. 93 to commercial traffic, which occurred when the new O'Callaghan-Tillman Memorial Bridge replaced the slow and indirect route across Hoover Dam. (Prior to October 2010, commercial traffic and motor vehicle operators who did not want to pass through the Hoover Dam security check-point established after the terrorist attacks of September 11, 2001 were rerouted to SR 68). The 2011-2015 AADT contains considerable monthly, daily, and hourly variation. Summer tourist months had higher volumes (422,000 vehicles in July) than winter months (329,000 in February). Weekends, Friday through Sunday, had 14 percent higher volumes than weekdays (Figure 12). Hourly traffic volume included high afternoon peaks (1068 vehicles per hour) that had an AADT equivalent of 25,632 vehicles per day (Figure 12). The afternoon AADT equivalent exceeds the 10,000 vehicles per day threshold where roadways become impermeable barriers (Iuell et al. 2003, Seiler 2003). The AADT hourly peak also occurs during the time of day when DBS, which are a diurnal species, are most active.

Figure 9. Mountainous Desert Bighorn Sheep Habitats in the U.S. 93 Study Area.
Rugged cliffs south of the highway near Fortification Hill (left) and
Mount Wilson and its foothills north of the highway (right)

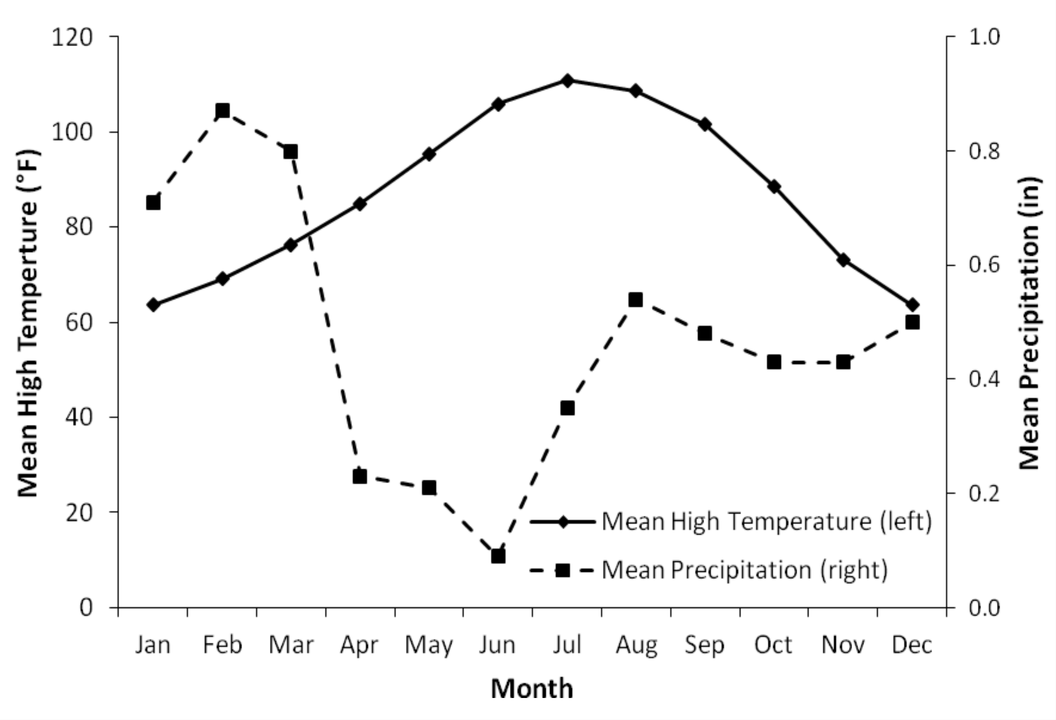

Figure 10. Mean Monthly High Temperature (left axis**) and Mean Monthly Precipitation** (right axis) Recorded 1967-2009 at Willow Beach Recording Station near U.S. 93.

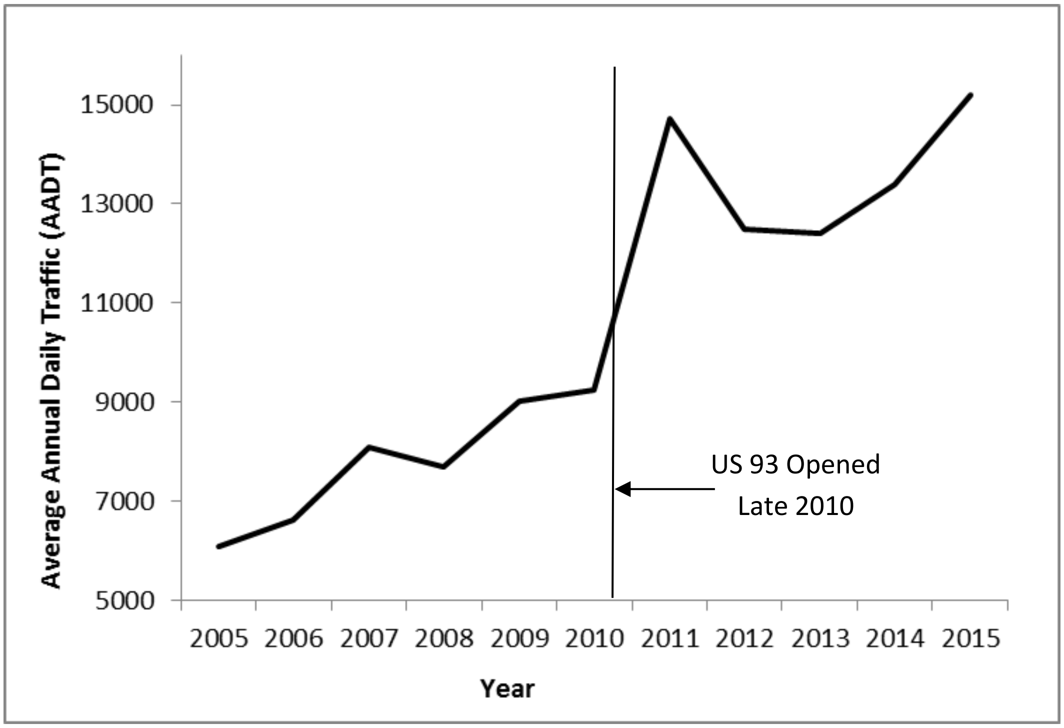

Figure 11. U.S. 93 Average Annual Daily Traffic Volume by Year, 2005-2015

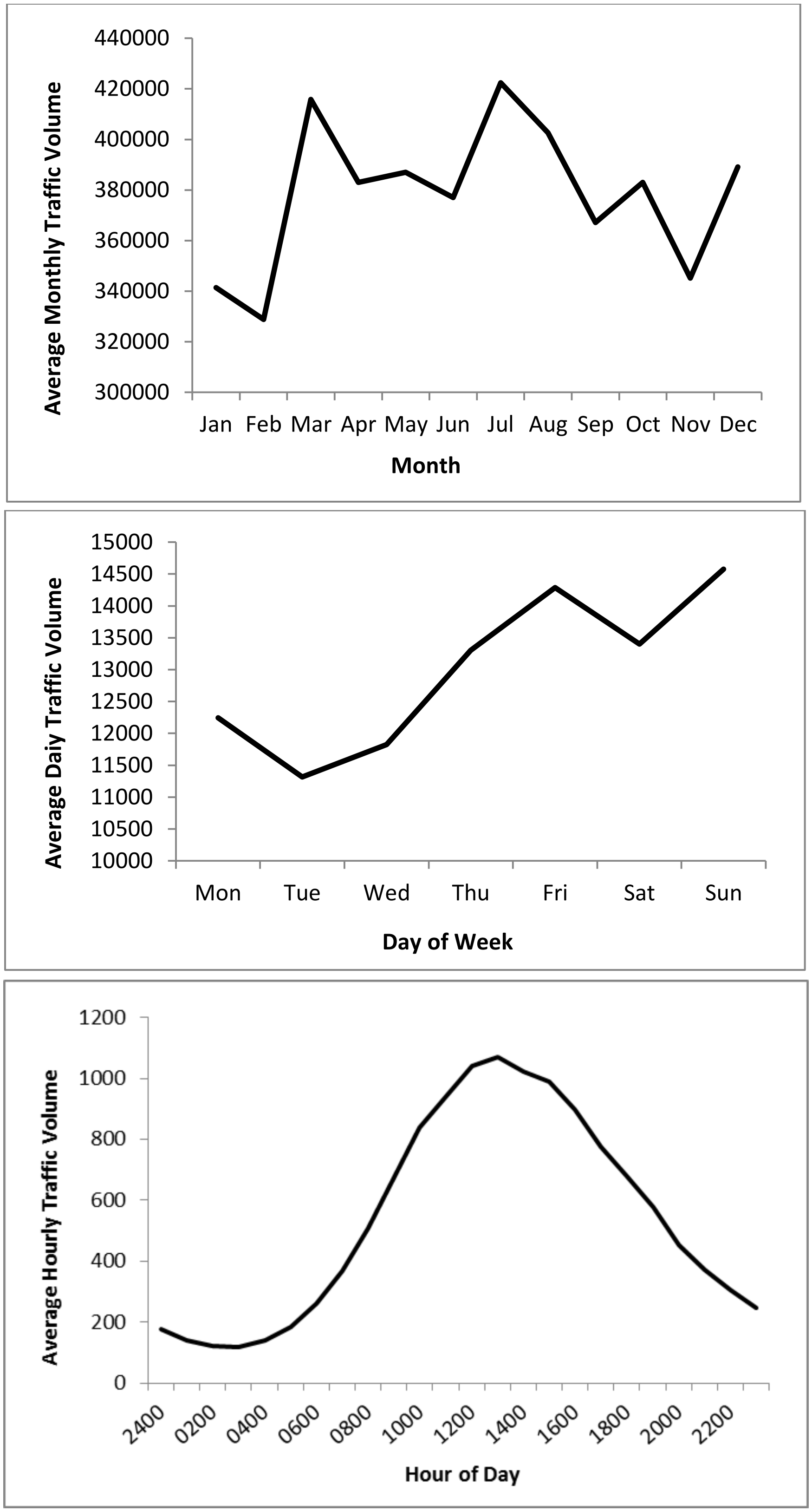

Figure 12. Average U.S. 93 Traffic Volume by Month, (top),
Day (middle)**, and Hour** (bottom)**, 2011-2015**

CHAPTER 3: METHODS

DESERT BIGHORN SHEEP CAPTURE AND MOVEMENTS

The research team captured DBS in the late fall and mid-winter to avoid sheep hunting seasons, minimize possible heat-related stress risks, and avoid capturing pregnant females. Researchers set out to distribute an equal number of DBS collars among the various herds that occupied a 5-mile roadway buffer on either side of the U.S. 93 study area (MP 0-17). The team used a net gun fired from a helicopter (Figure 13) to capture sheep that were located by fixed-wing aircraft and on-the-ground personnel. Upon capture, the research team blindfolded and hobbled the sheep and removed them from the capture net. The team assessed sheep for capture-related injuries, monitored their temperatures, and administered treatment (e.g., external/internal cooling, anti-inflammatory, and antibiotics) when appropriate. The research team fitted captured DBS with GPS collars and individually numbered ear tags and recorded sheep sex, approximate age, and any treatment(s) administered. The sheep were then released wearing the GPS satellite uplink collars (Model NSG-D GlobalStar; North Star Science and Technology, LLC; King George, VA) that included very high frequency (VHF) technology, mortality sensors, and release mechanisms. The collars were programmed to receive one GPS relocation every two hours between 0600 and 1800 hours every day for 24 months (Figure 13).

Figure 13. The U.S. 93 Desert Bighorn Sheep Capture Process:
Helicopter and net gunner pursue bighorn (top left); net gunner deploys net (top right); biologists collar, ear tag, and document captured sheep (bottom left); and collared sheep is released (bottom right).

For GPS post-construction monitoring analysis, the research team added relocation data from these collars to existing 2010 and 2011 DBS collar data sets. The team analyzed the compiled data set using ArcGIS Version 10.2 Geographic Information System (GIS) software (ESRI, Redlands, California) with techniques similar to those utilized by, among others, Gagnon et al. (2014) for DBS. The analysis included home range, crossing rate, distribution, and passage rate and was compared spatially and temporally to data collected by McKinney and Smith (2007) and Gagnon et al. (2014).

Home Range Analysis

The team calculated individual minimum convex polygon (MCP) home ranges for DBS that were collared for 12 months or longer. (An individual animal's MCP home range is a polygon defined by a perimeter that connects the outermost GPS locations that encompass all the animal's GPS locations.) This allowed the team to directly compare home range sizes to earlier DBS research conducted in the area (McKinney and Smith 2007, Gagnon et al. 2014). The research team used Kruskall-Wallis tests to determine mean differences between sexes and reconstruction treatments and MCP home ranges before reconstruction (2004-2008), during reconstruction (2009-2010), and after reconstruction (2011-2014).

Desert Bighorn Sheep Crossing Rates and Distribution Analysis

The research team used for DBS the same approach used for elk in Dodd et al. (2007; Figure 14) and divided the study area into 180 sequentially numbered 0.1-mile segments that correspond to ADOT roadway maintenance and WVC tracking units. The team then connected each animal's consecutive GPS fixes (location-specific readings) to infer that the animal crossed the roadway at all the locations where the lines between fixes intersected a U.S. 93 segment. The team compiled each animal's roadway crossings and calculated an individual crossing rate (total crossings and crossings per day) by dividing the number of crossings by the number of days a collar was worn.

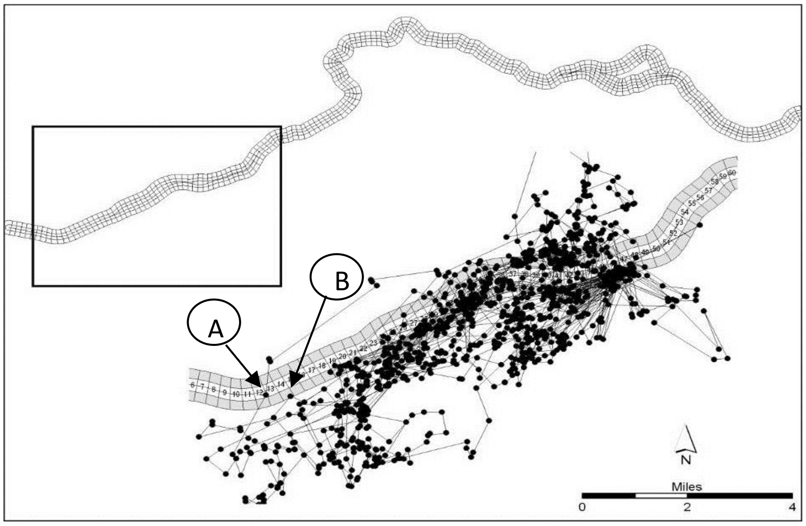

Figure 14. GPS Elk Locations and Lines between Successive Fixes in 0.1-Mile Roadway Segments along Interstate 17 in Northern Arizona (Source: Dodd et al. 2007)

Note: The expanded section shows GPS locations of elk and the lines between successive fixes used to determine approaches to the highway (shaded band) and crossings (clear numbered bands). Example A denotes an elk approach and crossing; Example B denotes an approach without a crossing. The ratio of approaches with a crossing to total approaches is the passage rate.

For each roadway segment, the research team calculated Shannon Diversity Indices (SDI), which take into account the number of individual DBS that crossed each U.S. 93 roadway segment and crossing frequency evenness (or variation) among animals (Dodd et al. 2007b). The use of SDI reduces the influence of an individual DBS on the overall crossing results and places a higher weight on segments with crossings by multiple individual DBS, thereby preventing skewing of the results by a few exceptional individuals that cross frequently. These weighted segments more accurately reflect the approximate number of DBS (collared and uncollared) that cross a particular road segment (Dodd et al. 2007b, Gagnon et al. 2014). The research team calculated SDI for each segment using this formula:

$$H' = -\sum_{i=1}^{S} p_i \ln p_i$$

Thus, to calculate SDI (or *H′*) for each roadway segment, the research team calculated and summed all ($p_i \ln p_i$) for each animal that crossed the segment, where each p_i is defined as the number of DBS crossings by an individual (collared) DBS within each segment divided by the total number of DBS crossings in the segment. The team used SDI to calculate weighted crossing frequency estimates for each segment, multiplying uncorrected crossing frequency by the number of SDI.

Because the data would not likely meet normality assumptions, the research team used non-parametric Mann-Whitney U tests to compare mean DBS crossing rates among these reconstruction classes before and during reconstruction (November 2008−October 2010; combined from Gagnon et al. 2014) and post-construction (November 2011–October 2014)

The team compiled the percentage of DBS crossings made within four U.S. 93 segments for comparison to those delineated by Gagnon et al. (2014):

MP 0−2.2	Existing roadway alignment.
MP 2.3−5.0	Segment with Overpass #3.
MP 5.1−9.0	Segment with Overpass #2.
MP 9.1−17.0.	Segment with Overpass #1.

Within each segment, the research team compared the distribution of DBS crossings from before reconstruction (2004–2009) with that during reconstruction (2008-2010).

Passage Rates Analysis

The research team calculated passage rates as the proportion of roadway crossings to approaches for those individual DBS that made at least five approaches to U.S. 93. Researchers defined a roadway crossing to have occurred when the line connecting an individual animal’s two consecutive GPS locations intersected a U.S. 93 segment. The team defined an approach to have occurred when an animal traveled from a point outside a 0.15-mile buffer zone to a point within 0.15-mile of U.S. 93, determined by successive GPS locations (Figure 14). The approach buffer zone corresponds to the road-effect zone, which is associated with traffic-related disturbance (Rost and Bailey 1979, Forman 2000) and was previously used for elk, mule, and white-tailed deer statewide, as well as for DBS within the same study area (Dodd et al. 2007a, Dodd et al. 2007b, Dodd and Gagnon 2011, Dodd et al. 2012a, Dodd et al. 2012b, Gagnon et al. 2013, Gagnon et al. 2014, Gagnon et al. 2015). The research team considered animals that directly crossed U.S. 93 from beyond 0.15 miles as having an approach and a crossing.

McKinney and Smith (2007) programmed DBS collars to receive GPS relocation data every five hours, an interval that was inconsistent with other statewide studies and too long to pinpoint crossing locations, and so prevented researchers from using that data to calculate pre-construction passage rates for those sheep. The present research team used 2008-2010 (Gagnon et al. 2014) passage rates before and during reconstruction to compare with after-reconstruction passage rates (2011-2014). The team used these passage rates as a relative roadway permeability measure that can be directly compared to the passage rates on other Arizona roadways (Gagnon et al. 2010, Dodd et al. 2011, Dodd et al. 2012a, Dodd et al. 2012b, Gagnon et al. 2013).

The research team compared mean DBS roadway passage rates and crossing rates before and during reconstruction (November 2008−October 2010; combined from Gagnon et al. 2014) with those after reconstruction (November 2011–October 2014). Because the data would not likely meet normality assumptions, the research team used non-parametric Mann-Whitney U tests for these comparisons.

To evaluate DBS ability to adapt to the newly constructed U.S. 93 and associated mitigation measures, the research team evaluated DBS passage rates over time for DBS in general and by sex and age (rams, ewes, and juveniles). The research team used a Kruskall-Wallis statistical test to compare passage rate across four years of monitoring.

VIDEO AND STILL CAMERA SURVEILLANCE

ADOT implemented measures to reduce U.S. 93's DBS-vehicle collisions and mitigate roadway barrier effects. To determine if the measures have been effective, the team conducted long-term monitoring to document and evaluate DBS use of crossing structures and escape/diversion mechanisms, as well as to document mortality from DBS-vehicle collisions. The research team installed video and still cameras to provide detailed, documented DBS use of crossing structures and escape mechanisms and to allow evaluation of any DBS adaptation to the structures. To monitor the occurrence of DBS-vehicle collisions, the team used collision documentation from multiple agencies and organizations.

Wildlife Structures Use

The research team evaluated use of crossing structure and escape/diversion mechanisms with sophisticated systems of video and rapid-fire still cameras (Figure 15 and Figure 16). The monitored structures included three OPs, the washes under two bridges, and three culverts (Table 2). ADOT installed eight escape mechanisms (ramps) and two single-wide cattle guards as diversion mechanisms. All research team monitoring occurred along U.S. 93 between MP 0 and MP 17.

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Figure 15. During Wildlife Overpass Construction, State-of-the-Art Video Surveillance Systems Were Incorporated into the Overpass Infrastructure.

Figure 16. Overpass Surveillance System Components and Resulting Imagery
Clockwise: (top right) three video cameras mounted atop a 12-foot pole;
(center right) four video display images, including shot of bighorns, from four-camera video system;
(lower right) still image of desert bighorn rams crossing; and (left) mid-structure video camera with infrared lights, still camera, and photo beam sensor to activate DVR recording.

Table 2. Structures Monitored with Video and/or Still Frame Cameras

Structure Designation	Milepost	Video Camera Installed	Number of Still Cameras Installed
Wildlife Crossing #1 (OP)	12.2	X	1
Devils Wash Bridge	8.0		3
Wildlife Crossing #2 (OP)	5.2	X	1
White Rock Canyon Bridge	4.2		2
Wildlife Crossing #3 (OP)	3.3	X	2
Culvert 13.1	13.1		1
Culvert 6.0	6.0		2
Culvert 5.2	5.2		2
Escape Ramp OP #1 NW	12.2	X	
Escape Ramp OP #2 NW	5.2	X	
Escape Ramp 3.3 NW	3.3		1
Escape Ramp 3.3 NE	3.3		1
Escape Ramp 3.3 SW	3.3		1
Escape Ramp 3.3 SE	3.3		1
Escape Ramp Kingman Wash	2.2		1
Escape Ramp Sugar Loaf NE	1.1		1
Kingman Wash SE Cattle Guard	2.2		1
Kingman Wash SW Cattle Guard	2.2		1

NE = northeast; NW = northwest; SE =southeast; SW = southwest

Wildlife Overpass Use

The research gathered data documenting animal use of OP structures with a solar-powered, four-camera, video monitoring system that was only activated when strategically placed photo beam sensor beams were broken (Dodd et al. 2007, Gagnon et al. 2007, Figure 16). The research team also used data from mid-OP Reconyx® rapid-fire, still cameras that served as a video monitoring system backup. These combined camera methods permitted researchers to track wildlife use and document the number of animals—total and by species—that used the structures to safely cross over U.S. 93.

Desert Bighorn Sheep Overpass Use

An SR 68 DBS study indicated that UP structures were rarely used by sheep to cross under the roadway and suggested that OP crossing structures may be more effective (Bristow and Crabb 2008). As a result, ADOT decided to construct three DBS OPs, and without direct data available, chose 50-foot and 100-foot widths. ADOT constructed two 50-foot-wide OPs and one 100-foot-wide OP. The research team used the aforementioned video and still cameras to document sex and age class (ram, ewe, and juvenile) use at these three OPs. Also for each structure, the research team calculated DBS passage rates, which provide a comparable, quantitative, and unbiased measure of OP use that is consistent with prior Arizona projects (Dodd et al. 2007d, Gagnon et al. 2007b, Gagnon et al. 2011). The research team calculated passage rates as a ratio of DBS that crossed the OP to those that approached the OP. For example, if 25 DBS cross an OP while 100 DBS approach that same OP, the passage rate is 25 percent (e.g., 25 DBS crossings ÷ 100 approaches = 0.25 or a 25 percent passage rate). Conversely, for the same example, the repelled or did not cross rate is 75 percent. Comparing passage rates for various structures through time verifies the effectiveness or ineffectiveness of the structure and can inform future OP design.

Desert Bighorn Sheep Bridge Use

Although Bristow and Crabb (2008) documented rare DBS UP use, those UPs were relatively small when compared to U.S. 93's multi-span bridges: DW and WRC. These two structures cross large seasonal desert washes, are connected by 7-foot exclusion fencing, and may be able to serve as dual-use structures for wildlife crossings and drainage. Gagnon et al. (2015) documented similar dual-use structures for elk in Arizona. Researchers mounted multiple still cameras at the two bridges and used the camera data to calculate total and cumulative DBS use by sex and age class (ram, ewe, adult [e.g., ram plus ewe], and juvenile). The analysis allows direct comparison between these two bridges, the three OP structures, and the three monitored culverts (Figure 17).

In addition to monitoring DBS crossings at WRC bridge, which also serves the numerous Arizona Hot Springs hikers that depart from the nearby trailhead (Figure 18), the research team tracked people crossing under the bridge for one year. There is evidence that excessive human use can limit animal wildlife structure use (Clevenger and Waltho 2000, Barrueto et al. 2014). The research team temporally compared DBS and human use of WRC Bridge.

Figure 17. Devils Wash (left) **and White Rock Canyon** (right) **Bridges with Cameras Below.**
Still camera placement denoted by red arrows, camera orientation by semi-transparent triangles.

Figure 18. White Rock Canyon Bridge and Arizona Hot Springs' Trailhead Parking Lot

Desert Bighorn Sheep Culvert Use

Culverts are regularly implemented to accommodate hydrology under roads. Numerous studies have shown that culverts can also simultaneously provide *de facto* wildlife crossings for various species (Clevenger et al. 2001a, Ng et al. 2004, Sparks Jr and Gates 2012). Although prior research indicated that culverts would not likely function as effective DBS crossings (Bristow and Crabb 2008), ADOT Maintenance and contractor personnel provided researchers with anecdotal evidence of DBS culvert use. Based on this evidence, the research team mounted still cameras at three culverts that appeared most likely to function as crossing structures for DBS (Figure 19). The team oriented still cameras to capture animals approaching the mouth of the culvert and using the culvert to cross under U.S. 93. The research team used this data to document culvert passage rates and use over time (Figure 19, Gagnon et al. 2011).

Figure 19. U.S. 93 Culverts Monitored for Use by Desert Bighorn Sheep and Other Wildlife.
One culvert, MP 13.1 (top), lacks direct line of sight under roadway. Two culverts,
MP 6.0 (bottom left) and MP 5.2 (bottom right), have direct line of sight under roadway.

Desert Bighorn Sheep Escape Ramp Use

Exclusion fencing along roadways is essential for two reasons: it excludes most ungulates from entering the ROW and it guides ungulates to wildlife crossings. Animals, however, occasionally gain ROW access and pose a risk to motorists and themselves if they are unable to exit the roadway. Escape ramps (commonly referred to as “jump-outs”) are placed within the fence line to allow animals an opportunity to exit the ROW. The ROW side of the ramps gradually slopes up to a designed fence low point, which permits ungulates to safely jump down and exit the roadway corridor but does not generally permit them to enter the corridor (Figure 20). Since the appropriate DBS escape ramp fence low point height is unknown, the U.S. 93 planning team used elk and deer height specifications—6 feet. The research team monitored escape ramp use with still cameras oriented to capture DBS approaching the escape ramp from both the ROW and non-ROW sides. The research team calculated escape ramp passage rates (crossings ÷ approaches = passage rate) for animals that used the ramps to exit or enter the roadway corridor. This permitted the team to document proper use (exiting the roadway) and improper use (entering the roadway) and change in use over time.

Figure 20. Two Examples of U.S. 93 Escape Ramps with the gradual ramp inside the U.S. 93 ROW sloping up to a designed fence low point (left) and the six-foot drop on the non-ROW side (right). U.S. 93 escape ramps allow animals an opportunity to exit the ROW while minimizing the opportunity to access the ROW.

Cattle Guard Effectiveness

When using 7-foot exclusion fencing to prevent large animals from entering the ROW and rather guide them to WCS, lateral access roads must also be considered as potential animal ROW access locations. Where fence lines cross lateral roads with low traffic volumes, gates can permit vehicle ROW access while prohibiting animal access. When gates are left open, however, they do not prevent animals from accessing the ROW. Crossing guards, such as cattle guards, can also permit vehicular roadway access while possibly excluding wildlife (similar to livestock); however, crossing guard effectiveness research for DBS and other wildlife species is limited (Allen et al. 2013, Huijser et al. 2015). The reconstruction of U.S. 93 MP 0-17 included double-wide and single-wide cattle guards to deter DBS from entering the ROW (Figure 21). Following reconstruction, the research team received multiple reports of DBS entering the ROW by crossing the Kingman Wash TI single-wide cattle guards. In January 2012, researchers installed still cameras at two Kingman Wash TI cattle guards to document whether DBS were crossing the guards and to calculate passage rates (cattle guard crossings ÷ cattle guard approaches = passage rate) if any crossings did occur.

Figure 21. Example of a Double-Wide (left) and Single-Wide (right) Cattle Guard on U.S. 93

DESERT BIGHORN SHEEP-VEHICLE COLLISION RELATIONSHIPS

Previous studies have documented U.S. 93 DBS-vehicle collisions and identified these collisions as a concern for the DBS population (Cunningham and Hanna 1992, Figure 22). ADOT implemented U.S. 93 DBS-vehicle collision mitigation measures during the MP 0-17 reconstruction. The research team documented past and present DBS-vehicle collision data throughout the study area and for the study's duration.

To gather this data, the research team relied on the submission of DBS-vehicle collision reports from AGFD, Arizona Department of Public Safety, ADOT Maintenance and Environmental, BOR, and NPS personnel. The collision reports included date, time, location (i.e., MP to the nearest 0.1), sex, and age (ram, ewe, and juvenile) of the animal(s) involved. The team culled reports for duplicates and compiled them into a database. The research team compared the yearly number of U.S. 93 post-reconstruction DBS-vehicle collisions from 2001 through 2015 to the estimated pre-reconstruction yearly number of 11 collisions per year (Cunningham and Hanna 1992).

Figure 22. Desert Bighorn Ram (left) **and Ewe** (right), **Struck and Killed by Vehicles on U.S. 93**

CHAPTER 4: RESULTS

WILDLIFE CAPTURE, GPS TELEMETRY, AND DATA ANALYSIS

Desert Bighorn Sheep Capture and Movements

Using a net gun fired from a helicopter, the research team captured 70 DBS along U.S. 93 during four capture events: November 19, 2010, January 29, 2011, November 17-19, 2011, and November 1-2, 2012. The team recovered adequate GPS data from 53 sheep (25 rams, 28 ewes, Figure 23) collars that were worn for an average of 454.4 days (standard error [SE] ±29.5). The 53 GPS collars accrued 167,300 GPS relocations (Figure 23) for a mean of 3157 relocations/sheep (SE ± 275.1). Of these, the team found that 21.1 percent (667.4/sheep SE ±92.0) were within 0.6 mi of U.S. 93, and 4.0 percent (125.9/sheep SE ±20.82) were within 0.15 mi of the roadway. Overall, DBS travelled an average of 650.2 feet (±30.7) between GPS relocations. Rams traveled 750.5 feet (±23.0) between relocations, which was on average 204.6 feet (37 percent) farther than ewes (545.86 ±25.; (U = 10.62, df = 1, P =0.001).

Home Range Analysis

The research team calculated DBS home ranges for post-construction DBS collared for at least 12 months to average 34.5 square miles (±5.3). The team noted that ram home ranges (62.8 square miles ±7.2) were more than four times larger than ewe home ranges (14.1 square miles ±1.3; H = 21.93, df = 1, P = < 0.001). The team also noted that average post-construction home ranges (34.5 square miles ±5.3) were larger than the average before construction (21 square miles ±5.4; McKinney and Smith 2007) and during construction (31.8 square miles ±5.2; Gagnon et al. 2011) home ranges. The team found that the home range size differences were only marginally significant ($H = 4.50, df =2, P = 0.10$) and primarily due to the increase in ram home range, which increased from before and during—43.0 square miles (±10.0) and 46.9 square miles (±7.6) respectively—to after construction, 62.8 square miles ($H = 5.0, df = 2, P = 0.08$). Ewes showed marginal differences in home ranges across all construction phases (pre = 10.7 square miles (±1.49), during = 15.5 square miles (±1.7), post = 14.1 square miles (1.44); H = 4.50, df = 2, P = 0.11).

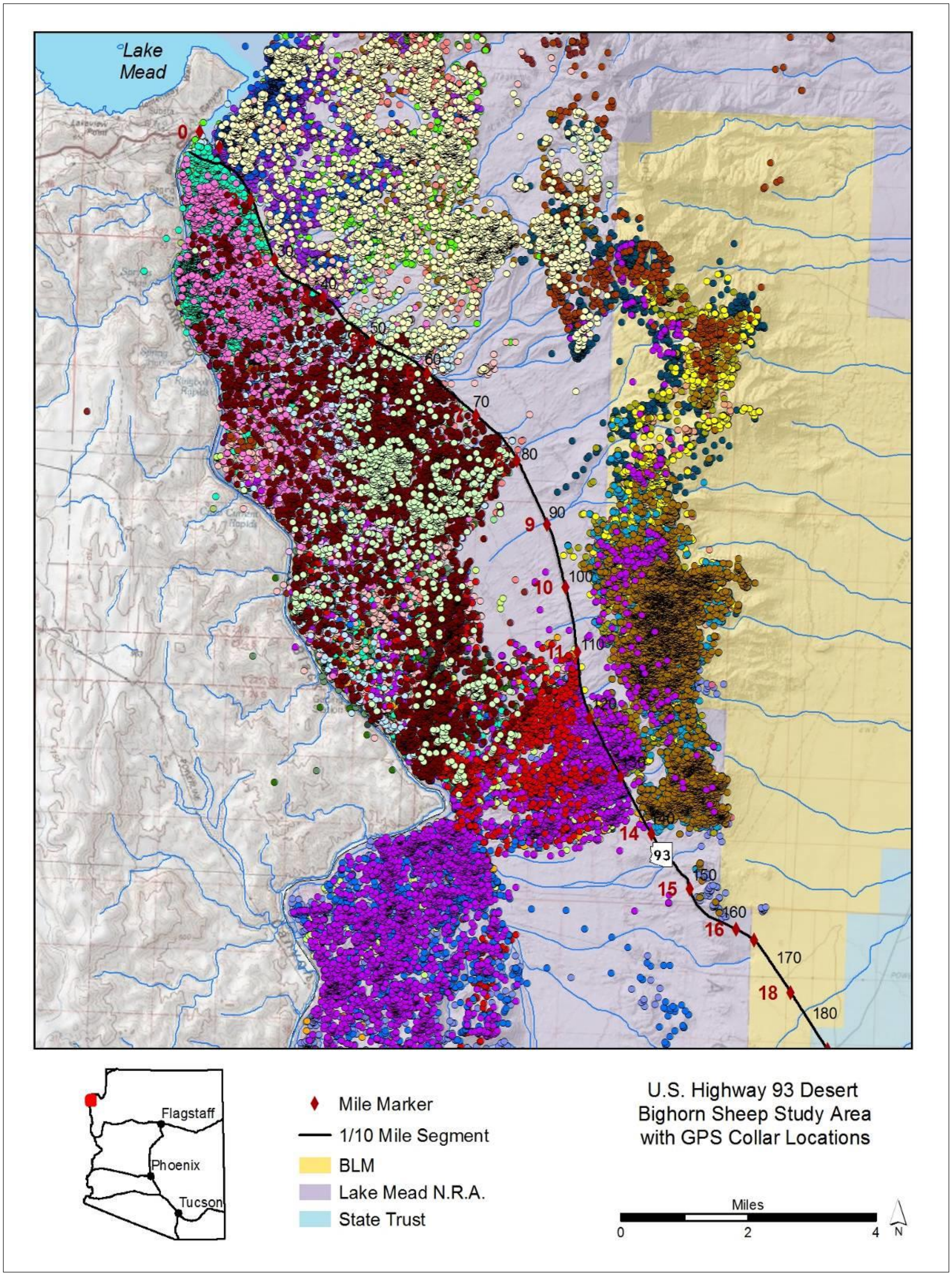

Figure 23. GPS Relocation Distribution for Individual Sheep Collared Along U.S. 93 2011-2014. Each color represents an individual desert bighorn sheep; each dot represents a relocation.

Desert Bighorn Sheep Crossing Rates and Distribution Analysis

The research team documented that 73.5 percent (36 of 53) of post-construction (2011-2014) collared DBS crossed U.S. 93 between MP 0-17 a total of 888 times. The number of crossings per collared sheep ranged from 1 to 84, with a mean of 17.1 crossings per sheep. In contrast, 41 percent (mean 10.2 crossings per sheep; McKinney and Smith 2007) and 42.9 percent (mean 9.3 crossings per sheep; Gagnon et al. 2014) crossed U.S. 93 before and during construction, respectively. This represents a 70 percent post-construction increase in number of collared DBS that crossed the road and the mean number of times each sheep crossed. The team found that the majority (61.4 percent; 545/888) of post-construction crossings occurred between MP 2.3 and 17 with a range of 0 to 78 crossings per DBS (mean = 10.2 crossings per DBS [SE ±2.47]). The researchers noted no substantial difference before and during construction between the number of crossings by rams and ewes (0.03 per day; *U = 2.91, df = 1, P = 0.09*).

The research team documented a 100 percent post-construction increase in crossings per day from before and during construction (0.2 [McKinney and Smith 2007, Gagnon et al. 2014]) to post-construction (0.4). Between MP 0 and 2.2, the team documented fluctuating crossing percentages: 56.6 percent of tagged individuals before construction (McKinney and Smith 2007, Table 3), 77.6 percent during construction (Gagnon et al. 2014, Table 3), and 38.5 percent after construction (Table 3). Following OP construction (MP 2.2-17), the research team observed that 38.5 percent of all DBS crossings occurred between MP 0 and 2.2 and 39.5 percent between MP 5.1 and 9.0—a section containing an OP. In addition, the team found that DBS could and did successfully cross all U.S. 93 roadway segments (Table 3, Figure 24).

Table 3. Desert Bighorn Sheep Crossings Percentage before, during, and after U.S. 93 Reconstruction

U.S. 93 MP Segment	Percentage of All Highway Crossings by Reconstruction Phase		
	Before (2004–2009)[1]	During (2009–2010)[2]	After (2011–2014)
0–2.2[3]	56.6%	77.6%	38.5%
2.3–5.0	25.8%	16.0%	8.1%
5.1–9.0	15.1%	1.5%	39.5%
9.1–17.0	2.6%	4.9%	13.9%

[1] Data from McKinney and Smith (2007) and Gagnon et al. (2014)

[2] Data from Gagnon et al. (2014); construction from MP 2.2-17

[3] Construction of MP 0-2.2 completed in 2004

Percents may not add exactly to 100 due to rounding.

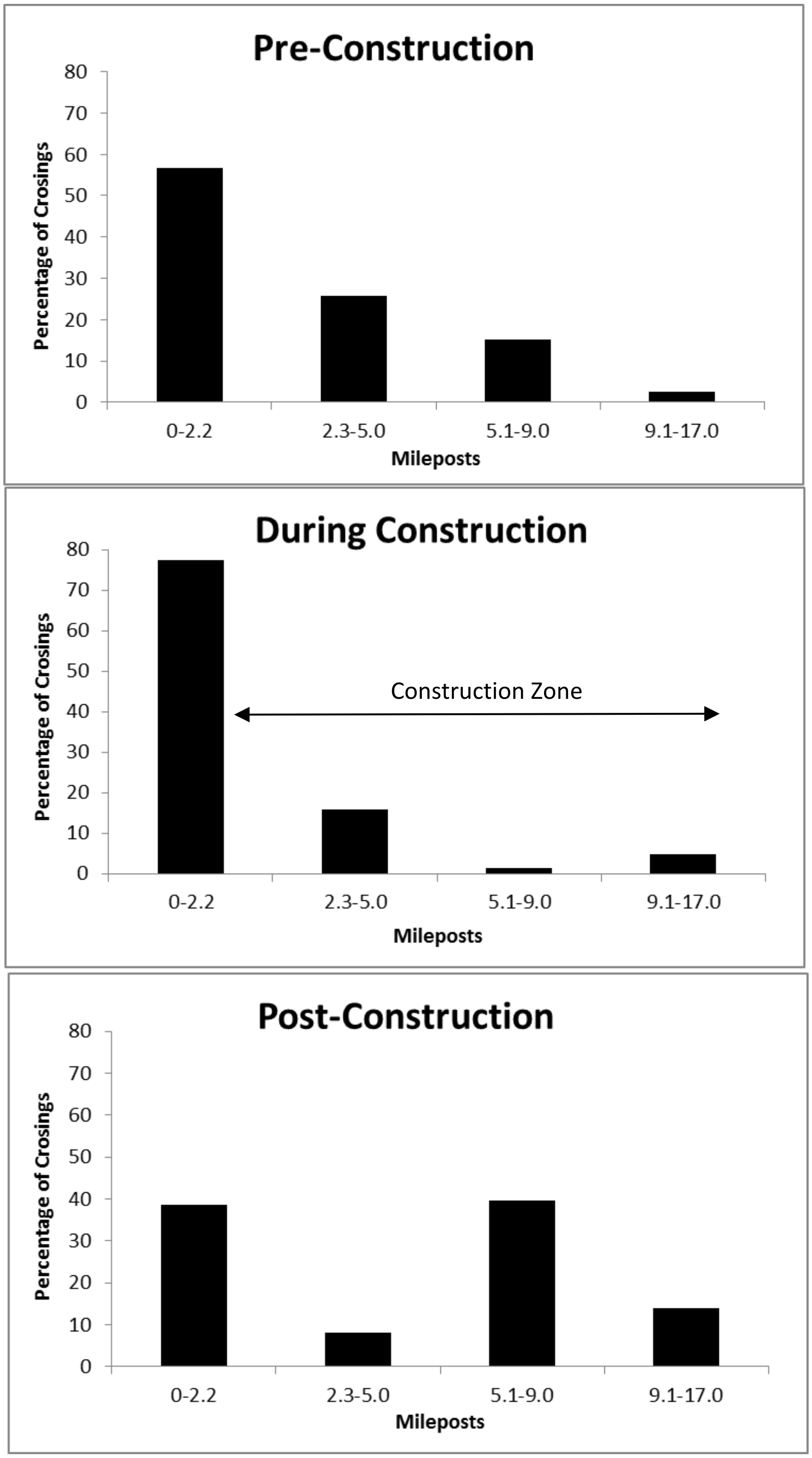

Figure 24. U.S. 93 Desert Bighorn Sheep Crossing Percentages by Milepost Segment Associated with Bighorn Crossing Structures, before, during, and after Construction

For MP 0-17, the research team calculated total and weighted (SDI) crossings (figures 25 and 26). SDI weighted crossings total and weighted crossings were 1349 and 255 (figures 25 and 26). Following construction (2011-2014), the research team found that 69.8 percent (37) of the 53 collared DBS crossed U.S. 93 at 89 unique 0.1 mi segments (covering a distance of 8.9 linear highway miles) for an average of 3.5 DBS crossings per segment. The team found that SDI-weighted crossings equaled 1505 (MP 0-17 total), which is 69 percent greater than the 888 unweighted crossings. During construction (2009-2010), the research team documented 308 crossings by 35.0 percent (26 of 33) of the collared DBS.

Analysis of Passage Rates

McKinney and Smith (2007) programmed deployed DBS collars to receive GPS relocations every five hours, a time interval that prohibited the research team from using the data to calculate passage rates before construction for those sheep. The team found that passage rates calculated for sheep collared before and during construction (2008-2010) were similar; thus, they combined the data and used the joined set for a comparison with the passage rates after construction (2011-2014). When comparing these rates, the team calculated the before and during construction crossing average (MP 2-17) to be 0.05 crossings per approach and the average after construction at 0.19. This equates to a 280 percent increase in the passage rate after construction (Table 4). The post-construction passage rate for the entire reconstructed segment (MP 0-17) increased by 167 percent, from 0.9 crossings per approach to 0.24 (Table 4).

**Table 4. Collared Desert Bighorn Sheep Crossing Data:
Comparative Mean Values before, during, and after Reconstruction for
Roadway Crossing Frequency, Crossing Rate, and Passage Rate on U.S. 93.**

Parameter	MP 0-17 Overall		MP 2-17	
	Before and during Construction (2008-2010)[1]	After Construction (2011-2014)	Before and during Construction (2008-2010)[1]	After Construction (2011-2014)
No. Highway Crossings	308	888	91	545
Mean Days DBS Collared (±SE)	357.2 (±36.3)	454.4 (±29.5)	357.2 (±36.3)	454.4 (±29.5)
Mean Crossings/DBS (±SE)	9.3 (±3.6)	17.1 (±3.4)	2.8 (±1.1)	11.4 (±2.7)
Mean Crossing Rate (crossings/day) (±SE)	0.02 (±0.01)	0.04 (±0.01)	0.01 (±0.01)	0.03 (±0.01)
Mean Passage Rate (crossings/approach) (±SE)	0.09 (±0.02)	0.24 (±0.04)	0.05 (±0.02)	0.19 (±0.03)
No. Collared DBS Approaching Hwy (for Passage Rate)	33	49	33	48

[1] Combined from Gagnon et al. 2014

The team found that the newly constructed MP 2.2-17 passage rate for rams (0.22 crossings per approach SE ±0.04) was higher than that for ewes (0.19 crossings per approach SE ±0.3, $U = 0.97$, $df = 1$, $= 0.32$). The passage rate from post-construction year 1 to year 4 increased by 1367 percent, from 0.03 crossings per approach (SE ±0.01) in year 1 to 0.44 (SE ±0.14) in year 4 ($H = 23.6$, $df = 3$, $P < 0.001$); see Figure 25. Ewe passage rates increased from 0.03 crossing per approach in year 1 to 0.28 in year 2, before somewhat leveling off and ultimately reaching 0.32 in year 4 ($H = 9.05$, $df = 3$, $P = 0.03$); see Figure 25. Rams had a steadier increase from 0.04 (SE ±0.02) in year 1 to 0.52 (SE ±0.22) in year 4 ($H = 14.4$, $df = 3$, $P = 0.002$); see Figure 25. This increase in passage rates may be attributable to the increased number of crossings per DBS per year (7.2 SE ±1.25), rising from 1.4 (SE = 0.71) in year 1 to as high as 13.3 (SE ±2.73, $H = 21.2$, $df = 3$, $P <0.001$) in year 4, while the approaches per DBS per year held steady at an average of 31.08 (SE ±2.6, $H = 0.25$, $df = 3$, $P = 0.97$).

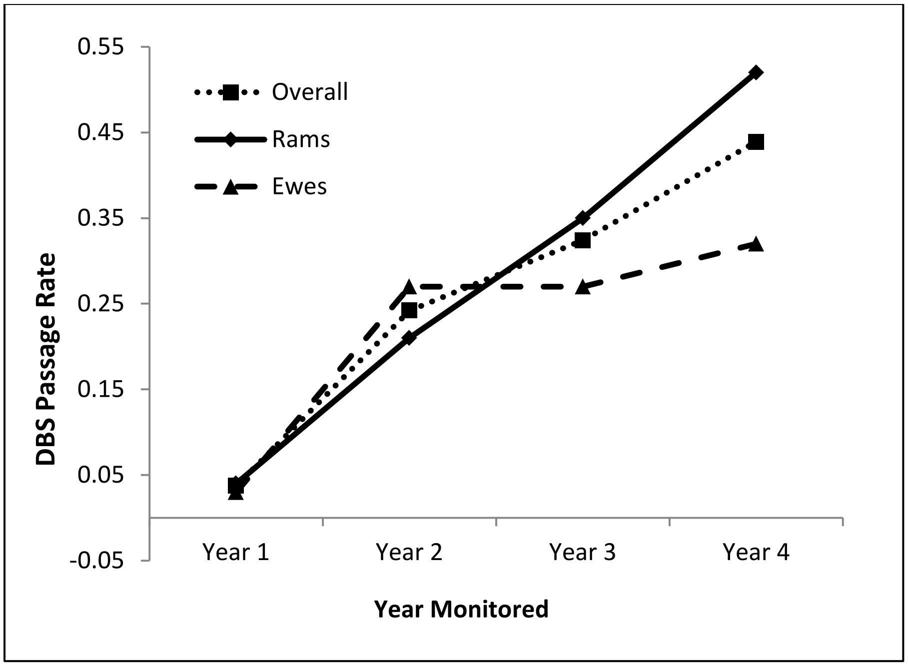

Figure 25. Desert Bighorn Sheep Passage Rate by Study Year for Rams, Ewes, and Sheep Overall after Reconstruction, U.S. 93, MP 2-17 (2011-2014)

Passage Rate Spatial Patterns

As distance from the Colorado River increased, passage rates from MP 0 to MP 17 generally decreased before and after completion of MP 2.2-17. Post-construction passage rates, regardless of distance to the river, increased by an average of 182 percent (Wilcoxon Matched Pair S = 10.5, df = 1, P = 0.02; Table 5).

Table 5. Bighorn Passage Rate by Distance to Colorado River before and after Reconstruction

U.S. 93 Distance to Colorado River	Before/during Construction Passage Rate (n)	After Construction Passage Rate (n)	Percent Increase
0-0.6 miles	0.29 (9)	0.47 (13)	62.1
0.7-1.2 miles	0.37 (8)	0.45 (13)	21.6
1.3-1.9 miles	0.06 (8)	0.18 (16)	200.0
1.9-2.5 miles	0.11 (9)	0.13 (18)	18.2
2.5-3.1 miles	0.04 (9)	0.27 (29)	575.0
3.2-3.7 miles	0.05 (11)	0.16 (16)	220.0
Mean (± SE)	0.15 (±0.06)	0.28 (±0.06)	182.8 (±86.2)

[1] Combined from Gagnon et al. 2014, Wilcoxon Matched Pair S = 10.5, df = 1, P = 0.02

Temporal Passage Rates before, during, and after Reconstruction

When the team analyzed passage rates temporally (by month, day of the week, and time of day), all post-construction rates increased when compared to rates before and during construction. The post-construction months other than July had an average passage rate increase of 181 percent (SE ±56.8, *U* = 7.4,*df* = 1, *P* = 0.007)(see Figure 26) but also showed monthly variation ranging from 0.1 crossings per approach (March) to 0.39 (August). Summer months generally had higher passage rates than fall months, which were more similar to the patterns before and during construction (2008-2010) noted by Gagnon et al. (2011); see Figure 26. Day of the week (Monday through Sunday) post-construction passage rates (0.23 crossings per approach, SE ±0.01) were 131.3 percent (SE ±17.6) higher than before and during construction rates (0.10 SE ±0.01, *U* = 10.3, *df* = 1, *P* = 0.001); see Figure 26. However, passage rates differed relatively little among days of the week, ranging from 0.22 to 0.27 crossings per approach. Post-construction time of day passage rates were 0.23 (SE ±0.03), or an increase of 130 percent (*U* = 8.4, *df* = 1, *P* = 0.004) when compared to before and during construction mean of .10 (SE ±0.01); see Figure 26.

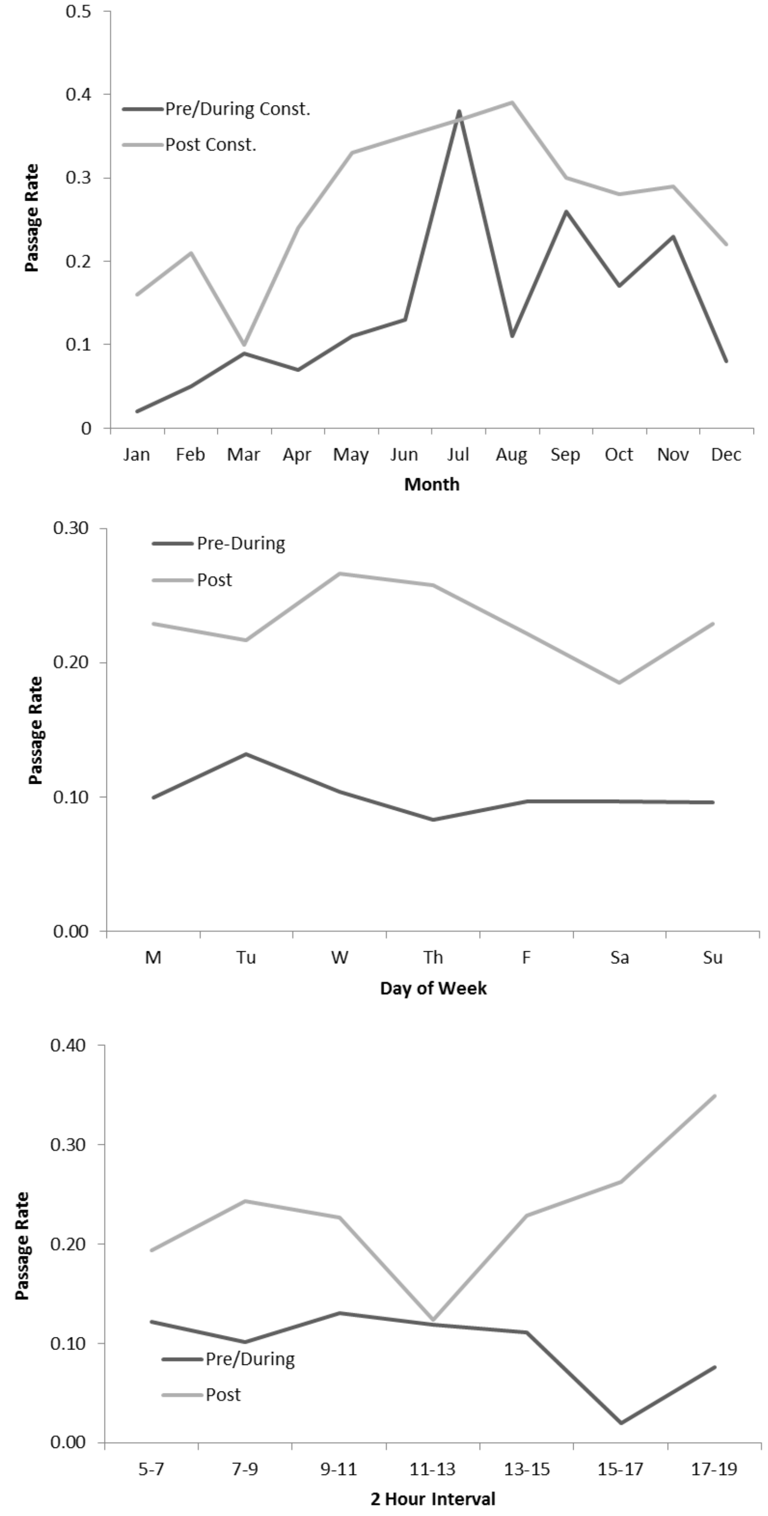

Figure 26. Mean Desert Bighorn Sheep Passage Rates before, during (black line) **and after Reconstruction** (gray line) **by Month** (top)**, Day** (middle)**, and Time of Day** (bottom). Two-hour intervals per GPS collar collection schedule of 0500 to 1900 hours

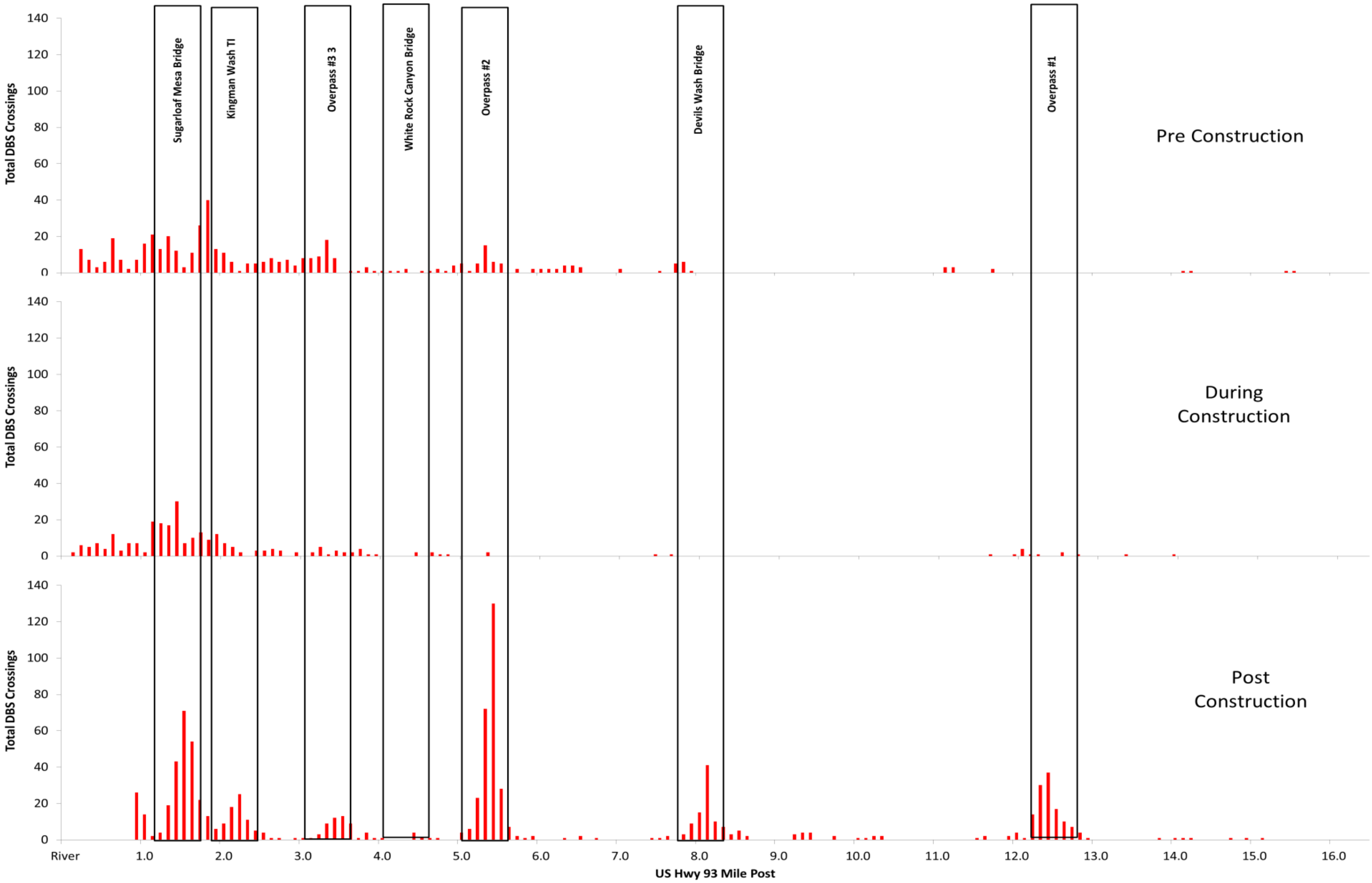

Figure 27. GPS-Collared Desert Bighorn Sheep Total Crossings before, during, and after Reconstruction.
Black boxes depict OPs and bridges constructed by ADOT.

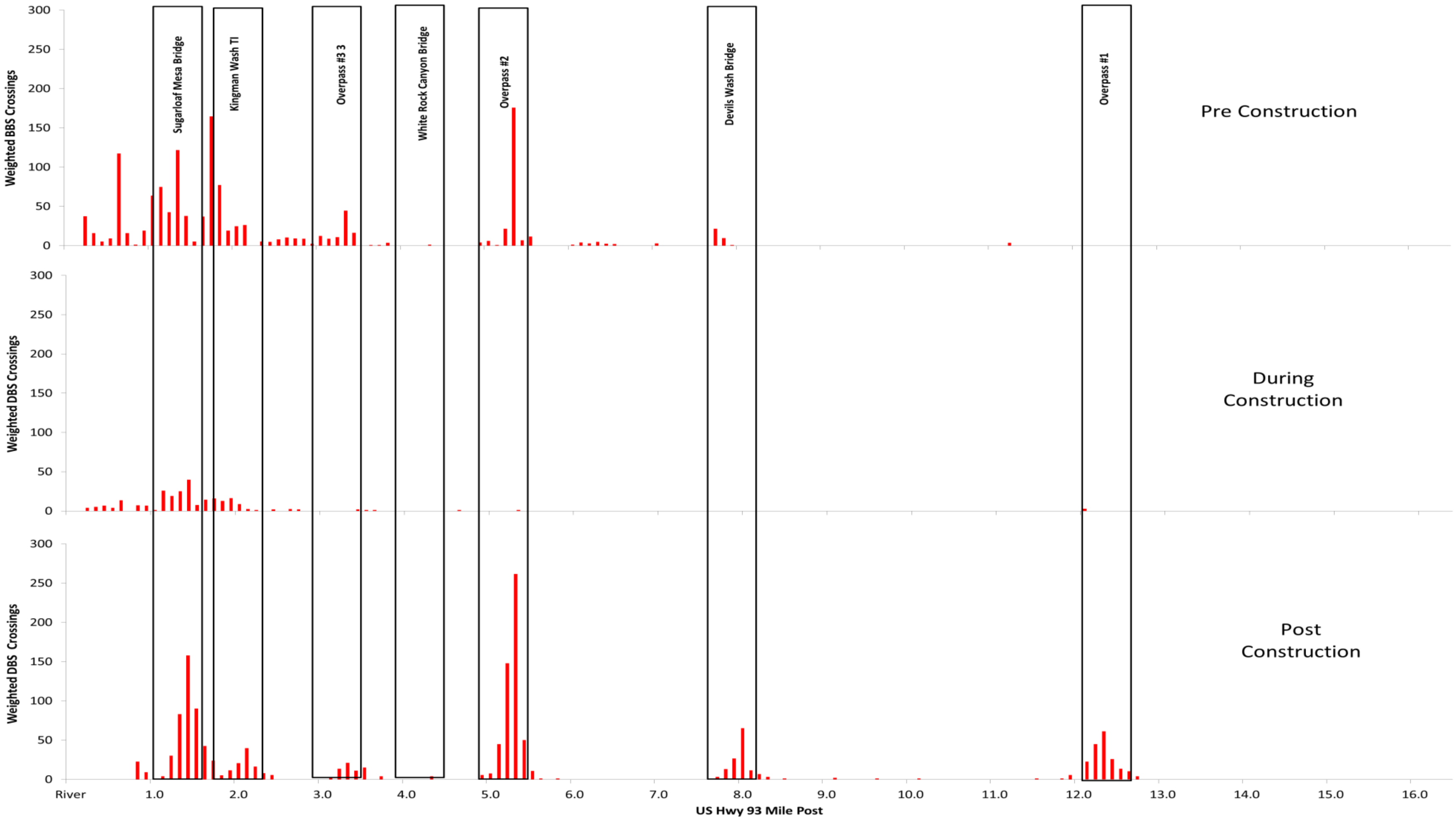

Figure 28. GPS-Collared Desert Bighorn Sheep Weighted Crossings before, during, and after Reconstruction.
Black boxes depict OPs and bridges constructed by ADOT.

Passage Rates and Traffic Volume

The research team found no significant change in passage rate as traffic volumes increased. Passage rates were slightly lower at the lowest traffic volumes (0-400) than at higher volumes (Figure 29). This indicates that when wildlife crossings are available, vehicular traffic volume has little or no impact on the ability of wildlife to utilize these crossings. This corroborates findings by Gagnon et al. (2007) for elk and Dodd and Gagnon (2011) for deer.

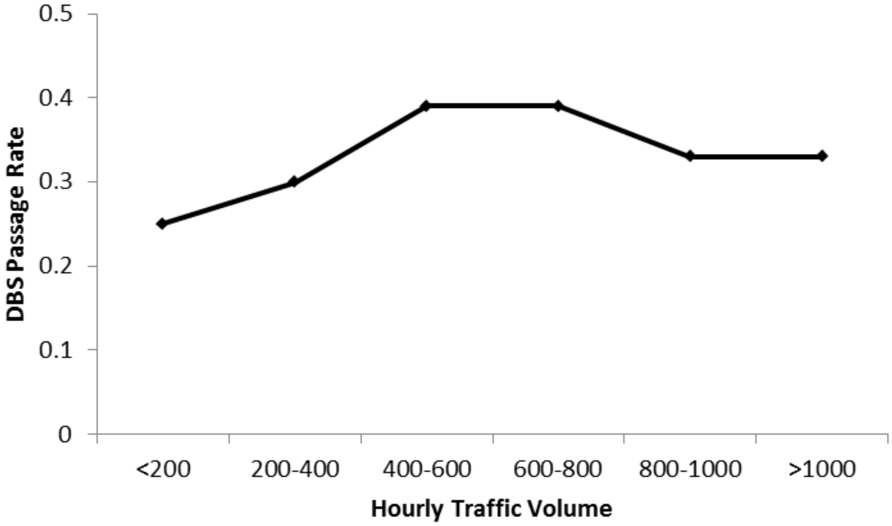

Figure 29. Mean Desert Bighorn Sheep Passage Rates by Traffic Volume Along U.S. 93, 2011-2014

EVALUATION OF OVERPASSES, BRIDGES, CULVERTS, ESCAPE RAMPS, AND CATTLE GUARDS

Overall Structure Use

From March 15, 2011 to March 15, 2015, the research team logged 11,680 days of video surveillance and still camera monitoring at eight structures. The camera systems recorded 15,134 crossings by nine species (Table 6, Figure 30). DBS accounted for 94 percent of all animals documented at the three OPs, while coyote and fox combined accounted for an additional 4 percent of all crossings (Table 6, Figure 30). The largest number of crossings were documented at the three OPs, accounting for 89 percent of all crossings (Table 6).

Table 6. Wildlife Use of Eight Structures along U.S. 93, MP 2-17, March 2011-March 2015

Structure	MP	DBS Crossings	Deer	Coyote	Bobcat	Fox	Other	All
OP #3	3.3	1407	2	75	0	52	6	1542
WRC	4	84	0	0	0	0	0	84
OP #2	5.2	2286	0	3	0	15	11	2315
Culvert 5.2	5.2	97	0	12	0	7	1	117
Culvert 6.0	6.0	96	0	8	1	15	1	121
DW	8.0	390	0	0	0	0	0	390
OP #1	12.2	2201	0	33	0	57	45	2336
Culvert 13.1	13.1	2	0	13	1	15	0	31
Total		**6563**	**2**	**144**	**2**	**161**	**64**	**6936**

When evaluating DBS use of the eight monitored structures, the research team noted a higher use of the three OPs over time (5861 crossings) than of the culverts (195) and of the washes under the bridges (474); see Figure 31a and Figure 31b. Use of the three OPs increased tenfold from 2011 (214 crossings) to 2012 (2151) before slightly dropping and leveling out in 2013 (1734) and 2014 (1762); see Figure 31a and 31b. Crossings in the washes under the two monitored bridges gradually increased from 53 crossings in 2011 to 171 crossings in 2014. Culvert use jumped dramatically from year 1 (1 crossing) to year 2 (67 crossings) and continued to increase in year 3 (110 crossings) before dropping back to only 17 crossings in year 4 (Figure 31a and 31b). Of the DBS crossings of the three types of structures, ewes accounted for 62 percent at the OPs and rams for 38 percent. Crossings under the bridges and through the culverts were more evenly distributed by sex, with 46 percent ewes and 54 percent rams using the bridges and use of the culverts equally divided.

Figure 30. Miscellaneous Wildlife Using Structures, U.S. 93 MP 2-17, March 2011-March 2015. Clockwise: (top left) bachelor herd of rams, (upper right) ewe with newborn lamb, (center right) bobcat at night, (lower right) kit fox at night, (lower left) mule deer buck, and (center left) coyote.

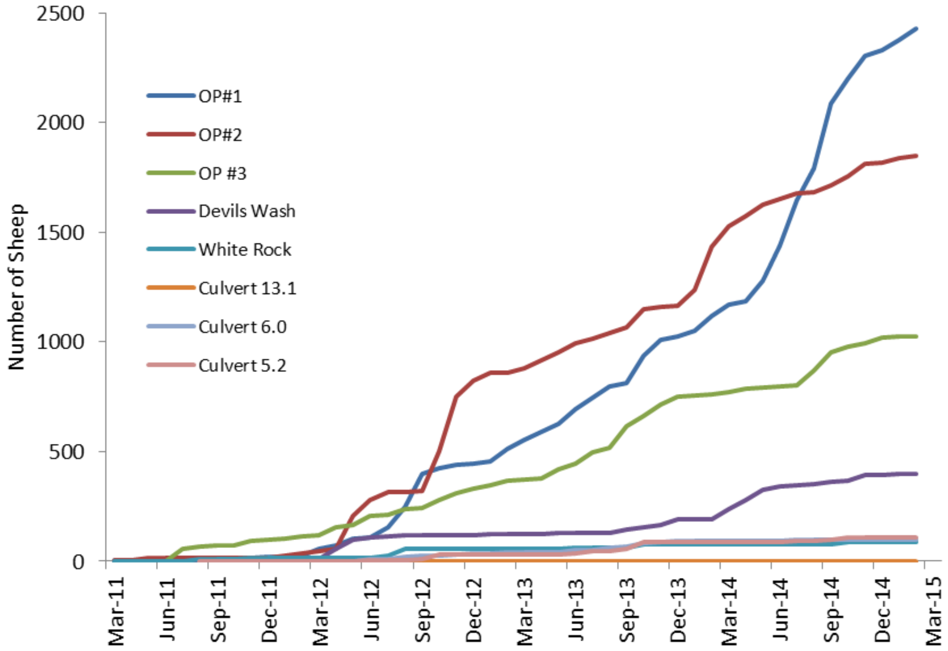

Figure 31a. Comparison of Cumulative Desert Bighorn Use of Eight Structures on U.S. 93, MP 2-17, March 2011-March 2015.

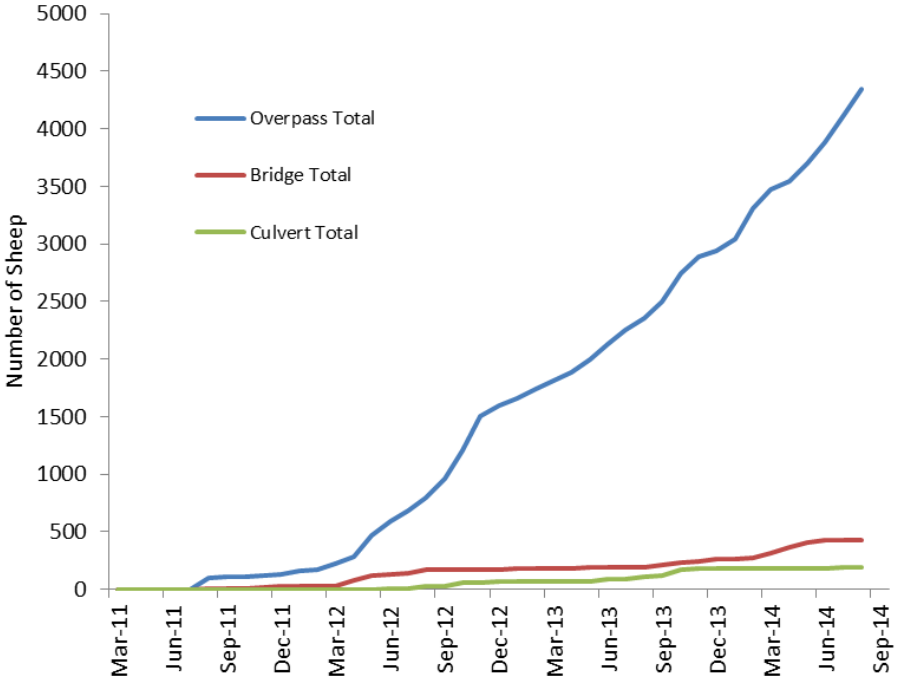

Figure 31b. Comparison of Cumulative Desert Bighorn Use by Structure Type (Overpass, Bridge, and Culvert) on U.S. 93, MP 2-17, March 2011-Sept. 2014

Desert Bighorn Sheep Overpass Use

Of the 5862 DBS OP crossings, researchers documented 2169 (37 percent) OP #1 crossings, 2286 (39 percent) OP #2 crossings, and 1407 (24 percent) OP # 3 crossings. The research team found DBS OP crossing use to change throughout the study. During year 1, OP #3 had more crossings (120) than OP #1 (53) and OP #2 (41) combined. However, the next three years had consistently higher OP #1 and OP #2 use when compared to OP #3 (Figure 31). Overall OP use by rams was initially higher (year 1 = 128) than by ewes (year 1 = 69). In the following three years, however, ewe OP crossings consistently exceeded those of rams and the study concluded with 2009 ram crossings versus 3297 ewe crossings over the four-year post-construction period. Juvenile use of OPs, like the usage by ewes, consistently increased and resulted in 528 juvenile OP crossings.

Ideally, the ratio of rams, ewes, and juveniles using the OPs would mirror that of the local population's sex and age ratios. However, the researchers did not find this mirroring. Instead, the four-year ratio of rams to ewes using the OPs exceeded that of the local population by 35 rams while the juveniles to ewes ratio was less than the population (18 fewer juveniles; Table 7).

Table 7. Comparison of Overpass Use with Local Population Estimate (AGFD Hunt Arizona 2015).
(Proportions expressed as rams per 100 ewes per juveniles)

	Rams : 100 Ewes : Juveniles				
Years Monitored	Year 1	Year 2	Year 3	Year 4	Average
Overpass Use	186:100:25	58:100:8	64:100:12	61:100:12	92:100:14
Local Population	77:100:31	62:100:39	45:100:27	45:100:31	57:100:32
Difference	+109:100:-6	-4:100:-31	+19:100:-15	+16:100:-19	+35:100:-18

The video surveillance systems captured 3044 events from 353 hours of recording. DBS were captured in 2393 (78.6 percent) of these events, which totaled 299 hours of footage. Of the 6780 sheep documented on video, 3902 (58 percent) approached the OPs from the west and were included in the passage rate analysis. During monitoring, the average DBS passage rates at all three OPs increased. Between years 1 and 2, the average passage rate increase was 168 percent, which then increased another 20 percent the following year (Table 8, Figure 32). The overall four-year DBS passage rate was 0.78 crossings/approach.

Table 8. Desert Bighorn Sheep Overpass Crossings and Passage Rates Compared by Sex, Age, and Structure, U.S. 93 MP 2-17, March 2011-March 2015

Overall DBS Crossings

OP	*Year 1*	*Year 2*	*Year 3*	*Year 4*	*Total*
#1	53	576	661	878	2168
#2	41	1094	684	467	2286
#3	120	481	389	417	1407
Total	214	2151	1734	1762	5861

Overall DBS Passage Rates

OP	*Year 1*	*Year 2*	*Year 3*	*Year 4*	*Total*
#1	0.24	0.78	0.94	0.91	0.72
#2	0.16	0.82	0.86	0.80	0.66
#3	0.44	0.65	0.89	0.90	0.72
Mean	0.28	0.75	0.90	0.87	0.70

Ram Crossings

OP	*Year 1*	*Year 2*	*Year 3*	*Year 4*	*Total*
#1	53	342	437	317	1149
#2	29	220	173	106	528
#3	46	131	60	95	332
Total	128	693	670	518	2009

Ram Passage Rates

OP	*Year 1*	*Year 2*	*Year 3*	*Year 4*	*Total*
#1	0.39	0.84	0.93	0.92	0.77
#2	0.24	0.83	0.86	0.92	0.71
#3	0.49	0.80	0.82	0.89	0.75
Mean	0.37	0.82	0.87	0.91	0.74

Ewe Crossings

OP	*Year 1*	*Year 2*	*Year 3*	*Year 4*	*Total*
#1	0	211	181	413	805
#2	8	826	452	339	1625
#3	61	317	264	224	866
Total	69	1354	897	976	3296

Ewe Passage Rates

OP	*Year 1*	*Year 2*	*Year 3*	*Year 4*	*Total*
#1	0.00	0.73	1.00	0.90	0.66
#2	0.09	0.83	0.87	0.78	0.64
#3	0.36	0.64	0.89	0.90	0.70
Mean	0.15	0.73	0.92	0.86	0.67

Juvenile Crossings

OP	*Year 1*	*Year 2*	*Year 3*	*Year 4*	*Total*
#1	0	23	39	143	205
#2	4	37	55	12	108
#3	13	41	63	98	215
Total	17	101	157	253	528

Juvenile Passage Rates

OP	*Year 1*	*Year 2*	*Year 3*	*Year 4*	*Total*
#1	0.00	0.67	1.00	0.92	0.65
#2	0.13	0.76	1.00	0.45	0.59
#3	0.75	0.37	0.97	0.93	0.76
Mean	0.29	0.60	0.99	0.77	0.66

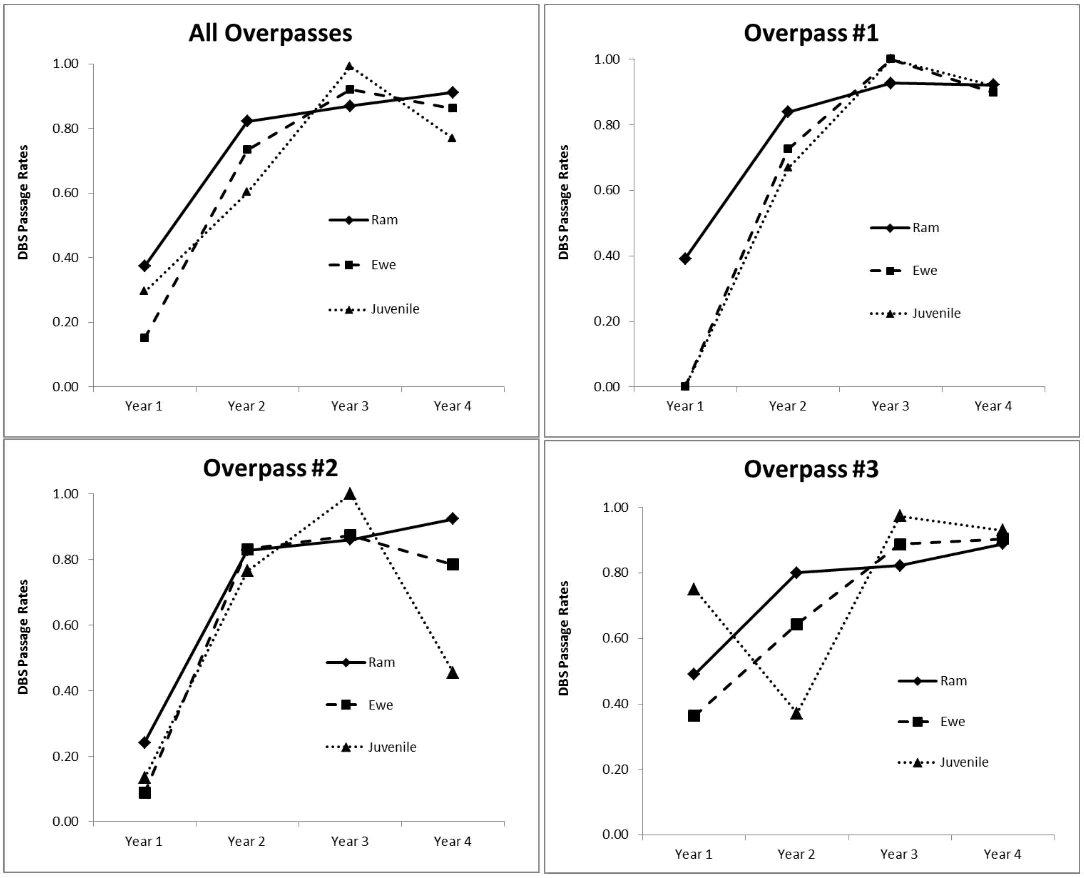

Figure 32. U.S. 93 Desert Bighorn Sheep Passage Rate (Crossings/Approaches) by Sex and Age, March 2011-March 2015

When comparing DBS passage rates between OPs, year 1 documented sheep using OP #3, the 100-foot structure, at a rate (0.44 crossings/approach) that was 2.8 times and 1.8 times greater than that of OP #2 and OP #1, the 50-foot structures (0.16 crossings/approach and 0.24 crossings/approach respectively). However, during year 2, the narrower structures' passage rates (OP #2 0.82 crossings/approach; OP #1 0.78 crossings/approach) surpassed those of OP #3 (0.65 crossings/approach) and at the end of the study, all structures had passage rates within 5 percent of each other.

OP use by rams, ewes, and juveniles also varied by year and OP structure (Table 8). In year 1, the average ram passage rate (0.37 crossings per approach) was more than double that of ewes (0.15 crossings/approach) and 28 percent more than that of juveniles (0.29 crossings/approaches; Table 8). While rams' year 1 use was relatively similar for all OPs (OP #1: 0.39, OP #2: 0.24, and OP #3: 0.49), ewes primarily used OP #3 (OP #1: 0.00, OP #2: 0.09, and OP #3: 0.36) as did juveniles (OP #1: 0.00, OP #2: 0.13, and OP #3: 0.75; Table 8). At the end of the study, however, rams, ewes and juveniles had used all three OPs relatively equally (Table 8).

Desert Bighorn Sheep Crossings Under Bridges

Still cameras placed at the WRC and DW Bridges documented 572 DBS approaches (99 and 473 respectively). Of the 572 approaches, 474 under-bridge crossings occurred; the dry wash at WRC had 84 DBS under-bridge crossings (18 percent of under-bridge crossings) and the dry wash at DW had 390 (82 percent of under-bridge crossings; Table 9).

Figure 33. Desert Bighorn Sheep Using Dry Washes to Cross Under U.S. 93 at the Devils Wash Bridge (top) **and White Rock Canyon Bridge** (bottom)

At WRC’s dry wash, yearly sheep use was consistently low and averaged 20 DBS crossings under the bridge per year, while crossings under the DW Bridge increased from 35 (year 1) to 153 (year 4; Table 9, Figure 34). Ram use fluctuated from year to year while ewe and juvenile use increased (Table 9, Figure 34). In general, the dry washes at the bridges showed low use (6.8 percent of all crossings) when compared to the OPs (89.0 percent).

Table 9. Desert Bighorn Sheep Use of Dry Washes at White Rock Canyon and Devils Wash Bridges per Study Year by Sex and Age, March 2011-March 2015

Both Bridges	Year 1	Year 2	Year 3	Year 4	Total
White Rock	18	28	20	18	84
Devils Wash	35	90	112	153	390
Total	53	118	132	171	474
White Rock	Year 1	Year 2	Year 3	Year 4	Total
Ram	2	6	5	5	18
Ewe	16	22	15	11	64
Juvenile	0	0	0	2	2
Total	18	28	20	18	84
Devils Wash	Year 1	Year 2	Year 3	Year 4	Total
Ram	13	71	69	32	185
Ewe	21	16	33	104	174
Juvenile	0	3	9	17	29
Total	34	90	111	153	388
Both Bridges	Year 1	Year 2	Year 3	Year 4	Total
Ram	15	77	74	37	203
Ewe	37	38	48	115	238
Juvenile	0	3	9	19	31
Total	52	118	131	171	472

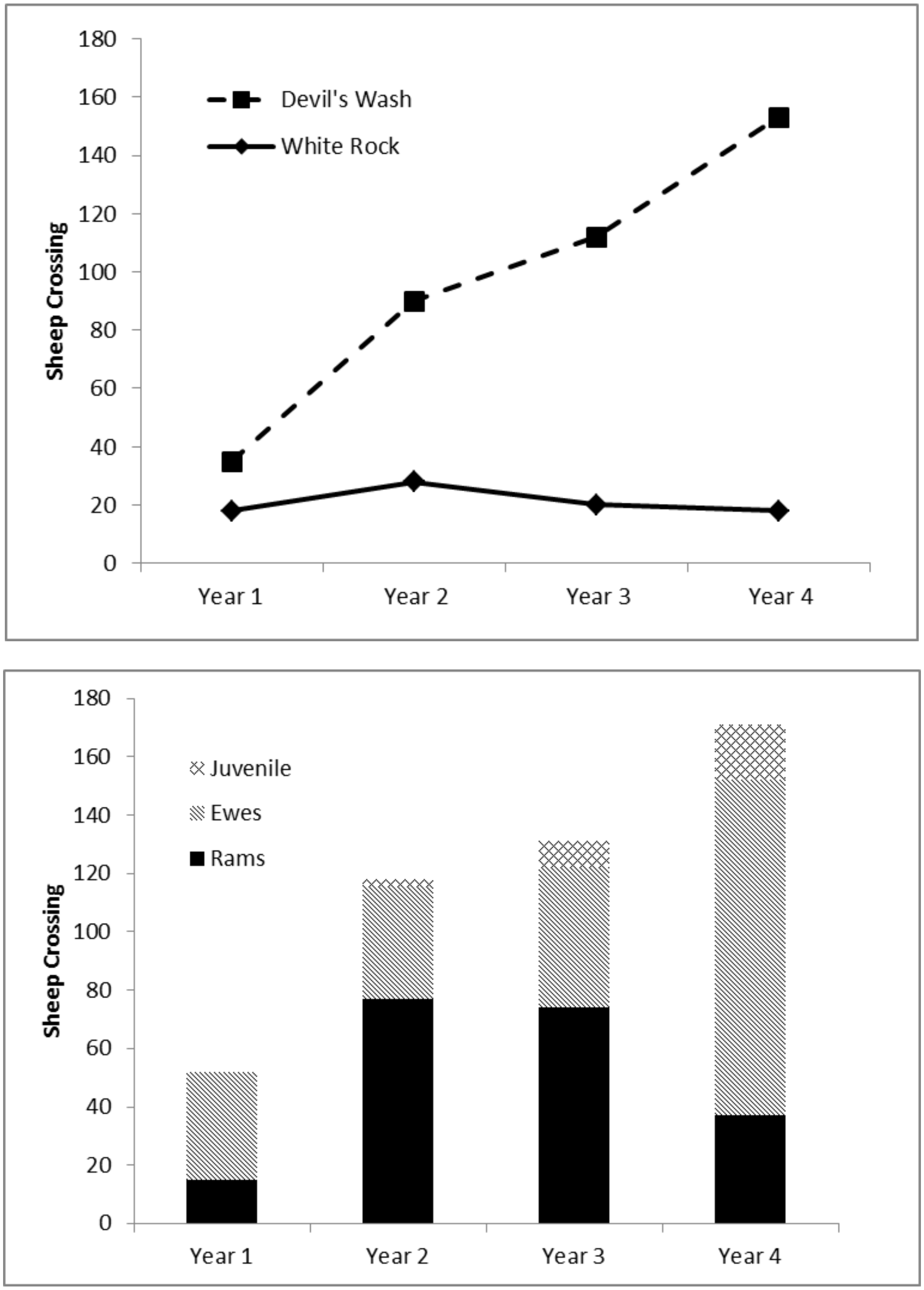

Figure 34. Desert Bighorn Sheep Yearly Crossings, Year 1 to Year 4, in Washes Under White Rock Canyon and Devils Wash Bridges on U.S. 93.
Total yearly crossings in washes (top), yearly use of washes by sex and age (bottom).

In addition to documenting DBS activity under the bridges, the cameras also captured 17,553 people and 904 dogs using the dry wash under WRC Bridge in 2011. When human use was high, sheep use was correspondingly low (Figure 35).

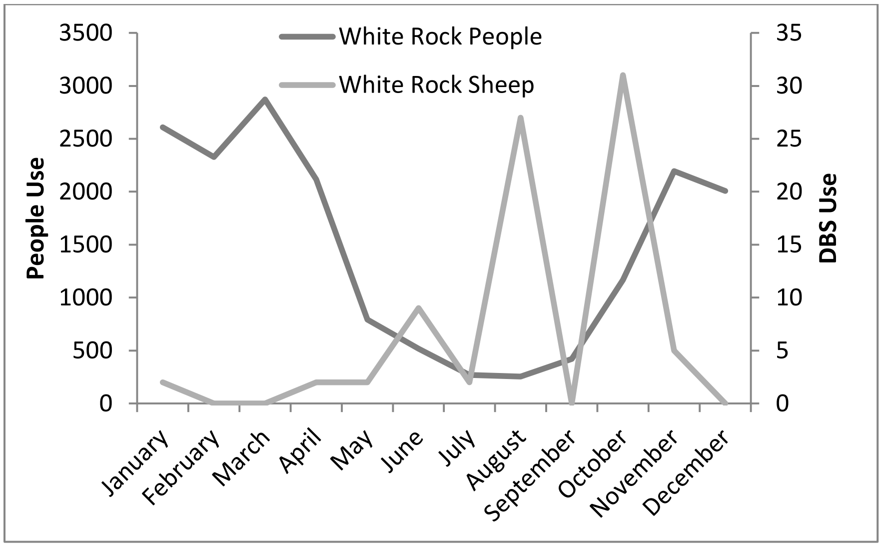

Figure 35. Human and Desert Bighorn Sheep Monthly Use Under White Rock Canyon Bridge in 2011

Desert Bighorn Sheep Culvert Use

At the three culverts on the reconstructed segment of U.S. 93, the research team documented 640 DBS culvert approaches and 195 crossings under the roadway (0.30 crossings per approach). DBS use at the MP 5.2 and MP 6.0 culverts increased considerably from year 1 (0 and 1 crossing respectively) to year 2 (30 and 37) to year 3 (57 and 52) before decreasing in year 4 (to 10 and 6; Figure 36). The MP 13.1 culvert had two DBS crossings (not apparent in the figure due to scale). Ram culvert use overall (94 crossings) was nearly identical to ewe culvert use (93 crossings).

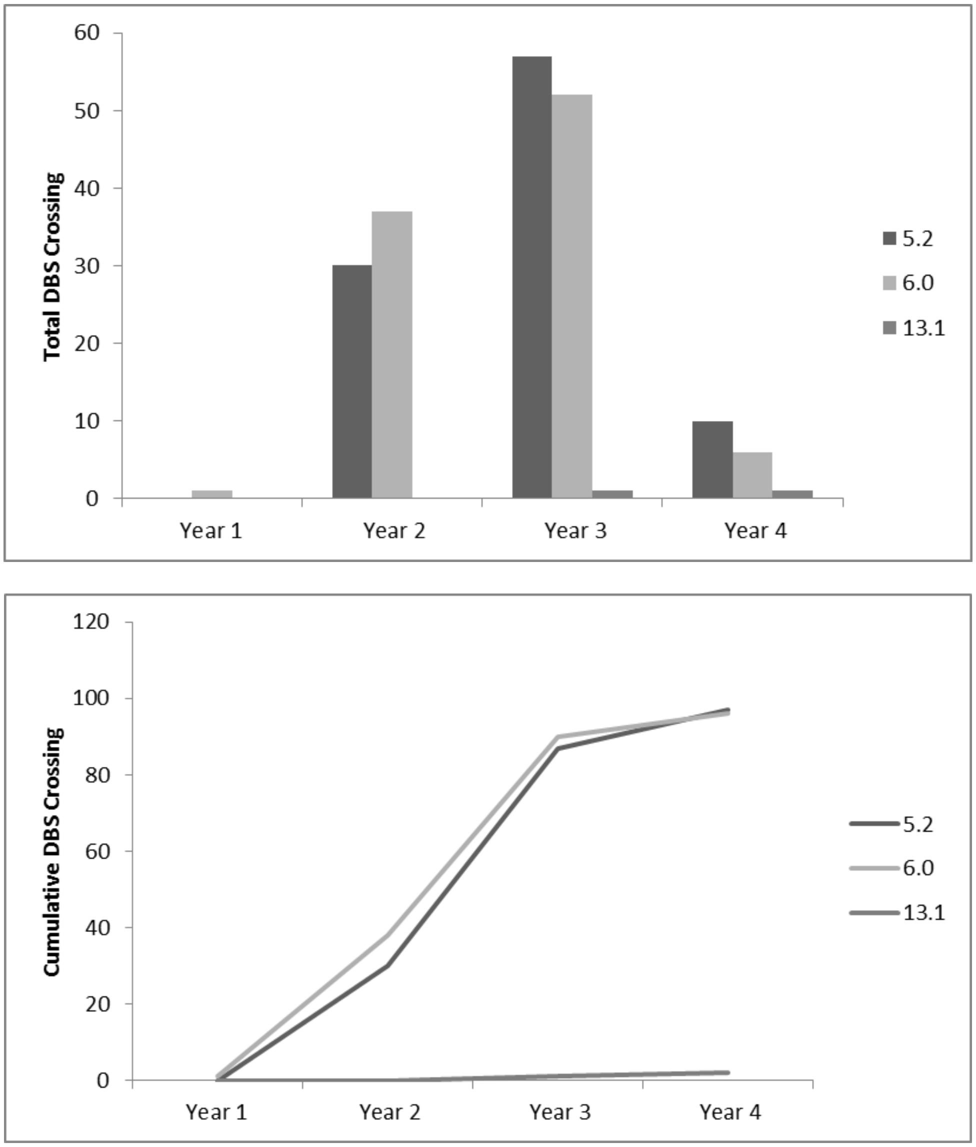

Figure 36. Desert Bighorn Sheep Culvert Use Under U.S. 93, Years 1 through 4 — Total Use (top) and Cumulative Use (bottom)
Legend: MP 5.2 culvert, MP 6.0 culvert, MP 13.1 culvert

Desert Bighorn Sheep Escape Ramp Use

Still cameras captured 2662 images of DBS approaching eight U.S. 93 escape ramps and 150 sheep using the ramps. Of these 150 sheep, 90 percent (135) used them to exit the ROW while 10 percent (15) used them to access the ROW (Figure 37).

Figure 37. Monitoring the Progression of Escape Ramp Improvements.
Clockwise from upper left: Desert bighorn sheep entering ROW via escape ramp as initially built; herd exiting ROW via escape ramp outfitted with additional wire; single sheep exiting ROW via escape ramp with polyvinyl chloride pipe meant to enhance wire visibility; and bighorn exiting the ROW via escape ramp with adjustable metal bar.

Cattle Guard Effectiveness

Two Kingman Wash TI still cameras documented DBS entering the ROW via single-wide cattle guards. The cameras recorded 840 DBS, non-ROW side approaches and 124 of those sheep crossed the guards for a passage rate of 15 percent (0.15 crossings/approach; Figure 38). The passage rate for sheep exiting the ROW was 81 percent (44 crossings/54 approaches; Figure 38).

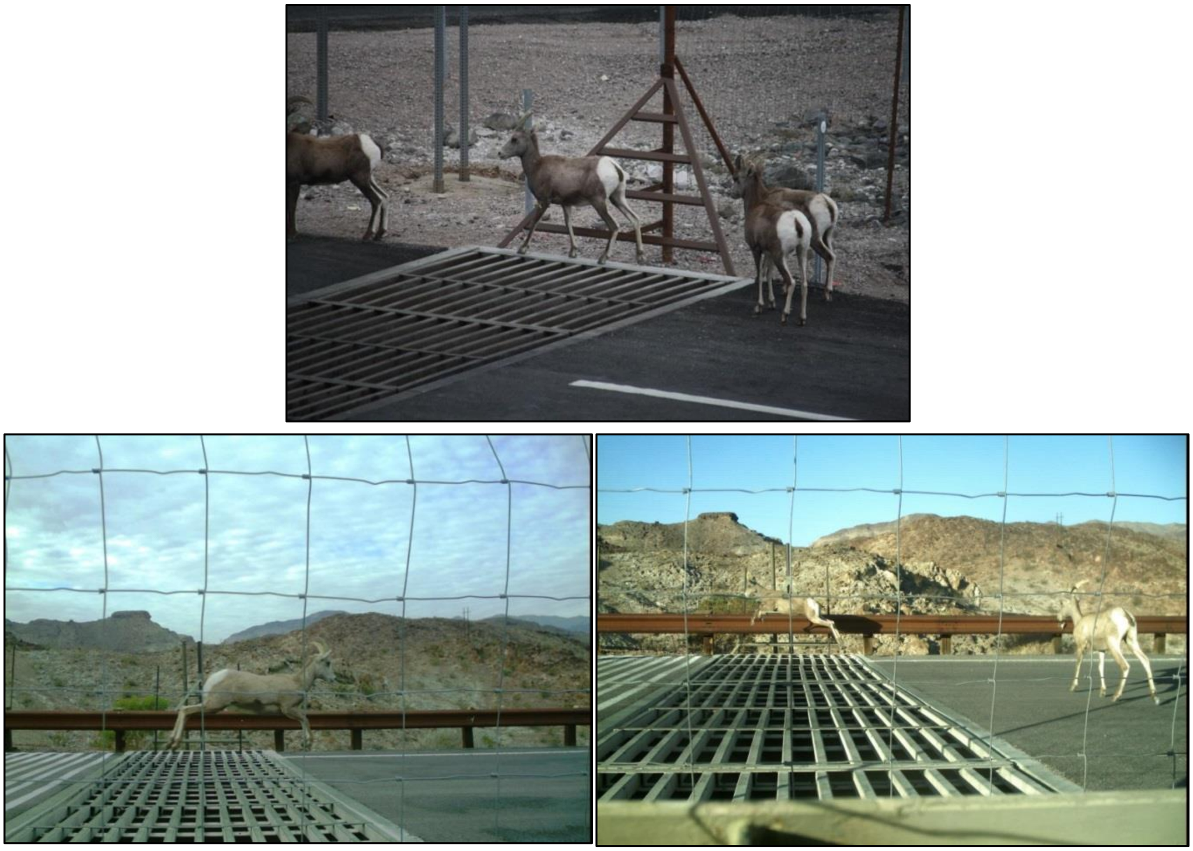

Figure 38. Desert Bighorn Sheep Using Kingman Wash TI Single-Wide Cattle Guards to Exit ROW (top and bottom left) **and Enter ROW** (bottom right). In 2015, ADOT made them double-wide.

DESERT BIGHORN SHEEP-VEHICLE COLLISIONS

After construction of the mitigation measures, DBS-vehicle collisions per year along U.S. 93 (MP 0 to MP 17) have declined by approximately 86 percent from the historic yearly average of 11 DBS-vehicle collisions reported by Cunningham and Hanna (1992) before construction. Wildlife exclusion fencing was completed in March 2011, and from then through 2015, eight DBS-vehicle collisions have been documented (the team continued to collect collision data following year 4 of the monitoring study). These collisions occurred between MP 0.8 and MP 3.2, involved two rams and six ewes (Table 10, Figure 39), and constitute a rate of 1.6 DBS-vehicle collisions per mile per year from 2011-2015.

Many of the eight sheep-vehicle collisions may have resulted from sheep accessing the road in four ways: 1) passing through holes in the fence, 2) jumping up escape ramps (the wrong direction) to enter the ROW, 3) jumping over single-wide cattle guards at the Kingman Wash TI, and 4) circumventing the fencing through a missing section of fencing where the ROW fence meets the O'Callaghan-Tillman Memorial Bridge. With this information, ADOT Kingman Maintenance permanently repaired each escape ramp by adding a horizontal bar above the ramp platform. Monitoring will continue ofsheep use of escape ramps through the current ADOT/AGFD research project (SPR-729); and ADOT will modify this horizontal bar's height if needed. In 2014, ADOT Kingman Maintenance replaced, re-anchored, and added a section of ROW fence adjacent to the O'Callaghan-Tillman Memorial Bridge and repaired a washed out section of the fence under the traffic bridges at WRC. In 2015, ADOT installed double-wide cattle guards at the Kingman Wash TI, which may deter sheep from jumping the cattle guards to enter the ROW. Evaluation of these cattle guards will occur during a currently ongoing ADOT/AGFD research project (SPR-729). The research team anticipates that the adaptive management approach ADOT has taken to address these concerns will nearly eliminate future DBS-collisions from MP 0-17 .

Table 10. DBS-Vehicle Collisions Documented on U.S. 93, 2008-2010

Year	Month	MP	Sex/Age
2011	July	2.2	Ram/Adult
2011	July	2.0	Ewe/Adult
2011	July	3.1	Ewe/Adult
2011	October	0.9	Ewe/Adult
2011	November	0.8	Ram/Adult
2012	May	3.1	Ewe/Adult
2012	November	0.8	Ewe/Adult
2014	May	3.2	Ewe/Adult

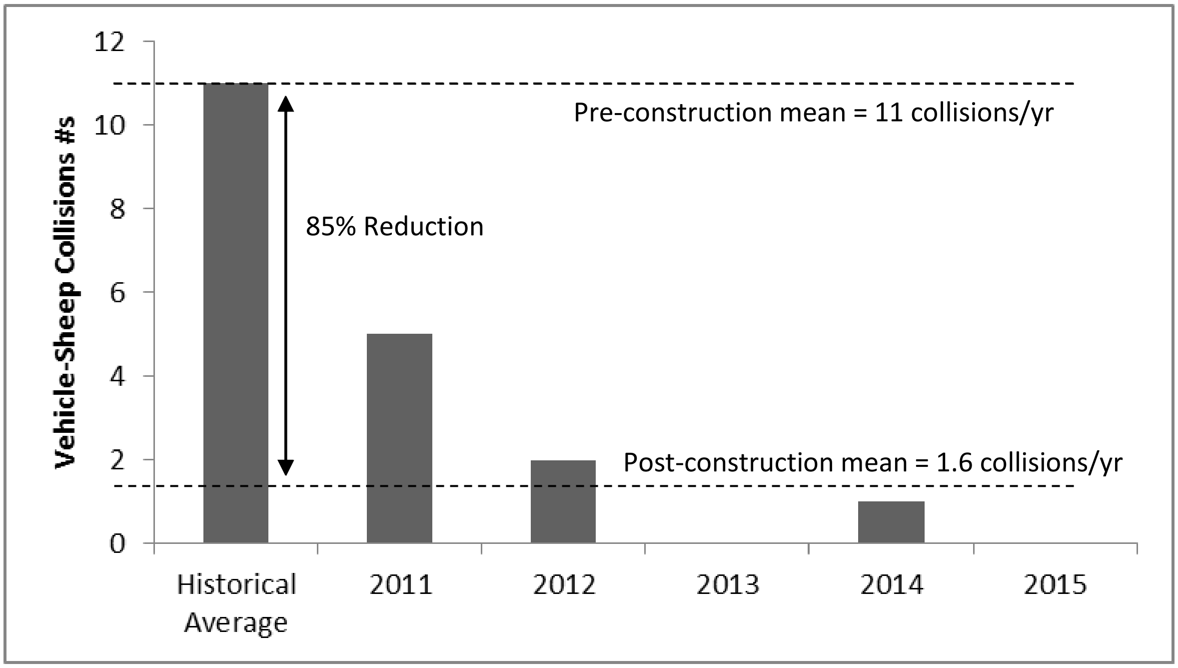

Figure 39. Reduced DBS-Vehicle Collisions, 2011-2014, Compared with Historical Levels

CHAPTER 5: DISCUSSION

The research team used various methods and U.S. 93 research before and during reconstruction (Cunningham and Hanna 1992, McKinney and Smith 2007, Gagnon et al. 2014) to determine the effectiveness of ADOT's mitigation measures that were designed to decrease the impact of the reconstructed U.S. 93 on DBS habitat fragmentation and reduce DBS-vehicle collisions. To measure mitigation effectiveness, the researchers used: 1) GPS collar relocation points to determine the newly constructed roadway's influence on sheep movements; 2) video and still camera surveillance to establish the effect that structures and exclusion fencing had on DBS movements; and 3) DBS-vehicle collision data to verify the ability of the mitigations to reduce DBS-collisions. These methods and the prior research data allowed researchers to objectively determine the effectiveness of mitigation measures and gain a better understanding of how various measures function together to address DBS welfare and motorist safety.

DESERT BIGHORN SHEEP HIGHWAY CROSSINGS AND PERMEABILITY

Generally, road reconstruction or widening is detrimental to wildlife because the new road continues to impede or further impedes wildlife movement. The roadway's impermeability (its unintended action as a barrier to normal wildlife movement) fragments wildlife habitat into smaller parcels that may not contain all the resources needed for survival of a population or subpopulation. However, reconstruction or widening also presents an opportunity to increase roadway permeability by incorporating properly designed and located wildlife crossing structures and exclusion fencing, which work together to permit animals to safely access resources on either side of the roadway. For many agencies and organizations, the reconstruction of U.S. 93 was an opportunity to increase DBS habitat connectivity, which prior to reconstruction was minimal and would have been reduced further as anticipated traffic volumes increased (Gagnon et al. 2014).

Prior to reconstruction, U.S. 93 between MP 2.2 and MP 17 constituted a notable barrier to DBS (McKinney and Smith 2007, Gagnon et al. 2014). A roadway's barrier effect can be quantified by calculating a species passage rate, which is the ratio of animal road crossings divided by animal road approaches (i.e., animal crossings per animal approach). The mean U.S. 93 DBS passage rate before and during reconstruction was less than 10 percent, a rate comparable to that of other species sensitive to highway barrier effects (Alexander et al. 2005, Dodd and Gagnon 2011, Dodd et al. 2011;2012b). Agencies and organizations involved with U.S. 93 reconstruction believed that the roadway's DBS permeability and passage rate would improve substantially with new WCS and fencing. This belief was verified by post-construction passage rate evaluation that underscores the effectiveness of properly implemented WCS and fencing.

Spatial Crossing Patterns and Passage Rates

Prior to reconstruction, DBS roadway crossings from MP 0 to 17 were few and the majority of these occurred between MP 0 and 2.2 where the dry wash at the expansive Sugarloaf Mountain Bridge is located. Two other bridges (WRC and DW) had dry washes also available for DBS use for crossing under the roadway, but they were utilized only a few times. This underutilization may be due partially to the absence of wildlife fencing to guide sheep to the washes under the bridges. During post-construction monitoring, when fencing was in place, DBS adjusted their MP 0-17 movement patterns and crossed over U.S. 93 primarily on OPs, but occasionally passed under the roadway bridges using the dry washes and culverts. The post-construction MP 2.2-17 DBS passage rate increased by 280 percent and the area's crossing rate per route mile far exceeded those of MP 0-2.2. Additionally, a 171 percent passage rate increase was documented for roadway sections more than 1.2 mi from the Colorado River, which is an important water source in this extremely arid environment, and suggests that wildlife crossings provided easier DBS access to the river's water and other essential resources. These results also seem to indicate that DBS consider OPs to be a more direct and reliable route versus travelling further distances along the roadway to the river and provide further evidence that wildlife passing structures and fencing increase roadway permeability for wildlife.

Desert Bighorn Sheep Temporal Passage Rates

The post-construction U.S. 93 passage rate from MP 2.2-17 increased 1143 percent during the study and showed monthly, day of the week, and time of day increases. Although a passage rate increase was expected based on prior elk and deer research (Dodd and Gagnon 2011, Gagnon et al. 2011, Sawyer et al. 2012, Cramer 2013), a change of this magnitude was unexpected given the prior road avoidance by DBS along U.S. 93. This temporal passage rate increase highlights the ability of appropriately placed OPs and fencing to allow DBS the daily and seasonal movements necessary to access the resources needed for individual survival and population persistence.

Desert Bighorn Sheep Passage Rates and Traffic Volume

Vehicular traffic can function as a "moving fence" that physically makes roadways impermeable to wildlife crossing at grade (Bellis and Graves 1978), and the "fence" effect becomes greater as the number of vehicles increases. Traffic volume also fluctuates throughout the day and diurnal species, such as DBS, are generally exposed to higher daytime volumes than are nocturnal species (e.g., elk). Theoretical models (Iuell et al. 2003, Seiler 2003) suggest that highways with 4000 to 10,000 AADT present strong barriers to wildlife passage, and highways with more than 10,000 AADT are impermeable barriers. However, prior research with elk and deer suggests that crossing structures can reduce these traffic volume barrier effects (Gagnon et al. 2007a, Gagnon et al. 2007b, Dodd and Gagnon 2011) and the research team found this to be the case for DBS along U.S. 93. During this study, U.S. 93 had an AADT of more than 13,000, which theoretically should be an impermeable barrier. After construction of the mitigation measures, however, DBS crossings of U.S. 93 increased and continued to do so at rates that outpaced growth in traffic volumes.

WILDLIFE CROSSING STRUCTURES AND FENCING

During the four years following reconstruction, which included adding wildlife crossings and exclusion fencing, DBS passage rates increased by 167 percent, and DBS-vehicle collisions fell by 85 percent. Without these comprehensive connectivity mitigation measures, U.S. 93 reconstructed as, a four-lane divided highway, along with the increased AADT, would have exacerbated the existing barrier effect and hastened the genetic isolation of the Black Mountains DBS population (Epps et al. 2005, Jaeger et al. 2005a, Jaeger et al. 2005b). Additionally, DBS attempting to cross U.S. 93 at grade to access essential resources would have increased the likelihood of DBS-vehicle collisions and placed more motorists and sheep at risk. These risks, however, seem to have been mitigated by the U.S. 93 crossing structure placement and design, along with exclusion fencing.

Wildlife Crossing Placement

Proper placement of crossing structures along known animal travel corridors is essential to the structures' prompt success. Travel corridor locations can be obtained through various methods: roadkill data, wildlife movement data, or modelling (Clevenger et al. 2002, Dodd et al. 2007b, McKinney and Smith 2007, Gunson et al. 2009, Sawyer et al. 2016). Each method has its functionality and depends on the existence and availability of reliable data and expert opinion. Roadkill and wildlife movement methods are data-driven approaches that depend on the existence or collection of species-specific, long-term, consistent, accurate, and fine-scale data. Modelling is a theoretical method that often relies more on expert opinion than on data. Although long-term, consistent, accurate, and fine-scale data did not exist for DBS within the study area, a data-driven approach was considered an appropriate method to place structures in line with sheep travel corridors. McKinney and Smith (2007) placed GPS collars on DBS to collect data that defined ridgeline DBS travel corridors that intersected U.S. 93. The crossing structures were located at these ridgelines and sheep began using them shortly after reconstruction was completed.

Wildlife Crossing Design

In the past, little was known about WCS design and many wildlife and roadway planning teams assumed that generalized structure types would serve a variety of species. However, roadway ecology research has discovered that individual species react differently to structure design. Elk will most readily use large UPs that have natural slope embankments and are aligned to ensure maximum visibility from one side of the roadway to the other (Dodd et al. 2007d, Gagnon et al. 2011). Deer will use smaller UPs than elk but are sensitive to structure size (Reed 1981, Gordon and Anderson 2003, Sparks Jr and Gates 2012, Cramer 2013). Pronghorn, which rely on eyesight and speed to avoid and evade predators, prefer OPs to UPs (Sawyer et al. 2016). Likewise, DBS that rely on vision and steep or rugged terrain to avoid predation do not readily use UPs (Bristow and Crabb 2008). These roadway ecology findings factored into ADOT's decision to construct U.S. 93 OP structures for DBS, which the sheep used 6563 times (representing 90 percent of all documented DBS crossings) to cross over the roadway. These research findings further support the idea that species-specific crossing structure design is important.

Exclusion fencing is an important component of the success of a WCS. When structures cannot be placed at all desirable locations in a wildlife corridor, or a locally feasible design is not appropriate to a particular species, exclusion fencing can guide animals to the crossing and occasionally compel them to cross. Without fencing, many species will avoid using an unfamiliar structure and continue to cross at grade. This structure avoidance was documented for elk along SR 260 where ADOT constructed seven wildlife crossings within a five-mile roadway segment (Dodd et al. 2007a, Dodd et al. 2012a). The initial project included minimal exclusion fencing and within the first year, 50 elk-vehicle collisions were documented and video crossing surveillance showed that 81 percent of the animals avoided the structures and crossed at grade (Dodd et al. 2007c). When additional fencing was added, elk-vehicle crashes were reduced by 87 percent and wildlife structure use increased by 522 percent (Dodd et al. 2007c). Gagnon et al. (2015) demonstrated that fencing can compel elk to use structures that were initially designed for drainage purposes. However, fencing did not compel many U.S. 93 DBS to use drainage structures (bridges), which further indicates that DBS prefer to cross over roadways.

The original MP 2−17 reconstruction plans included 1.6 miles (11 percent) of 7-foot fencing in the roadway corridor. After discussions with the AGFD, additional 7-foot fencing was installed between MP 2.4 and MP 5.7 and on either side (0.3 mi) of the DW Bridge and MP 12.2 OP. This represented 4.5 miles (31 percent) of the roadway corridor and was anticipated to intercept 82 percent of the DBS at-grade road crossing attempts and funnel the animals toward the passage structures. Five-foot fence was installed in the remainder of the corridor. Since limited or intermittent fencing reduces the success of mitigation measures and can increase collisions (Ward 1982, Clevenger et al. 2001b, Dodd et al. 2007c, McCollister and van Manen 2010, Huijser et al. 2016), this continuous fencing likely contributed to OP success and DBS-vehicle collision reduction. The combination of appropriately designed and placed OP structures and fencing appears central to the success of U.S. 93 mitigation measures and is a model for future wildlife-roadway mitigation projects.

Desert Bighorn Sheep Mitigation Structure Use

During the four years following reconstruction, collared DBS made 5862 crossings of the three OP structures. These represent approximately 90 percent of DBS crossings at all monitored structures (three OPs, two dry washes under bridges, and three culverts). Although these results were anticipated based on the findings of Bristow and Crabb (2008) and McKinney and Smith (2007), the effect of various OP widths on use of DBS structures was unknown. The reconstructed U.S. 93 has three OPs: two 50 feet wide and one 100 feet wide. All are 203 feet in length. The first year of monitoring found that the 100-foot OP was more successful (had more DBS crossings and a higher passage rate) than either 50-foot structure. However, at the end of the four-year monitoring period, both 50-foot structures either equaled or exceeded the 100-foot OP’s crossings and passage rates and all OPs converged on an average of 0.87 crossings per approach. These findings support the conclusion that, given adequate time, DBS can adapt to 50-foot and 100-foot wide OPs. In addition, these findings emphasize the importance of long-term monitoring. If researchers made determinations based on only one year of monitoring, the data would have supported the conclusion that 100-foot OPs more effectively allow DBS to cross roadways than 50-foot structures. It is assumed that the resulting recommendation would have incorrectly advocated the need for more expensive 100-foot-wide OPs, which would have unnecessary increased the cost of future DBS roadway projects.

Prior to this study, not only was the appropriate structure width for OPs unknown, but so was whether all sexes and age classes would use the OPs. Past research (Bristow and Crabb 2008) documented a few rams using UPs, but did not record any ewe or lamb usage. This limited and single-sex use was not expected to be the case for OP structures, which were predicted to promote crossings by rams, ewes, and lambsfor reasons mentioned above. During the study's first year, rams used all OPs while ewes and lambs primarily focused their use on the 100-foot-wide structure. Long-term monitoring, however, did not support this short-term conclusion. Overall, all the structures, regardless of width, were used by many DBS rams, ewes, and lambs to cross over U.S. 93.

DBS adapting to structure size over time indicates that sheep have a learning curve similar to elk, deer, and pronghorn (Clevenger and Waltho 2003, Gagnon et al. 2011, Sawyer et al. 2012, Sawyer et al. 2016). In addition, Gagnon et al. (2011) and Sawyer et al. (2016) also noted that elk and mule deer have a similar convergence of passage rates over a multi-year period. Sawyer et al. (2012) suggest that mule deer take up to three years to adapt to structures. However, Gagnon et al. (2011) documented structures where use did not increase over time and some structures where use decreased. These researchers concluded that the lack of wildlife use was attributable to structure size (e.g., too confining) or uninviting (e.g., site-specific variables such s line of sight across the highway).

When departments of transportation invest limited resources in new wildlife crossings, the investment's return can be measured in species-specific passage rates. U.S. 93 OP passage rates indicate that these structures most effectively reduce DBS habitat fragmentation. The dry washes at bridges and culverts are used less than OPs consistent with a previous study (Bristow and Crabbe 2008). Although the research found 50-foot- and 100-foot-wide OPs to convey sheep over the roadway effectively, it is likely that DBS, like most wildlife, have a threshold of confinement, and OP widths of much less than 50 feet may not be effective. To determine a DBS confinement threshold, narrower OPs would need to be constructed and long-term monitoring established, or alternatively, an existing OP could be artificially narrowed and monitored. Both alternatives have risks. The newly constructed scenario risks the funding needed to build a narrow structure that may be ineffective and fail to fulfill the mitigation's intent. The artificial narrowing of a preexisting structure risks drawing conclusions from findings that cannot account for the sheep's preexisting adaptation to a wider structure that was already in place and has now been narrowed.

Desert Bighorn Sheep Crossing Under Bridges

The dry washes at the WRC and DW bridges, located between OPs frequently used by DBS, provide numerous opportunities for sheep to cross under the roadway. However, during the study, DBS use of the dry washes was minimal (7 percent of U.S. 93 DBS crossings) when compared to that of the three OPs. Of the bridges, WRC had the fewest DBS under-bridge crossings (84 in four years), but extensive human use (17,553 in one year) from a nearby trailhead (about 400 feet away) that leads people to pass under the bridge. DBS crossings under the DW bridge did increase (from 53 in year 1 to 171 in year 4) but accounted for less than 9 percent of all crossings every year. These results and those of previous research (Bristow and Crabb 2008) corroborate the recent idea that DBS generally avoid UPs. These findings, however, may not be applicable to larger UP structures like Sugarloaf Mountain bridge (900 feet long, 82 feet high), which previous research showed (McKinney and Smith 2007, Gagnon et al. 2014) is a location where DBS cross under U.S. 93.

Desert Bighorn Sheep Culvert Use

Various wildlife species have been documented using drainage culverts to pass under roadways (Clevenger et al. 2001a, Kenneth Dodd Jr et al. 2004, Ng et al. 2004, Mata et al. 2005, Ascensão and Mira 2006, Grilo et al. 2008, Sparks Jr and Gates 2012). When successful, these dual-use structures can provide a cost-effective alternative to more expensive wildlife crossings. Although there was anecdotal information that DBS would use culverts to cross under roadways, the implementation of culverts in lieu of WCS was unsupported by data. To gather data, the research team monitored three study area culverts that appeared most likely to be used by DBS.

During four years of monitoring, the research team documented sheep using three culverts 195 times (3 percent of all DBS crossings) to cross under U.S. 93. While year 1 had a single sheep using a culvert, that number increased to 78 and 110 in years 2 and 3 respectively, and then decreased to 17 in year 4. These findings demonstrate that DBS will use culverts but culverts are less effective as habitat fragmentation mitigation measures and should not be relied upon as the sole or primary measure.

Desert Bighorn Sheep Escape Ramp Use

Escape ramps, which are designed to allow animals in the ROW to exit, have become a common ROW escape mechanism for roadway corridors lined by exclusion fencing. However, the limited escape ramp effectiveness research has primarily focused on the ramps' use by elk and deer and no studies have included DBS. Since the U.S. 93 corridor would have exclusion fencing, escape ramps were included in U.S. 93's reconstruction plans and were anticipated to allow DBS egress as they had for elk along SR 260 and deer elsewhere (Bissonette and Hammer 2000, Dodd et al. 2007a).

The first U.S. 93 DBS escape ramps were added within exclusion fencing between MP 0 and 2.2. The effectiveness of these ramps was not formally monitored, but McKinney and Smith (2007) captured a photo of a ewe and lamb using them to access the ROW and concluded that the current ramp design would not preclude DBS from entering the ROW. This information led the research team to evaluate the installed escape ramps from MP 0 to 17. Soon after monitoring began, the research team documented sheep gaining ROW access via the ramps and initiated an adaptive management ramp modification process with ADOT. After some trial and error, AGFD worked with ADOT to add crossbars at 16 inches above the ramps' edge. This modification appears to have eliminated DBS ROW access while still allowing egress, both of which further reduce U.S. 93 DBS-vehicle collisions. The information gathered during this study adds to our escape ramp design knowledge; however, a more comprehensive understanding is needed. Huijser et al. (2015) suggests "initiating more studies into the optimal height of escape ramps for single target species as well as situation with multiple target species with different jumping and climbing capabilities." AGFD and ADOT have launched a statewide study (*SPR-729 Effectiveness of Wildlife Crossing Guards and Right-of-Way Escape Mechanisms*) with the intent of advancing our understanding of how various species interact with escape ramps. The statewide study and this one of U.S. 93 will allow wildlife and roadway managers to make more informed, financially prudent, and effective decisions.

Cattle Guard Effectiveness

Cattle guards, which are designed to prevent animals from entering the ROW, have become a common feature included with escape ramps, exclusion fencing, and wildlife crossings. While single-wide guards have traditionally been used for cattle and occasionally ungulates, double-wide guards, which are reasonably assumed to present ungulates with a bigger obstacle and more effectively bar them from the ROW, have become increasingly common.

While the U.S. 93 reconstruction included double-wide cattle guards on most lateral access roads, single-wide guards were installed at the Kingman Wash TI, a dual-use structure intended for use by vehicles and DBS. Following construction, the project team observed DBS crossing these single-wide guards. To determine crossing frequency, the research team installed still cameras to monitor two of the four Kingman Wash TI guards. From 2011 to 2014, the team documented 124 DBS crossing the guards to enter the ROW, which caused agency concern. In 2015, ADOT converted all existing Kingman Wash TI single-wide cattle guards to double-wide and the research team continues to monitor them. (As part of another joint study, researchersinstalled additional cameras at other U.S. 93 double-wide guards to determine their effectiveness.)

DESERT BIGHORN SHEEP-VEHICLE COLLISIONS

On U.S. 93 prior to reconstruction, Cunningham and Hanna (1992) documented an average of 11 DBS-vehicle collisions per year. After reconstruction, when fencing and structures were in place (2011), and through the additional year of collision data collection (2015), the research team documented an 85 percent reduction in U.S. 93 DBS-vehicle collisions. The average dropped from 11 DBS-vehicle collisions per year to 1.6 per year (2011-2015).

Although the post-construction 85 percent DBS-vehicle collision reduction is proportionately large, the team considers it a conservative estimate. Early in the study, many collisions were attributed to documented fence breach points: the O’Callaghan-Tillman Memorial Bridge fence gap, Kingman Wash TI single-wide cattle guards, and sheep using unmodified escape ramps to enter the ROW. Through 2011 and 2012 ADOT addressed the bridge gap and modified the escape ramps. During the next three years (2013-2015), the research team documented only one DBS-vehicle collision.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

This research project evaluated the effect that U.S. 93 reconstruction mitigation measures had on DBS movements and roadway permeability, use of crossing structures, and DBS-vehicle collision patterns. The mitigation measures included OPs, exclusion fencing, escape ramps, and cattle guards. Additionally, the team monitored locations (dry washes at roadway bridges) and structures (drainage culverts) that were not designed to mitigate roadway effects but that sheep might use nonetheless.

The research team compared DBS ability to move across U.S. 93 MP 2-17 after construction to their ability to cross the same section before and during construction. The team also compared DBS-vehicle collision rates following construction to those before construction. Along with DBS crossing and collision rates, the research team evaluated the effectiveness of escape ramps at allowing DBS to leave the ROW and the effectiveness of cattle guards at limiting ROW access.

REDUCING VEHICLE COLLISIONS AND HABITAT FRAGMENTATION

Post-construction U.S. 93 monitoring of mitigation measures was required to determine whether the measures promoted DBS permeability, whether structure design characteristics (e.g., width) affected sheep use, and whether any structure type (e.g., OP or culvert) was more effective than others. Additionally, monitoring provided insights into the interactions of sheep with escape ramps and cattle guards—insights that permitted timely, corrective actions that enhanced motorist and DBS safety and helped determine the appropriateness of these measures for future projects.

During the reconstruction of U.S. 93, ADOT integrated three OP structures—two 50 feet wide and one 100 feet wide. They are Arizona’s first wildlife OPs and North America’s first DBS OPs.

DBS can adapt to 50-foot-wide and 100-foot-wide OPs that are 220 feet in length. Although the research team documented a relatively low initial DBS OP use (0.28 crossings per approach in study year 1), use consistently increased so that by study year 4, all OPs had high DBS use (0.87 crossings per approach).

DBS tend to use OPs to cross over roadways rather than crossing under via culverts or washes. Sheep used the three OPs (5862 crossings) much more than the washes under the two bridges (474 crossings) or the three culverts (195 crossings).

DBS will likely use modified, traditional escape ramps to exit the ROW but not enter the ROW. The research team’s preliminary results indicate that traditional escape ramps with an added metal cross bar (16 inches above the ramp’s edge) are an effective DBS ROW escape mechanism, but monitoring continues through 2019 and will result in more definitive findings. The results are drawn from data that show 53 DBS using unmodified, traditional escape ramps to gain access into the ROW and only one using a ramp in this manner after modification. DBS then continued to use the ramps to exit the ROW (0.84 crossings per approach), as intended.

The research team noted escape ramp fill and ramp leading edge material sluffing over time. The leading edge sluffing results in a platform that sheep may be reluctant to use. DBS that do not use these escape mechanisms will wander the ROW and remain a threat to the travelling public until they find an alternative means of escape or are struck by a vehicle. Gabion basket escape ramps are not recommended for future projects unless a resolution to the sluffing can be addressed.

DBS will cross single-wide cattle guards to enter the ROW, even though this equipment is intended to deter animal crossings. The research team's still cameras documented DBS crossing single-wide cattle guards on 168 occasions from 2012 to 2014. As a result, ADOT converted all existing Kingman Wash TI single-wide cattle guards to double-wide. The research team continues to monitor these guards as part of another ongoing research project.

Recommendation:

The research team recommends that OP crossing structures at least 50 feet wide be incorporated into construction and reconstruction projects as the most effective mitigation approach to reduce DBS habitat fragmentation. In addition, structure locations should be determined by species-specific, long-term, consistent, accurate, and fine-scale data (e.g., GPS movement data) that can also be used to determine the spacing between OP structures and the placement of 7-8foot exclusion fencing. (see DBS Highway Permeability recommendations above).

The research team recommends that future escape ramps be constructed using retaining walls that are 6 feet high, and for DBS have an adjustable metal crossbar located 16 inches above the ramps' edge. Gabion basket ramps, without substantial design improvements, should not be used, because leading edge sluffing exposes the gabions. The research team also recommends that the current U.S. 93 gabion basket escape ramps be maintained or modified to retain material being lost through sluffing and erosion along the leading edge of the escape ramps.

Single-wide cattle guards do not effectively prevent DBS from accessing the ROW. Double-wide guards are likely more effective at limiting DBS ROW access and should be included in planning until additional research can verify or refute their effectiveness.

ONGOING COLLISION MONITORING

After the U.S. 93 reconstruction mitigation measures, DBS-vehicle collisions dropped by at least 85 percent.That percentage may actually even understate the beneficial impact of the mitigations on roadway safetys because it compares the post-construction, high-AADT, four-lane, divided U.S. 93 to a pre-construction, lower-AADT, two-lane, undivided U.S. 93. If ADOT's mitigation measures had not been implemented, motorists traveling the reconstructed roadway would likely have encountered more sheep in the ROW and DBS-vehicle collisions might have increased.

Recommendation:

The research team recommends that U.S. 93 DBS-vehicle collisions between MP 0-17 continue to be monitored. DBS-vehicle collision locations may signify a nearby fence breach point, which can then be quickly addressed to prevent additional DBS-vehicle incidents.

The research team recommends frequent and consistent roadkill data collection for roadways that have a high number of WVCs and for roadways scheduled for reconstruction or major upgrade. Accurate and complete WVC data complements GPS-generated wildlife movement data when attempting to locate effective wildlife crossings, fencing, and other mitigation measures. The data also provides a baseline to determine the efficacy of mitigation measures meant to reduce WVCs.

ROADWAY PERMEABILITY

The research team measured the permeability of U.S. 93 to DBS after reconstruction and compared it to the permeability before and during reconstruction as measured by previous studies. To measure post-construction permeability, the team calculated passage rates, a consistent metric that permits direct comparison to other roadways. Analysis findings are:

Following reconstruction, which included OPs and exclusion fencing, crossings of the MP 2-17 segment increased by 280 percent. Before and during construction, DBS movements concentrated in the previously completed MP 0-2 segment, which included the Sugarloaf Mountain Bridge; note that few crossings at that time occurred between MP 2 and 17. The data after reconstruction indicate that roadway permeability increased after the OPs and exclusion fencing were built.

U.S. 93 post-construction passage rates from MP 2 to 17 increased by 1143 percent from 0.04 crossings per approach (year 1) to 0.46 (year 4). This large increase likely results from DBS use of reconstruction mitigation measures to cross the expanded roadway, which previous research had found to be a barrier even in its narrower form. Appropriate planning during the early U.S. 93 design stages allowed the local DBS population to remain connected and healthy. If fragmented, DBS population persistence would have been lowered and DBS extinction in the area might have followed.

Recommendation:

During design phase of major reconstruction projects that include WVC concerns, as well as wildlife habitat connectivity concerns, it is recommended that ADOT continue to use GPS telemetry data and analysis as the primary data-driven approach to determine placement of wildlife mitigation measures. This approach may be a cost-effective way to increase the likelihood that mitigation measures will be successful, while also providing the data required to validate the effectiveness of the measures.

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