Evaluation of Distribution and Trans-Highway Movement of Desert Bighorn Sheep: Arizona Highway 68

Final Report 588

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16. Abstract
We monitored desert bighorn sheep via satellite telemetry, remote cameras, and track beds between 2006 and 2007, to evaluate the effectiveness of the 3 design features (underpasses) incorporated to facilitate wildlife movement under State Highway 68 (SR 68) between Kingman and Bullhead City, Arizona. We fitted 25 desert bighorn sheep with GPS radio telemetry collars and tracked movements in proximity to SR 68 for 15 months beginning in November of 2006. To evaluate use of underpasses by all ungulates we installed 5 remote passive infrared triggered cameras at each underpass. We monitored wildlife use at the underpasses for 9,789 camera/days and documented 25 crossing events by desert bighorn sheep (≤ 32 individual crossings). None of the bighorns documented using the underpasses were ewes and no marked ewes crossed SR 68. The majority (88%) of crossings by bighorns occurred at the easternmost underpass (milepost 12.1), which also had the narrowest span and was located in the most rugged terrain. There were 3 crossings by bighorns at the westernmost underpass (milepost 7.8), which had the widest span and was located far from rugged terrain. No bighorns crossed at the remaining underpass (milepost 10.8), however other ungulates, such as wild burros (86%) and mule deer (14%), were seen more often there. At higher levels, presence of other ungulates and humans may preclude bighorn use of underpasses. While proximity to steep terrain, sight ability, underpass structure, and presence of other animals may all be important factors affecting bighorn use of highway underpasses, placement of crossing structures relative to traditional travel corridors of bighorns is likely the most important factor affecting their use.

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		LENGTH					**LENGTH**		
in	inches	25.4	millimeters	mm	mm	millimeters	0.039	inches	in
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		MASS					**MASS**		
oz	ounces	28.35	grams	g	g	grams	0.035	ounces	oz
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		ILLUMINATION					**ILLUMINATION**		
fc	foot candles	10.76	lux	lx	lx	lux	0.0929	foot-candles	fc
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2	cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE AND PRESSURE OR STRESS					**FORCE AND PRESSURE OR STRESS**		
lbf	poundforce	4.45	newtons	N	N	newtons	0.225	poundforce	lbf
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa	kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

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I. EXECUTIVE SUMMARY

Highway construction can affect desert bighorn sheep (*Ovis Canadensis*) populations by increasing habitat fragmentation and isolation which can impede access to critical habitats, increase the effects of stochastic events and reduce gene flow. There is rapid expansion of road networks near bighorn habitat and increased use of high animal fencing along highways to reduce wildlife/vehicle collisions. Proper design and placement of wildlife crossing structures is crucial to allow for animal movement and reduce the potential for habitat fragmentation.

Three wildlife crossing structures (underpasses) were incorporated into the realignment and improvement of State Route 68 between Kingman and Bullhead City - Arizona, to facilitate movement of bighorn sheep. State Route 68 was realigned and widened from a 2-lane to a 4-lane highway over a 14 mile stretch from County Route 68 to Mile Post 14. This was accomplished between the year 2000 and 2002. To evaluate the effectiveness of the different underpasses we fitted 25 bighorn sheep with GPS radio telemetry transmitters and tracked movements in proximity to the highway for 22.5 months beginning in November 2006. To evaluate use of underpasses by all ungulates we installed 5 remote passive infrared triggered cameras at each underpass.

We monitored wildlife use at the underpasses for 20 months (9,789 camera-days) and documented 25 times where bighorn sheep crossed under the highway (≤ 32 individual crossings). All except one (whose gender couldn't be determined) of bighorns photographed by remote cameras at underpasses were rams. Crossings often occurred at the beginning and end of the breeding season. None of the marked bighorn ewes crossed the highway during the study. 88% of the crossings by bighorns occurred at the easternmost underpass (Union Pass), which also had the narrowest span and was located in the most rugged terrain. There were three crossings by bighorns at the westernmost underpass (Arabian Mine), which had the widest span and was located far from rugged terrain. No bighorns crossed at the remaining underpass. However, other ungulates such as wild burros and mule deer were often seen there. At higher levels the presence of other ungulates and humans may preclude underpass use by bighorns.

Bighorns moved quickly when traveling through the underpasses but seemed more at ease, often stopping to browse, while in the right of way. We documented three times when bighorns approached the easternmost underpass without crossing the highway. This behavior is likely related to traffic levels but may be indicative of unfamiliarity with the area and the general cautious nature of bighorn movement. Cautious behavior documented during most crossings may be related to underpass structure. Highway permeability could likely be enhanced with higher, more open structures. Underpasses should have an index of openness[1] greater than 75 to enhance visibility and increase probability of use by bighorns.

[1] : The index of openness is calculated by multiplying the height by the width and dividing the product by the length : (height x width)/ (length)

Bighorn sheep follow traditional movement patterns, where travel corridors are learned from older individuals. Rams often move long distance to access different ewe groups during the breeding season. Use of underpass structures was more associated with documented movement patterns of the bighorn sheep population than proximity to steep terrain. While proximity to steep terrain, sight ability, underpass structure, and presence of other animals may all be important factors affecting bighorn sheep use of highway underpasses, placement of crossing structures relative to traditional travel corridors of bighorns is likely the most important factor affecting their use.

Future crossing structures should be placed in traditional travel corridors connecting high quality habitat with steep (greater than 60% slope) rugged terrain on both sides of the roadway. Unstable, loose, or unnatural substrates used to stabilize side slopes may impede bighorn sheep use. Reducing structural diversity on abutments, such that shaded areas are minimized while incorporating a trail half way up the side slopes will likely enhance permeability.

Right-of-way fencing (at least 2 meters high) should be maintained throughout bighorn sheep habitat to guide bighorns to crossing structures and reduce bighorn sheep/vehicle collisions. Jump-outs (2.5 meters high or more) would reduce potential for bighorn sheep/vehicle collisions when right-of-way fences are breached.

II. INTRODUCTION

Substantial effort has been expended in the past three decades in the design and building of mitigation passages across roadways. As human populations continue to grow in the United States, there is increased demand for improved highways to handle higher traffic volumes (Federal Highway Administration 1998), allowing for increased vehicle speeds on the nation's roadways (Cook and Daggett 1995). Increased traffic volumes and speeds on highways potentially affect wildlife through direct mortalities and habitat fragmentation (Foster and Humphrey 1995, Hughes et al. 1996).

Collisions with wildlife occur often on Arizona's highways, causing loss of human lives and economic losses associated with vehicle damage. In 2006, 1,398 vehicle collisions with animals were reported in Arizona; two persons were killed, and 276 were injured (Arizona Department of Transportation 2006). Estimated mean property damage was $8,200, estimated costs of injuries averaged $11,500, and estimated costs associated with fatalities averaged $1,210,000 (Arizona Department of Transportation 2006).

Three wildlife crossing structures (underpasses) were incorporated into the realignment and improvement of 14 miles of State Route (SR) 68 between Kingman and Bullhead City - Arizona, to facilitate movement of wildlife, particularly desert bighorn sheep, across the highway. Underpasses such as those incorporated into this redevelopment have been widely used in the United States to mitigate effects of roadways on ungulate movements and reduce collisions. However, few studies have addressed post-construction efficacy of these measures (Clevenger 1998, Clevenger et al. 2002).

Bighorn populations have declined throughout their historical range coincident with European settlement of the West, possibly due to the introduction of diseases carried by domestic animals (Jessup 1985, deVos 1989), subsistence hunting, and habitat isolation (Gionfriddo and Krausman 1986, Bleich et al. 1990). The bighorn population in the Black Mountains near SR 68 is a sub-unit of the largest surviving bighorn population in Arizona and is important in several respects, serving as the source herd for reintroductions into several sites in Arizona and other southwestern states. The population also provides enjoyment through wildlife watching on the study site and along the Colorado River, as well as providing recreational opportunity to those who hunt bighorns in the area.

Previous studies on the bighorns of the Black Mountains near Highway 93 indicate the potential for adverse impacts of highway construction to this metapopulation. Research on the Highway 93 alignment located approximately 30 miles to the north of this study's site documented bighorn movements across Highway 93 and suggested high vehicle-related mortalities along a portion of U.S. Highway 93 could have serious implications for the local population (Cunningham and deVos 1992, Cunningham and Hanna 1992, Cunningham et al. 1993, McKinney and Smith 2007). High right-of-way fencing (more than 2 meters/ 6.56 feet) installed as part of the improvement of SR 68 was designed to reduce the potential for wildlife/vehicle collisions. This might bisect the bighorn population of the area if the wildlife crossings are impermeable to bighorn movement.

Bisecting this population would likely increase the risk of extirpation due to loss of genetic exchange. Genetic diversity and population fitness is enhanced through genetic exchange (Diamond 1975, Mader 1984, Schwartz et al. 1986). The ability to move freely can protect wildlife populations from random events such as introduction of diseases, localized shortage of resources, predation pressure or other challenges to their survival (Jessup 1985, Wilcox and Murphy 1985, deVos 1989, McKinney et al. 2003).

Research evaluating wildlife use of highway underpasses has focused primarily on ungulates (Clevenger 1998), but information on the use of underpasses by bighorns is limited (McKinney and Smith 2007). Information on bighorn movement patterns and their use of underpasses in the vicinity of SR 68 is needed to enhance future efforts of highway engineers, design specialists, and resource managers in incorporating wildlife crossing structures and design features to increase public safety and ensure permeability of the highway to wildlife. This will in turn reduce adverse impacts to the bighorn sheep herd and increase the probability of population persistence. This information could also have high economic returns on investment by assisting with the design of mitigation features for future highway projects and potentially reducing construction costs due to ineffective or unnecessary highway crossing structures. This type of information will also enable resource managers to identify key habitat features regarding movements of bighorn sheep, potentially minimizing adverse impacts of highway construction.

The objectives of the study were: 1) To determine if and how often large desert mammals (mule deer, bighorn sheep, mountain lion, etc.) use the underpasses incorporated into the SR 68 realignment; 2) To determine the movement patterns of bighorns in the vicinity of SR 68 realignment, assess potential impacts to bighorn sheep distribution, and identify trans-highway movements; 3) Identify factors potentially affecting use of underpasses by bighorn sheep.

We assumed that use of underpasses by bighorns was related to the placement and structure of the underpasses rather than traffic levels. This assumption is based on the observation that few vehicles were exiting SR 68 within the study area. Therefore traffic levels at each underpass should be nearly the same.

A. STUDY AREA

The study area was located in northwestern Arizona in the Black Mountains within 10 miles north and south of SR68 and was bounded on the west by the Colorado River and to the east by Golden Valley. The elevation of the study area ranged from about 146m (479 ft) on the Colorado River to 1,496m (4907 ft.) in Golden Valley. The topography ranged from mountainous terrain with steep talus slopes and rugged cliffs to dry washes among rolling hills (Cunningham and Hanna 1992). Average temperatures ranged from 31°C (88ºF) in summer (May–September) to 12°C (54ºF) in winter (December–February). Rainfall was about 5.6 cm (2.18 in) and 4.7 cm (1.83 in) during summer and winter respectively, and totaled about 15.4 cm (6 in) annually. Vegetation in the lower bajadas, flats and desert wash areas is dominated by Creosote-bursage (*Larrea tridentata-Ambrosia dumosa*) while mixed-cacti and shrub communities predominate the mountainous regions of the study area (Brown et al. 1979). Predators on the study area included bobcats, coyotes, gray foxes, and mountain lions. Domestic livestock were infrequent in most of the study area, except that feral burros were common. Based on aerial surveys, numbers of bighorns in the general area declined sharply between 2001 and 2004. Legal hunting of bighorns occurred during the month of December each year.

There were 3 underpasses incorporated into the realignment and improvement of SR 68 between Kingman and Bullhead City, Arizona to facilitate movement of wildlife, particularly bighorns, across the highway (Fig. 1). Union Pass at milepost 12.1 was 51m wide, 25m high and 17m long (167ft, 82ft, and 56ft; Fig. 2). With good visibility through the underpass, Union Pass had the shortest length of the three underpasses as it had no median separating the east and west bound traffic lanes. The Hole at milepost 10.8 was 56m wide, 19m high and 38m long (184ft, 62ft, and 125ft; Fig. 3). It is characterized by low visibility from both sides. Arabian Mine at milepost 7.8 was 116m wide, 18m high and 37m long (380ft, 59ft, and 121ft; Fig. 4). The widest structure, Arabian Mine, was not perpendicular to the wash that it crossed. Nonetheless, visibility inside as well as across the underpass was good.

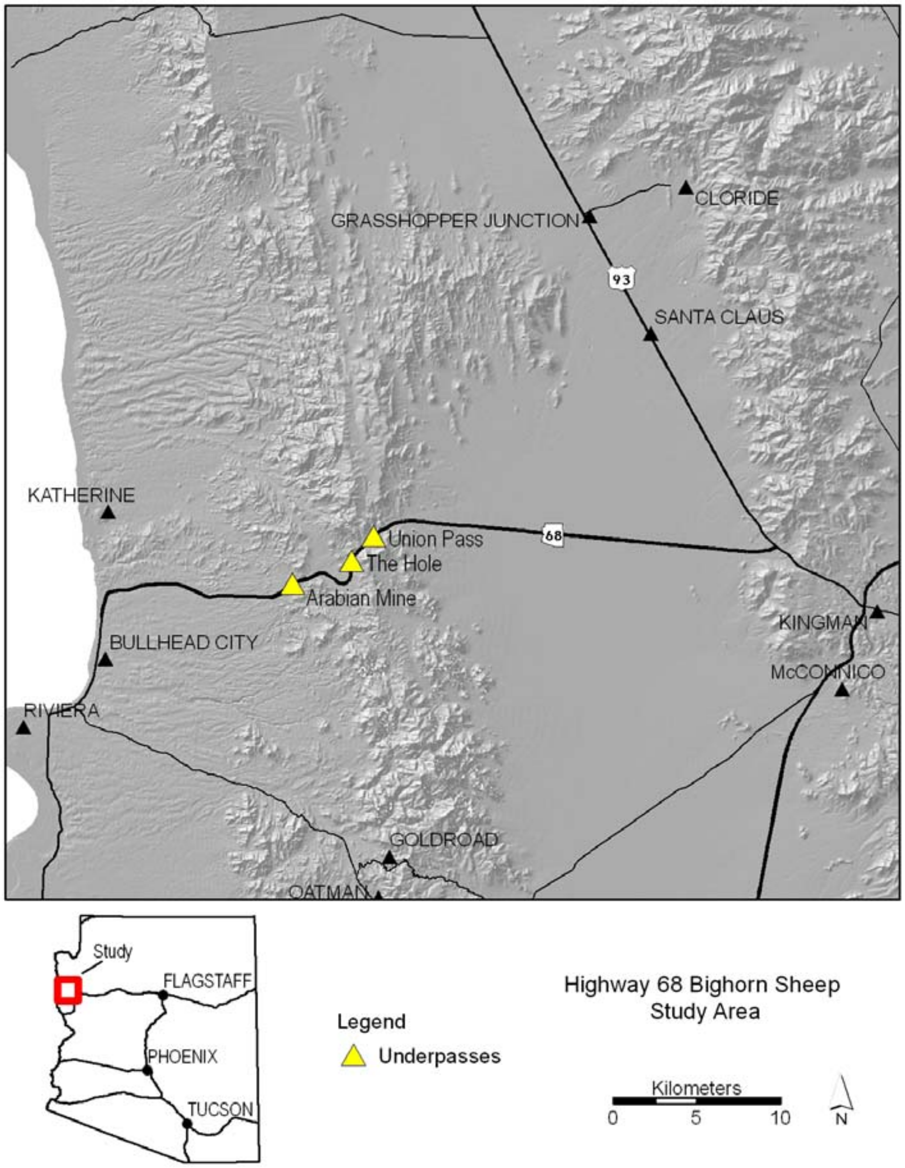

Figure 1. Location of State Route 68 desert bighorn sheep study area in northwestern Arizona. Study area extends along the highway between Bullhead City east to Golden Valley, Arizona.

Figure 2. Union Pass wildlife underpass (MP 12.1) on State Route 68 in northwestern Arizona, 2005-2007.

Figure 3. The Hole wildlife underpass (MP 10.8) on State Route 68 in northwestern Arizona, 2005-2007.

Figure 4. Arabian Mine wildlife underpass (MP 7.8) on State Route 68 in northwestern Arizona, 2005-2007.

III. METHODS

A. CAPTURE AND TELEMETRY

Adult bighorns were captured from a helicopter using tranquilizer darting in November 2005 and using net-gunning in November 2006. GPS radio transmitter collars and unique ear tags (manufactured by Telonics, Inc. of Mesa, Arizona) were securely attached to all bighorns. Transmitters were equipped with motion sensors triggering a specific mortality signal if no animal movement occurred within 4 hours. Transmitters were designed to provide a GPS location fix every five hours for the store-on-board transmitters and every six hours for the spread-spectrum transmitters. All collars were programmed to automatically disconnect and drop off animals after 22.5 months, for transmitter recovery. Animal location data could be uploaded remotely from spread-spectrum transmitters during a 3-hour window available every 14 days, and after final recovery. Animal location data collected on store-on-board transmitters could be downloaded only after collars dropped off and were recovered.

Aerial telemetry flights were conducted at least monthly and often bi-weekly between November 2005 and September 2007 using fixed-wing aircraft. This facilitated the download of data from spread-spectrum transmitters, the location of bighorns fitted with store-on-board transmitters, and the documentation and location of mortalities. We incorporated data from spread-spectrum transmitters into ArcGIS® Version 8.3 software (ESRI, Redlands, California) following each flight, and incorporated data from store-on-board transmitters following collar drop-off and recovery at the end of fieldwork or when transmitters were retrieved from mortality sites. For every case of mortality we identified the cause of death based on signs found at the carcass site, including signs of disease, presence of scat, tracks, caching of kill, and canine punctures.

Home ranges of marked bighorns were calculated using minimum convex polygons (100% MCP; White and Garrott 1990). The home ranges of individuals were also described qualitatively in relation to SR 68. Highway crossings made successfully by marked bighorns were determined by connecting consecutive GPS location fixes in ArcGIS® and identifying crossings where lines between fixes crossed SR 68. Whenever possible, we verified the occurrence of crossings by marked bighorns using ground or aerial telemetry. To estimate bighorn habitat use near underpasses we calculated the number of locations of marked bighorns within 1 km buffers around the Union Pass, The Hole, and Arabian Mine wildlife crossing structures.

B. CAMERAS AND TRACK BEDS

Five remote passive infrared triggered cameras were deployed at each of the three underpasses along SR 68. We programmed 4 cameras (manufactured by Reconyx, LLP of Holmen, WI) to take 30 pictures (one picture every quarter of a second) each time movement was detected, and record date, time and temperature on each image. We positioned cameras for full coverage of the underpass to record wildlife use of crossing structures. We also positioned cameras to cover approach trails near the underpasses to document wildlife that approached without crossing. One video camera (manufactured by Leaf River, Inc. of Taylorsville, MS) was deployed at each underpass and programmed to take a 90 second video each time motion was detected, to better document wildlife behavior in proximity to the highway.

We developed track beds at each of the three underpasses along SR 68 to supplement data collected by the cameras. Each track bed was at least two meters wide and all were of variable length depending on the underpass. We counted tracks once a week, and cleared and restored track beds after each examination.

C. HABITAT SELECTION

To describe the configuration of underpasses we calculated an index of openness as (height x width)/ (length) for the Union Pass, The Hole, and Arabian Mine wildlife crossing structures. To estimate availability of bighorn escape terrain in proximity to wildlife crossing structures we calculated the amount (km^2) of area with slope $\geq 60\%$ (McKinney et al. 2003) within a 1 km buffer around the Union Pass, The Hole, and Arabian Mine underpasses. To estimate land surface ruggedness throughout the study area we calculated a Vector Ruggedness Measure (VRM) for each $900 m^2$ area (Sappington et al. 2007).

To establish the characteristics of habitat availability we generated random points within the MCP home range estimate for each marked bighorn. We plotted random points equal to the number of bighorn locations used to calculate each MCP home range estimate using ArcGIS®. We overlaid all bighorn locations and random points on available GIS habitat characteristic covers and recorded values for each of the following habitat variables: Vegetation Type, Elevation, Slope, Aspect of Slope, and VRM. To predict habitat use by bighorns we developed logistic regression models (Hosmer and Lemeshow 1989) using habitat variables that were not correlated ($\alpha<0.1$). We developed probable models *a priori*, and calculated Akaike's Selection Criterion (AIC) to select the most parsimonious model (Burnham and Anderson 1992) and assigned 0.5 as the cut point for classification of use and random sites.

IV. RESULTS

A. CAPTURE AND TELEMETRY

We captured and marked 25 bighorns in two capture efforts, and combined data from them for our analyses. During the first capture, we deployed 10 spread-spectrum transmitters (six to females, four to males) and 10 store-on-board transmitters (six to females, four to males). In the second capture, we captured five animals (two females, three males) not captured before and deployed four spread-spectrum and one store-on-board transmitters. In total we placed transmitters on six females and six males north of SR 68, and eight females and five males south of SR 68.

There were 10 (40%) mortalities among the 25 marked bighorns during the study. Mountain lion predation caused 5 (50%) of mortalities; known predation only occurred north of the highway. Legal harvest (1; 10%), capture related mortality (1; 10%), and poaching (1; 10%) caused fewer deaths than mountain lions. There were two mortalities where cause of death could not be determined (20%).

We conducted 27 fixed-wing flights to upload data from spread-spectrum transmitters and check mortality status of individuals. One transmitter stopped recording GPS points after five months, one store-on-board transmitter failed and was unable to be recovered, and one collar malfunctioned and dropped off almost a year early. We retrieved and downloaded data from 13 operative transmitter collars after they all dropped off on September 15, 2007. Twenty-four marked bighorns provided 38,790 usable GPS locations.

Distribution and movements of marked bighorns generally occurred throughout the study area but movement across the highway was rare (Fig. 5). Bighorn ram locations within 1km of underpasses was greatest at Union Pass followed by Arabian Mine and then The Hole (Table 1). Bighorn ewe locations within 1km of an underpass were greatest at Arabian Mine followed by Union Pass and then The Hole (Table 1).

We documented eight crossings of SR 68 by three marked rams (12% of all marked animals and 27 % of marked rams). Thus 88% of marked bighorns did not cross the highway (Fig. 6). We documented six crossings at Union Pass, one crossing at Arabian Mine, and no crossings at The Hole. Evidence from remote cameras corroborated the estimates of crossing locations. The remaining crossing by a marked animal that was not recorded by remote cameras likely occurred between Arabian Mine and The Hole, in an area where the right-of-way fencing was low (less than two meters). Crossings by marked bighorns occurred in both directions (four heading north, four heading south.)

We calculated home ranges for 10 females and 10 males that were alive for more than six months following capture and marking. Mean home ranges for females and males were 70.84 km^2 (± 61.3 Standard Deviation) and 223.76 km^2 (± 134.56 SD), respectively. Mean home ranges of males that crossed (mean = 277.09 km^2, ± 220.52 SD) and those that did not cross (mean = 200.91 km^2, ± 94.44 SD) the highway were similar.

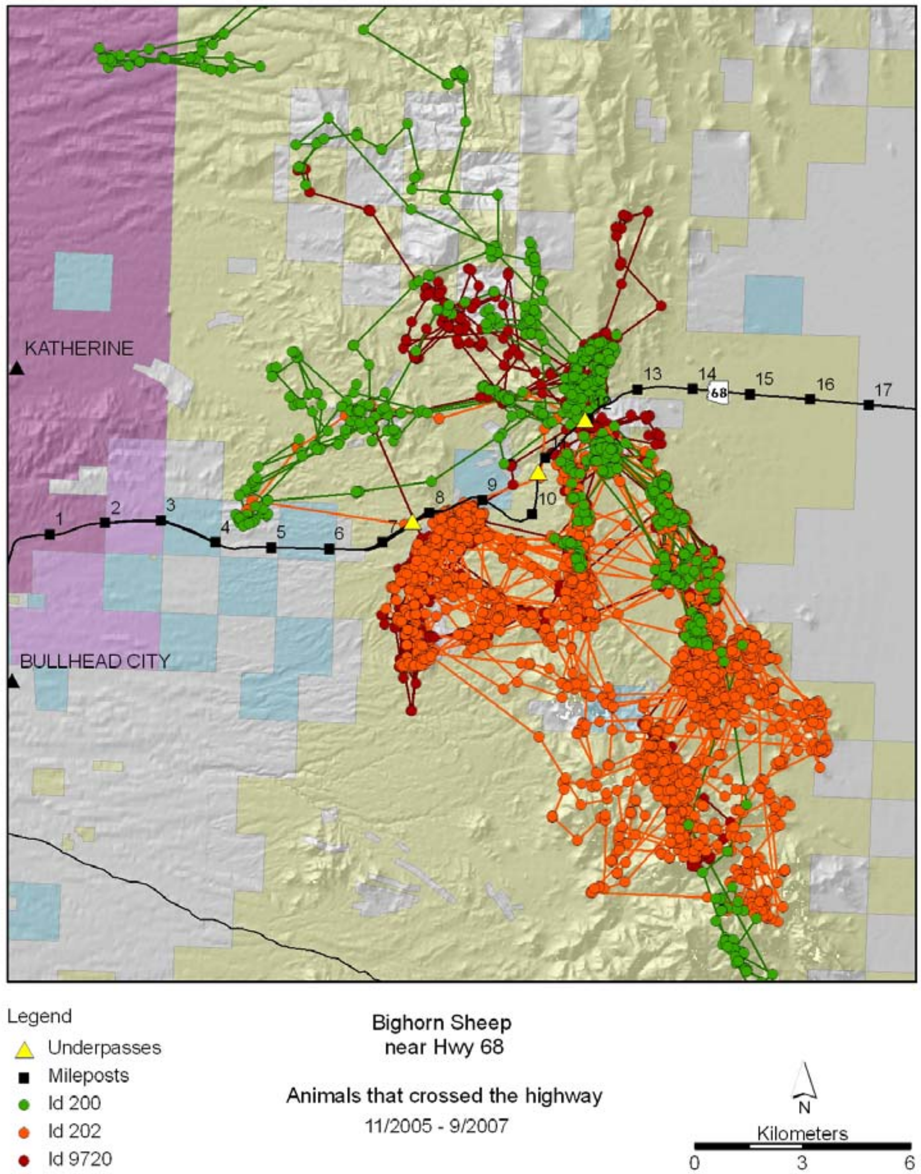

Figure 5. Movements of marked desert bighorn sheep that crossed State Route 68 in northwestern Arizona, 2005-2007.

Table 1. Escape terrain (slope 60% or greater), marked bighorn use within 1km of underpasses, photo-documented bighorn crossing events, and index of openness (height x width)/(length) of wildlife underpasses on State Route 68 in the Black Mountains, northwestern Arizona, 2005-2007.

	Wildlife Underpass		
	Union Pass	The Hole	Arabian Mine
Escape Terrain (km^2)	0.28	0.17	0.02
Marked ram (n = 10) locations	427	97	239
Marked ewe (n = 14) locations	56	35	588
Bighorn crossing events	22	0	3
Index of Openness	75	28	56

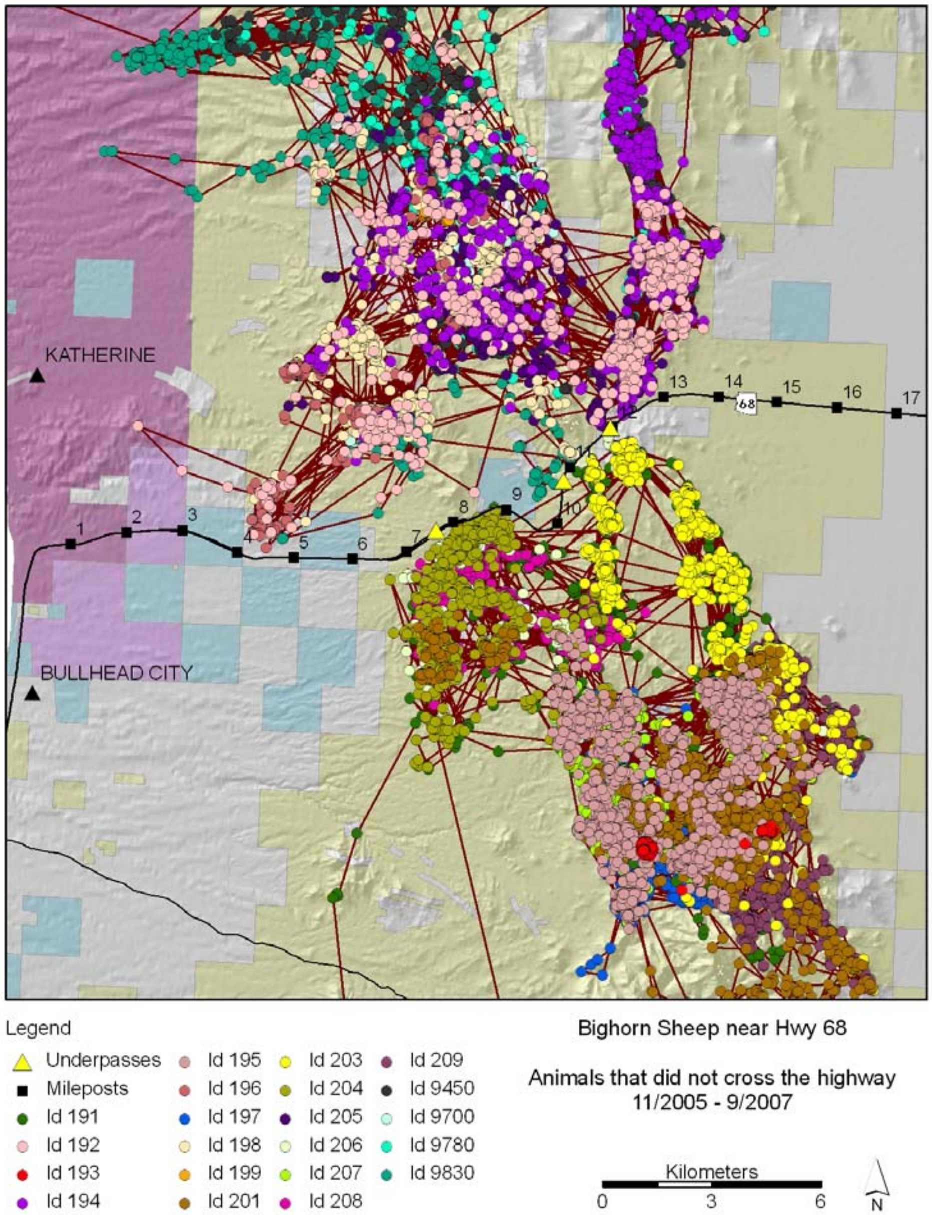

Figure 6. Movements of marked desert bighorn sheep that did not cross State Route 68 in northwestern Arizona, 2005-2007.

B. CAMERAS AND TRACK BEDS

With remote cameras we documented 25 highway crossings by bighorns accounting for up to 32 individuals (Table 1). Only three crossings included two or more animals, the rest were by single animals. All bighorns captured by cameras at underpasses were rams except for one unknown. Bighorn movements across the highway were in both directions, with 17 animals heading north and 15 animals heading south. 84% of bighorn crossings occurred between May and October, which corresponds to the beginning and ending of the breeding season. All bighorn crossings occurred between 8 am and 6 pm. We documented three bighorn approaches that did not result in a crossing: all were on the south side of the Union Pass underpass. Bighorns made up a relatively small proportion of the animals using underpasses. Burros and humans accounted for the majority of observed use followed by bighorns and deer (Fig. 7). Data from track beds generally corroborated results from the remote cameras. No mountain lions were documented using the underpasses.

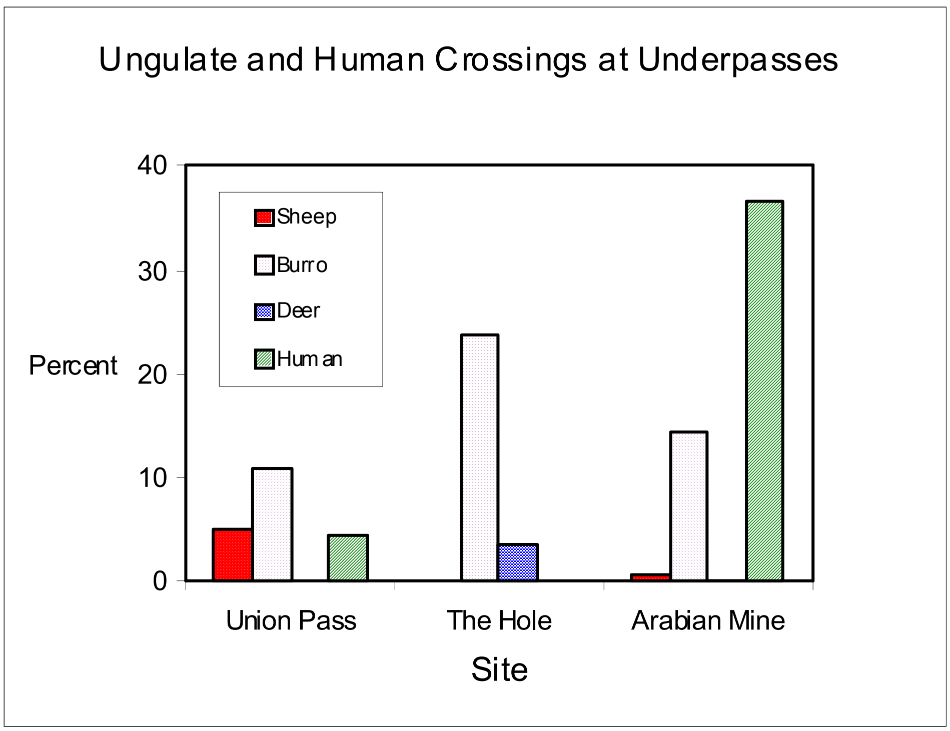

Figure 7. Percent use of wildlife underpasses by humans and ungulates along State Route 68 in northwestern Arizona, 2006-2007.

All bighorns photographed on approach to underpasses were walking and exhibited cautious, alert, (vigilance) behavior. One bighorn was documented looking at a passing vehicle before proceeding. Of the bighorns that crossed, 15 walked through the underpass, 11 ran through it, and two both ran and walked. We were unable to accurately categorize the behavior of four bighorns while they were directly under the roadway due to lack of images. At the Union Pass underpass six bighorns (32%) stopped while under the roadway and looked around, at some point each looked at a shadowed bench located on the northeast corner of the abutment (Fig. 8). Bighorns that crossed in a group did not stop while under the roadway and the first half of animals that crossed in a group all walked while the second half ran. Approximately 50% of the individuals that crossed alone at Union Pass ran through the underpass. No bighorns were seen running after crossing, and three were seen feeding close to the underpass after crossing (Fig. 8).

Figure 8. Desert bighorn sheep at the Union Pass underpass (MP 12.1) exhibited cautious behavior while traveling under roadways but seemed more comfortable in the right-of-way near State Route 68 northwestern Arizona, 2006-2007.

1. *Union Pass (MP12.1)*

Burros made the majority of the crossings at Union Pass, accounting for 53% followed by bighorns at 25%, and finally humans at 22%. There were 22 crossings (29 individuals) by bighorns at Union Pass. Bighorns that crossed the highway showed vigilance while traversing through the underpass. This vigilance was reduced in the right of way on both sides of the highway (Fig. 8). There were a large number of foxes that used the underpass, along with some coyotes and a few bobcats.

2. *The Hole (MP 10.8)*

Burros accounted for 86% of crossings at The Hole (Fig. 9), followed by deer at 14%. There were no bighorns detected at this underpass. Bobcats commonly used The Hole to cross under the highway; coyotes and foxes were rarely seen.

Figure 9. Burro use was common at The Hole underpass (MP 10.8) on State Route 68 in northwestern Arizona, 2006-2007.

3. *Arabian Mine (MP 7.8)*

Humans made up 71%of the Arabian Mine underpass users. Most were in vehicles with a fair number stopping to rest in the shade of the underpass (Fig. 10). Burros made up 28% of the crossings with bighorns and deer making up the remaining 1%. The bighorns crossing at Arabian Mine exhibited the same vigilance behaviors as those documented at Union Pass. Coyotes were occasionally seen at this underpass; foxes and bobcats were rarely seen.

Figure 10. Human/vehicle use was common at the Arabian Mine underpass on State Route 68 in northwestern Arizona, 2006-2007.

C. HABITAT SELECTION

The Union Pass structure had a higher index of openness than either The Hole or Arabian Mine underpasses (Table 1). The Union Pass structure also had more bighorn escape terrain (areas with slope greater than 60%) within 1km of the underpass than The Hole underpass, which in turn had more than the Arabian Mine underpass (Table 1 & Fig.11).

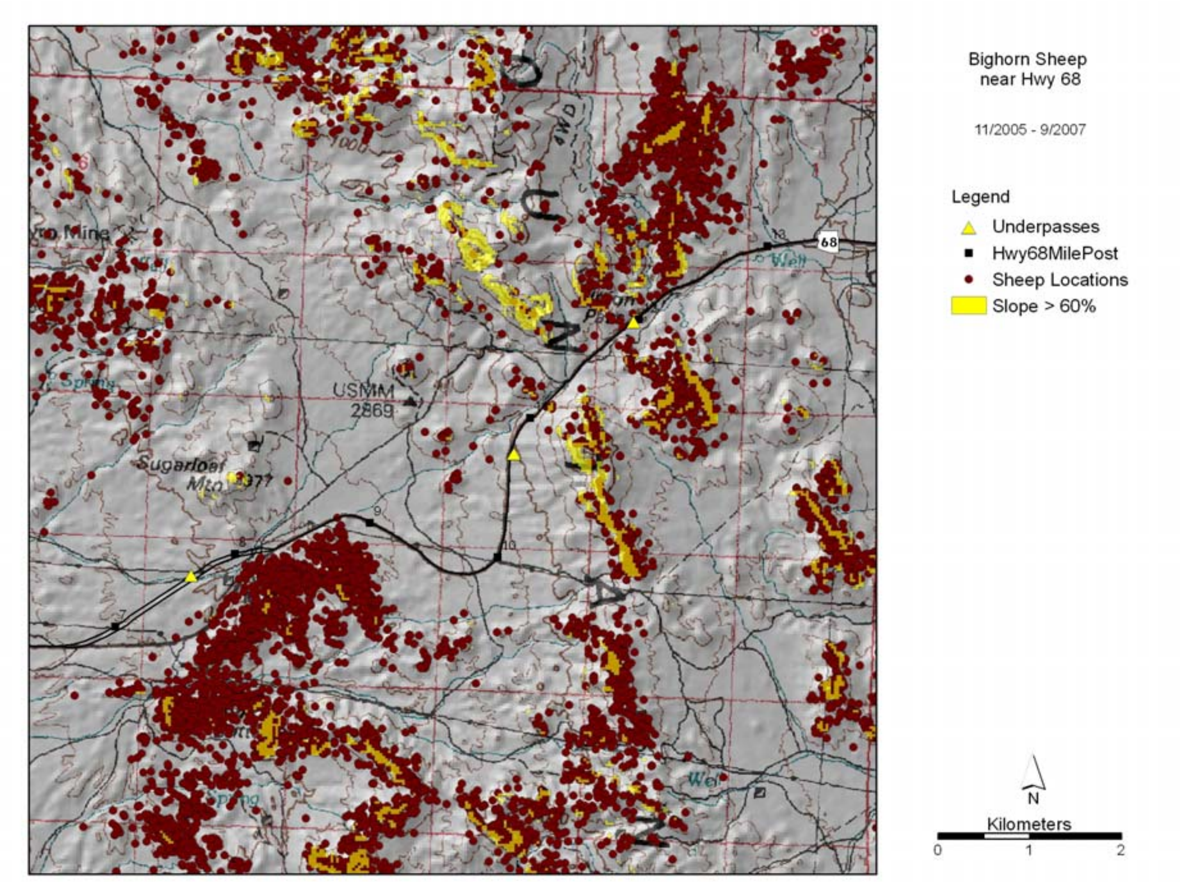

Figure 11. Locations of marked desert bighorn sheep and escape terrain (slope 60%or greater) in the area of State Route 68 in northwestern Arizona.

We developed 5 different *a priori* habitat selection models based on competing theories of factors affecting bighorn use (Table 2). The global model including all available habitat variables was the most parsimonious model describing bighorn habitat selection (Table 2).

Table 2. Ranking of logistic regression models[1] for marked bighorn (n = 24) habitat use in the Black Mountains near State Route 68, northwestern Arizona, 2005-2007.

Model	K	-2 log likelihood	% bighorns correctly classified	% random correctly classified	AIC	Delta AIC
1 Global	5	93,822.5	64.3	71.4	93,832.5	0
2 Migratory	3	97,569.4	62.8	66.9	97,575.4	3,742.9
3 Slope	1	99,605.8	58.4	69.0	99,607.8	5,775.3
4 Ruggedness	1	99,977.8	48.0	79.1	99,979.8	6,147.3
5 Vegetation	1	104,020.1	59.8	60.5	104,022.1	10,189.6

[1] *P*-values for all models were <0.001 (n = 38,790), and degrees of freedom was equal to the number of variables included in the model. Models are presented in order of parsimony:

1 Global model; Vegetation type, elevation, percent slope, slope aspect, and VRM

2 Migratory model; Vegetation type, elevation, and percent slope

3 Slope model; percent slope only

4 Ruggedness model; Vector ruggedness only

5 Vegetation model; Vegetation type

V. ANALYSIS AND CONCLUSIONS

The impacts of highways constitute some of the more widespread factors altering natural wildlife ecosystems. Collisions between vehicles and wildlife result in extensive human deaths, injuries, and property damage (Forman 2000). Impacts of highways on wildlife populations are widespread: they block animal movements, reduce habitat connectivity, fragment habitats and populations (Forman 2000), and contribute directly to mortality of wildlife.

We found that desert bighorn sheep used wildlife underpasses but that use was restricted to 12% of marked animals and consisted of only rams. Reed et al. (1975) found 61% of deer migrated safely using underpasses, 89% of mountain goat crossings were successful (Singer and Doherty 1985), and up to 96% of elk used underpasses (Waters 1988) in various areas. Some studies indicate use of underpasses may increase over time (Reed et al. 1975, Singer and Doherty 1985, Waters 1988), but others reported reluctance for deer to use underpasses even after 10 years (Reed 1981).

Environmental features associated with underpasses influence their use by ungulates (Clevenger 1998, Ng et al. 2004). The most commonly used underpass on SR 68, Union Pass, had the highest availability of steep rugged terrain. Bighorn use of the Arabian Mine underpass was higher than use of The Hole although availability of steep rugged terrain was higher at The Hole. McKinney and Smith (2007) found bighorn use of habitat near highways was associated with Continuous Linear Elevated Guideways (CLEG), ridgelines that offered good visibility and connected habitats on both sides of the highway. Although escape terrain (60% slope or higher) was more available near The Hole, the main spine of the Black Mountains and associated CLEG was located well to the east (Fig. 3).

Bighorns follow established traditions in their movement patterns with young learning seasonal movements and travel routes from adults (Geist 1967). Marked bighorn locations in the vicinity of Arabian Mine were more common than near The Hole. This is an indication of a higher probability that bighorns would encounter that underpass. Thus while proximity to steep rugged terrain likely affected underpass use by bighorns it may have been less important than underpass placement relative to traditional movement patterns. Due to the conservative nature of bighorn movement patterns (Geist 1967), maintaining traditional routes within a complex of habitat is critical to long term population persistence (Bleich et al. 1990). Underpasses located without reference to established travel corridors may be ineffective in enhancing highway permeability to wildlife (Hanna 1982).

Bighorn crossings were more common at Union Pass than Arabian Mine despite the fact that marked animal locations were more numerous near Arabian Mine. However, marked bighorn locations near Arabian Mine were mostly ewes which we never documented as crossing SR 68. Marked bighorn crossings of SR 68 were rare; the highway formed the boundary of many home ranges. Bighorn use of underpasses on SR 68 was restricted to rams and usually occurred during the six month period coincident with the beginning and end of the breeding season. Bighorn rams often travel great distances during the breeding season to access ewe groups. This behavior has evolved to ensure genetic diversity among metapopulations in a naturally fragmented distribution (Bleich et al. 1997). Bighorn ram crossings of SR 68 are likely related to breeding behavior. Consequently the permeability of SR 68 is critical to maintaining genetic diversity within the Black Mountain habitat complex. Small, isolated populations, more than larger populations or metapopulations, are subject to extinction through stochastic events and potential loss of genetic heterozygosity (Diamond 1975, Wilcox and Murphy 1985, Gaillard et al. 1998).

Desert bighorn sheep occur throughout northern Mexico and the southwestern USA and are distributed in naturally fragmented populations, often as small, isolated demes as well as metapopulations (Krausman and Leopold 1986, Bleich et al. 1990, Andrew et al. 1999). Bighorn population persistence as it relates to population size is a controversial topic among biologists, and whether association exists between these variables remains contentious (Berger 1990, Krausman et al. 1993, Wehausen 1999). In general, no specific population size ensures population persistence (Thomas 1990), but small bighorn populations occupying marginal or comparatively poor habitat (Berger 1990), or small patches of suitable habitat (Gross et al. 1997, McKinney et al. 2003) may require management intervention to ensure long-term persistence. Conservation efforts should emphasize preventing fragmentation and loss of habitat and restoring habitat (Fahrig 1997).

Structural features of wildlife underpasses can affect ungulate use. On the other hand, animals are unlikely to use areas where their predator avoidance strategies are compromised (Dodd et al. 2007). Bighorn predator avoidance behavior is dependent upon the need for detecting threats from a distance (Geist 1971, Krausman et al. 1999). Narrow passages with reduced visibility can impede this ability. This may explain the cautious behavior exhibited by bighorns while maneuvering through underpasses and the avoidance of The Hole. The Hole had the lowest index of openness and was the only underpass not used by bighorns.

Wildlife use of underpasses may be affected by the presence of other animals and high human use **(**Clevenger and Waltho 2000). Wild burros, and other animals can displace bighorns at seasonally critical habitats (Foster et al. 2005, Osterman et al. 2005), and bighorns have been portrayed as poor competitors in social interactions (Geist 1985). Burro crossing use at Arabian Mine and The Hole (Fig. 9) was higher than at Union Pass which had the highest incidence of bighorn use. Human use was also high at Arabian Mine (Fig. 10) and bighorns may abandon areas associated with high human use (Jorgenson 1988). Bighorns seek predictable environments to live in and may become habituated to human activities that follow a predictable pattern (Bristow et al. 1996). Human activity at Arabian Mine however, was not predictable and vehicle traffic intersected potential travel corridors for bighorns.

Our best model for habitat selection by bighorns included all five variables. One variable was not sufficient to explain the habitat selection patterns of bighorn sheep throughout the study area. Habitat quality encompasses relative environmental capability to provide conditions associated with individual and population persistence (Hall et al. 1997). Bighorn habitat selection patterns are different between sexes and between different seasons (Bleich et al. 1997, Krausman et al. 1999). As rams disperse before breeding seasons to access disparate ewe groups, their habitat selection patterns are likely different from other seasons (Bleich et al. 1997). Habitat evaluations designed to include habitat selection patterns of dispersing rams could provide insights to placement of wildlife crossing structures. McCarty and Bailey (1994) and McKinney et al. (2003) suggested habitat evaluations should consider spatial requirements for viable bighorn populations. Quantitative evaluations of habitat patches may provide insight into population persistence and management implications of introducing bighorn sheep into unoccupied locations, as well as for maintaining existing populations (Caughley 1994, Fahrig and Merriam 1994, Gross et al. 1997, Singer et al. 2001, McKinney et al. 2003).

VI. RECOMMENDATIONS

Design and placement of crossing structures will influence highway permeability for bighorns, and more natural structures connecting suitable bighorn habitat will increase their effectiveness. Connecting high quality habitat on both sides of the highway especially in areas with escape terrain will increase the likelihood that a structure will be encountered. Placement of structures should be along existing travel routes whenever possible. Underpasses in particular need to have a high index of openness: (height x width)/ (length); the higher and wider the more effective a structure will be. The index of openness at Union Pass, the underpass used most by bighorns was 75 and may represent a minimum since we documented three approaches that resulted in aborted crossings, which could have been due to inadequate visibility. A higher index of openness would likely have increased permeability at this site. Visibility through the underpass is critical for animals approaching the structure. Underpasses whose sides have steep slopes and loose substrates, or fence rip-rap to stabilize the sides may impede use or force bighorns to cross at the bottom where predator avoidance strategies may be compromised. A shelf or game trail below and extending the length of underpass abutments may provide easier access and security to bighorns. Natural substrate with short, low-density vegetation throughout the crossing structure may enhance permeability. Reducing structural diversity on abutments such that shaded areas are minimized may reduce apprehensive behaviors of bighorns and enhance permeability. Following are recommendations for improvement of each of the existing underpasses.

A. UNION PASS (MP12.1)

1) Recontouring the side slopes to remove the shadowed bench that is along the abutment on the northeast side of the underpass could enhance bighorn use by reducing vigilance behavior associated with that feature. Many bighorns crossing at Union Pass stopped and looked with suspicion at the shaded area before proceeding.

2) Stabilizing substrate along the steep slopes beneath the underpass and adding a small game trail about half way up may increase bighorn use. Currently due to the loose steep sides of the underpass the bighorns cross at the bottom, where their predator detection/avoidance strategies are compromised. A shelf below and extending the length of underpass abutments may provide easier access and a feeling of security for bighorns.

B. THE HOLE (MP 10.8)

1) Many of the factors affecting bighorn use of underpasses — proximity to traditional movement corridors, terrain features, index of openness, and presence of other animals — are problematic at The Hole. The index of openness is likely the only factor that could be addressed here. However, given the high burro use and the relatively low probability that bighorns would encounter this site, restructuring the underpass to increase the index of openness would likely be ineffective.

C. ARABIAN MINE (MP 7.8)

1) Reducing the amount of human activity at the underpass and preventing vehicle access to the wash on either side of the highway at Arabian Mine may enhance bighorn use.

2) Recontouring the side slopes to remove the shadowed bench that is along the abutment on the northwest side of the underpass could enhance bighorn use by reducing vigilance behavior associated with that feature. All the bighorns that crossed here avoided this feature.

Right-of-way fencing height should exceed two meters throughout potential bighorn habitats. We estimated that one marked ram crossed the highway in an area where right-of-way fencing was low (MP 8-10), and the single bighorn/vehicle collision was documented in this same area. Right-of-way fencing between MP 8 and MP 10 should be raised to two meters and this fencing height should also be extended east from MP 12.5 to MP 13, at the very least. Frequent monitoring of right-of-way fencing is necessary to identify breaches that bighorns could use, especially in areas with high erosion potential. Jump-outs designed to allow bighorns to climb up a ramp of rocks and jump out of right-of-way fenced areas could reduce potential for bighorn/vehicle collisions when right-of-way fences are breached. Jump-outs should exceed 2.5 meters (8.2 ft) in height to ensure that bighorns can not jump over into the right-of-way.

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