US93 Bighorn Sheep Study: Distribution and Trans-Highway Movements of Desert Bighorn Sheep in Northwestern Arizona

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Prepared by:

Ted McKinney and Thorry Smith
Arizona Game and Fish Department
Research Branch
2221 West Greenway Road
Phoenix, AZ 85023

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This report has several illustrations. Color versions of these illustrations are available on the version published on theArizona Department of Transportation's internet site.

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16. Abstract

Desert bighorn sheep were monitored via satellite telemetry, ground observations, and track beds between 2004 and 2006, primarily to determine distribution and movements relative to mileposts (MP) 3 to 17 of U.S. Highway 93 in the Black Mountains of northwestern Arizona. Bighorns were distributed and moved throughout the study area, but locations of trans-highway movements were not random. Construction of a highway bypass structure between MP 0 and 3 had no apparent effects on permeability of the right-of-way corridor to bighorns. Bighorns concentrated trans-highway movements in the area of proposed highway realignments between MP 3 and 17 at five locations. The research team identified five continuous, linear, elevated guideways (ridgelines) in this area where bighorns concentrated trans-highway movements. Specifically, these ridgelines were located near MP 3.3, 5.1, 7.7, 12.2, and 15.3. Eighty-two percent of highway crossings between MP 3 and 17 occurred near ridgelines at MP 3.3, 5.1, and 12.2, and the research team concluded highway crossing structures at these locations likely would promote highway permeability at a level ensuring genetic heterogeneity and vigor of the resident desert bighorn sheep population.

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Arizona, desert bighorn sheep, distribution, Ovis canadensis, trans-highway movements, U.S. Highway 93, wildlife

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SI (MODERN METRIC) CONVERSION FACTORS*

APPROXIMATE CONVERSIONS TO SI UNITS					APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	When You Know	Multiply By	To Find	Symbol	Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH					**LENGTH**		
in	inches	25.4	millimeters	mm	mm	millimeters	0.039	inches	in
ft	feet	0.305	meters	m	m	meters	3.28	feet	ft
yd	yards	0.914	meters	m	m	meters	1.09	yards	yd
mi	miles	1.61	kilometers	km	km	kilometers	0.621	miles	mi
		AREA					**AREA**		
in^2	square inches	645.2	square millimeters	mm^2	mm^2	Square millimeters	0.0016	square inches	in^2
ft^2	square feet	0.093	square meters	m^2	m^2	Square meters	10.764	square feet	ft^2
yd^2	square yards	0.836	square meters	m^2	m^2	Square meters	1.195	square yards	yd^2
ac	acres	0.405	hectares	ha	ha	hectares	2.47	acres	ac
mi^2	square miles	2.59	square kilometers	km^2	km^2	Square kilometers	0.386	square miles	mi^2
		VOLUME					**VOLUME**		
fl oz	fluid ounces	29.57	milliliters	mL	mL	milliliters	0.034	fluid ounces	fl oz
gal	gallons	3.785	liters	L	L	liters	0.264	gallons	gal
ft^3	cubic feet	0.028	cubic meters	m^3	m^3	Cubic meters	35.315	cubic feet	ft^3
yd^3	cubic yards	0.765	cubic meters	m^3	m^3	Cubic meters	1.308	cubic yards	yd^3
	NOTE: Volumes greater than 1000L shall be shown in m^3.								
		MASS					**MASS**		
oz	ounces	28.35	grams	g	g	grams	0.035	ounces	oz
lb	pounds	0.454	kilograms	kg	kg	kilograms	2.205	pounds	lb
T	short tons (2000lb)	0.907	megagrams (or “metric ton”)	mg (or “t”)	Mg	megagrams (or “metric ton”)	1.102	short tons (2000lb)	T
		TEMPERATURE (exact)					**TEMPERATURE (exact)**		
$^\circ$F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celsius temperature	$^\circ$C	$^\circ$C	Celsius temperature	1.8C + 32	Fahrenheit temperature	$^\circ$F
		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

SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380

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I. EXECUTIVE SUMMARY

The research team captured and placed global positioning satellite (GPS) radiocollars on desert bighorn sheep (*Ovis canadensis*), conducted ground surveys, and developed track beds to study distribution and trans-highway movements of bighorns in northwestern Arizona between 2004 and 2006. The study area extended between Hoover Dam (milepost [MP] 0) and MP 17 to the south along U.S. Highway 93. An abundance of bighorns on the study area declined between research prior to construction activities during 1989 to 1991 and our study. The research team collared fewer bighorns and used different methods of survey, compared to earlier studies. The research team found that bighorns were distributed and moved throughout the study area between Highway 93 MP 0 and 17. Moreover, the research team believes the home range sizes of ewes (females) and rams (males) and number of highway crossings by bighorns were comparable during our study and previous research during 1989 to 1991. The research team suggests that permeability of Highway 93 to trans-highway movements of bighorns was not meaningfully different during highway pre-construction (1989 to 1991) and construction (2004 to 2006) periods. Compared to earlier research, the research team found dramatically fewer deaths of bighorns (25 versus 1) from collisions with vehicles, probably reflecting lower vehicle speeds and restriction of large trucks from using the highway during construction activities between 2004 and 2006. Conversely, predation by mountain lions accounted for more bighorn mortality during 2004 to 2006 than during pre-construction studies, a finding independent of construction activities. The research team documented that Highway 93, between MP 0 and 17, presented a barrier to distribution and movements of bighorns, in that fewer GPS fixes than random fixes occurred within a buffer zone extending parallel to and 328 feet from both sides of the highway than farther from the roadway. Moreover, Highway 93 was the boundary of home ranges of multiple bighorns. Nonetheless, Highway 93 did not preclude bighorns from crossing the highway right-of-way.

The research team focused investigations on areas between Highway 93 MP 0 and 3 (Hoover Dam bypass construction area) and between MP 3 and 17 (proposed highway realignment). The research team documented 50 highway crossings by bighorns between MP 0 and 3 at the newly constructed Sugarloaf Mountain underpass, indicating continued highway permeability during bypass construction. The research team also documented 342 crossings by bighorns through right-of-way fencing constructed in that general area. The research team documented 345 highway crossings by bighorns between MP 0 and 17, 232 crossings between MP 0 and 3, and 113 crossings between MP 3 and 17. The number of highway crossings by bighorns and number of bighorns that crossed the highway declined southward between MP 0 and 17. Thus, the highest number of bighorn highway crossings and number of bighorns that crossed the highway occurred between MP 0 and 3. Most rams ($N = 5$) crossed the highway between MP 0 and 8, whereas most ewes ($N = 8$) crossed between MP 0 and 5. Six females crossed the highway between MP 0 to 3, and seven crossed between MP 3 and 17. Four males crossed the highway between MP 0 to 3, and five crossed between MP 3 and 17. Our study demonstrated that crossing areas used by bighorns between MP 3 and 17 were not distributed randomly, and locations of highway crossings appeared to be independent of capture site locations. The research team identified five continuous, linear, elevated guide-ways (CLEGs) that corresponded with ridgelines where bighorns concentrated activities and trans-highway movements. Specifically, the research team identified CLEGs at Highway 93 MP 3.3, 5.1, 7.7, 12.2, and 15.3. The research team recommends construction of underpass or overpass structures at these locations, in association with proposed Highway 93 realignment, to facilitate right-of-way permeability and highway crossings by bighorns. The research team recommends that construction of highway mitigation features be given priority near the three CLEGs at MP 3.3, 5.1, and 12.2. Eighty-two percent (93/113) of highway crossings by bighorns between MP 3 and 17 occurred at these locations. Regardless of this assessment, the research team believes crossing structures at the other CLEG locations would be valuable in ensuring sufficient highway permeability to maintain genetic heterogeneity of the Black Mountain desert bighorn sheep population and maintain population vigor.

II. INTRODUCTION

Desert bighorn sheep (*Ovis canadensis*) occur throughout much of northern Mexico and southwestern USA and are distributed in naturally fragmented metapopulations.[10,11,67] They also often occur as small, isolated demes.[1,75] Population persistence, as it relates to bighorn sheep population size, is a controversial topic among biologists.[7,8,123] Whether association exists between these variables remains contentious.[76,77] No specific population size ensures population persistence.[117] Small bighorn sheep populations occupying marginal or comparatively poor habitat or small patches of suitable habitat may require management intervention to ensure long-term persistence.[7,62,89] Smaller, isolated habitat areas tend to support smaller populations with higher rates of extinctions than large populations.[66] Habitat patch size may be the primary correlate of bighorn sheep population performance and persistence.[82,89,114] However, factors other than patch geometry may influence extinction and colonization.[53]

Conservation efforts should emphasize preventing habitat fragmentation and loss and restoring habitat.[6,11,43] Habitat fragmentation at local and regional scales threatens effective wildlife conservation.[5,6,11] (See references 42 and 109) Throughout the Southwest, most populations of desert bighorn sheep are small (<100) and isolated.[75] Berger suggested that desert bighorn populations with fewer than 50 individuals tend to go extinct but that extirpation of populations is not caused by food shortages, weather, predation, or interspecific competition.[7] In contrast, population size alone may not indicate accurately persistence of desert bighorn sheep populations in Arizona.[77] Other factors, such as disease and quality of available nutrition, may impact desert bighorn populations.[33,69,80] Predation might play a role.[26,31,122] Patterns of precipitation also are well known to influence desert bighorn sheep populations.[37,84,121] Recent studies found associations between drought, production, and productivity in an Arizona population.[88,90] Whether association exists between population persistence and these variables is uncertain.[7,8,77,123]

Moreover, environmental stochastic forces intrinsic to the dynamics of small populations may result in extinction, and recent studies indicate spatial requirements of desert bighorn sheep influence population variability.[14,89,117] Small, isolated populations, more than larger populations or metapopulations, are subject to extinction through stochastic events and potential loss of genetic heterozygosity.[34,58,85] (See references 116 and 126) Wilcox and Murphy and Gaillard et al. reached a similar conclusion.[58,126] However, inbreeding depression in a free-ranging natural population has seldom been demonstrated, and impact is unclear.[111]

Habitat quality influences the relative environmental capability to provide conditions associated with individual and population persistence.[63] McCarty and Bailey and McKinney et al. suggested habitat evaluations should consider spatial requirements for viable bighorn populations.[86,89] Quantitative evaluations of habitat patches may provide insight into population persistence and management implications of introducing bighorn sheep into unoccupied locations and maintaining existing populations.[20,42,62] (See references 89 and 114)

Highways are some of the most widespread features altering natural ecosystems in the United States.[44,93,118] Collisions of vehicles with wildlife result in extensive human deaths, injuries, and property damage.[102,110] Highways block animal movements, reduce habitat connectivity, fragment habitats and populations, and contribute directly to mortality of wildlife.[54,55,56] (See reference 93)

Desert bighorn sheep populations may be fragmented and isolated by anthropogenic constructions, such as highways, fences, railroads, agricultural developments, canals, and housing developments.[61,82,105] Although little research has directly addressed effects of highways on movements of desert bighorn sheep, highways potentially block gene flow and cause rapid decline in genetic diversity of desert bighorn sheep.[41] About 19% of the total area of the United States is directly affected ecologically by public roads and associated vehicular traffic.[54] Traditional management techniques such as habitat protection and improvement and maintenance of dispersal corridors are important in conservation of bighorn sheep populations.[111] However, preservation of natural wildlife movement corridors and creation of wildlife movement corridors in areas formerly unobstructed often might provide inadequate conservation measures in absence of appropriate scientific foundations.[5,25] Placement and features of mitigation structures are of critical importance, and underpasses located without reference to established travel corridors may be ineffective in enhancing highway permeability to wildlife.[64] Mule deer (*Odocoileus hemionus*), elk (*Cervus elaphus*), moose (*Alces alces*), and mountain goats (*Oreamnos americanus*) all use developed highway-crossing corridors.[113] Mountain goat use of constructed travel corridors was affected little by construction activities.[113] However, use of developed crossings by bighorn sheep or effects of construction activities on their behavior or distribution are uncertain.

GPS telemetry has found considerable favor as a cost-effective and reliable approach to studying movements of wildlife.[18,32,104] Presently, GPS telemetry has been used to assess highway permeability for black bears (*Ursus americanus*), caribou (*Rangifer tarandus*), elk, and grizzly bears (*U. arctos*), but has not been reported for evaluation of highway crossings and permeability for desert bighorn sheep.[36,39,87] (See reference 119)

Previous researchers evaluated movements of desert bighorn sheep in relation to proposed construction on U.S. Highway 93 between MP 0 and 4 in northwestern Arizona.[28,29] Subsequently, construction was initiated on new alignment of U.S. Highway 93 between MP 0 and 3 to bypass Hoover Dam, and our study focused on this alignment, as well as on possible mitigation constructions between MP 3 and 17. Construction began in 2003 to modify alignment of Highway 93 by developing a bypass from Hoover Dam to about MP 2.5 that will route vehicle traffic around the dam to alleviate traffic congestion. Presently, modifications are proposed for Highway 93 MP 3 to 17 to further alleviate traffic congestion and limit bighorn-vehicle collisions. Fragmentation of the desert bighorn sheep population on the eastern part of the study area, from the larger Black Mountains population, due to highway construction and bighorn-vehicle collisions along U.S. Highway 93 are of major concern. Our study focused on evaluating bighorn trans-highway movements relative to current construction upgrades, and identifying locations for future placement of mitigation features to enhance highway permeability to bighorns and reduce wildlife-vehicle collisions.

Objectives of the research team were: 1) determine distribution and movements of bighorn sheep in relation to highway upgrade construction along MP 0 to 3, 2) identify concentrated areas of highway crossings south of the upgrade construction site (MP 3 to 17) and recommend locations for future construction features between MP 3 and 17 to enhance highway permeability, and 3) evaluate collisions, injuries, and mortalities of bighorn sheep resulting from highway vehicle traffic.

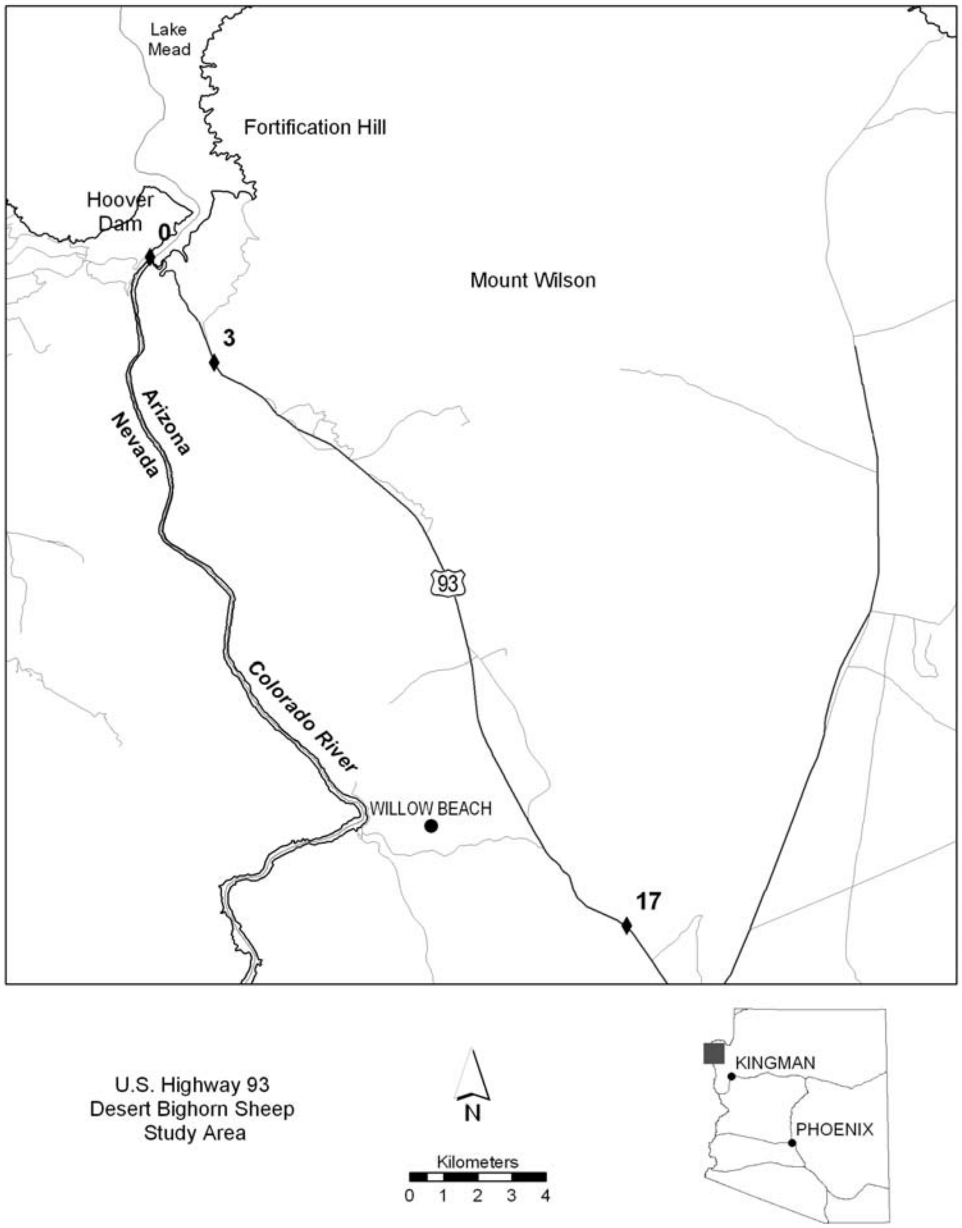

Figure 1. Location of Highway 93 desert bighorn sheep study area in northwestern Arizona.

III. STUDY AREA

Hoover Dam is located on the Colorado River about 70 miles northwest of Kingman, Arizona, and 20 miles southeast of Las Vegas, Nevada. United States Highway 93 passes through Kingman and crosses the Colorado River at Hoover Dam. The 183 $mile^2$ study area (Figure 1) extended between MP 0 and 17, and from Hoover Dam on the northeast to the east side of Fortification Hill, south along the east side of Wilson Ridge to Highway 93 MP 17, west to Willow Beach, and north along the Colorado River to Hoover Dam. The research team focused research in relation to MP 0 to 17 and two sections of Highway 93 to meet funding requirements and objectives of the study: MP 0 to 3, and MP 3 to 17. Construction of the Highway 93 bypass approach (MP 0 to 3), including the Sugarloaf Mountain underpass (158 feet high and 879 feet wide; associated approximately with Highway 93 MP 1.5; Appendix 1), was begun in 2003, and was nearly completed by October 2004, except for alignment paving. The section of Highway 93 from MP 3 to 17 is slated for upgrades by widening the alignment from a 2-lane to a 4-lane divided highway, and constructing ungulate-proof right-of-way (ROW) fencing along both sides of the roadway.

Elevation ranged from about 636 feet on the Colorado River to 4,957 feet on Mount Wilson. Topography varied from mountainous terrain with steep talus slopes and rugged cliffs to dry washes among rolling hills.(27) Average temperatures ranged from 31^{o}C in summer (May–September) to 12^{o} C in winter (December–February). Rainfall was about 2.2 inches during the summer and 1.9 inches during the winter, and about 6.1 inches annually. Creosote-bursage (*Larrea tridentata-Ambrosia dumosa*) and desert wash communities predominated.(15,27,29) Predators included bobcats (*Lynx rufus*), coyotes (*Canis latrans*), common gray foxes (*Urocyon cinereoargenteus*), and mountain lions (*Puma concolor*). Domestic livestock were absent, except that feral burros (*Equus asinus*) were uncommon. Based on aerial surveys, relatively few mule deer occurred, and numbers of desert bighorn sheep declined about 54% between 2001 and 2004.(2) Legal hunting of bighorn sheep occurred during December seasons, and two collared rams were harvested during 2004 and 2005.

IV. DATA COLLECTION PROCEDURES

The research team combined results for MP 0 to 3 and MP 3 to 17 for purposes of this report because bighorn sheep in the broad study area represent a single biological population. Nonetheless, the research team analyzed data focusing on results relative to distributions and movements of bighorns associated with MP 0 to 3, identifying areas of highway crossings and recommendation of mitigation features for MP 3 to 17, and documenting bighorn-vehicle collisions between MP 0 to 17.

A. CAPTURES

The research team captured adult desert bighorn sheep using net-gunning from a helicopter in April 2004, and equipped all bighorn with Generation III, Model TTW 3590 GPS spread spectrum or store-on-board very high frequency (VHF) satellite telemetry collars (hereafter collars) with mortality sensors (Telonics, Inc., Mesa, AZ). Sensors on collars transmitted a specific mortality signal if no animal movement occurred within 8 hours. Collars were designed to provide a GPS location fix every 5 hours for 2 years, and drop off animals automatically after 2 years via pre-programmed devices on collars. The research team placed spread-spectrum collars on five adult bighorns, and location data for these animals could be uploaded remotely during a 3 hour window every 14 days. The research team placed store-on-board collars on the remaining 25 bighorns, and location data for these animals could be retrieved upon collar drop-off and recovery. All collars possessed VHF beacons to facilitate locating study animals in regards to trans-highway movements and to recover collars in the event of mortality or collar drop-off.

The research team placed spread-spectrum collars on females and males on both sides of Highway 93 to monitor distribution and movements of bighorns in vicinities of MP 0 to 3. The research team placed store-on-board collars on females and males captured along the length of Highway 93 between approximately MP 3 and 17 to collect data on distribution of bighorns and locations of highway crossing areas along the length of the proposed highway alignment.

Faulty collar manufacturing required replacement of collars on study animals. The research team recaptured all previously collared bighorns except one ram and recovered malfunctioning collars during a second capture effort between October 29 and November 2, 2004, and placed new collars on 30 adult bighorn sheep (20 females, 10 males). At this time, the research team deployed 15 spread-spectrum GPS collars (replacing 10 of the original VHF store-on-board collars) and 15 store-on board collars. The research team captured bighorns in the same manner as the first capture, except that one female was chemically immobilized using the experimental opioid drug thiafentanil oxylate (A 3080) and xylazine hydrochloride administered with a dart gun fired from the helicopter. The research team captured and placed collars on six animals that had not been captured previously, because of collar failure ($N = 1$), capture-related death ($N = 1$), and mortalities ($N = 4$) that had occurred prior to the second capture effort.

B. MONITORING

The research team conducted aerial telemetry flights monthly between April 2004 and April 2006 using fixed-wing aircraft (Cessna 182 or 185) to download data from spread-spectrum collars, locate bighorns fitted with store-on-board collars, and document and locate any mortality. The research team incorporated data from spread-spectrum collars into ArcGIS® Version 8.3 software (ESRI, Redlands, CA) following each flight, and incorporated data from store-on-board collars following collar drop-off and retrieval at end of fieldwork or if mortalities occurred. The research team monitored bighorn deaths due to vehicle collisions using continual ground surveys and consultations with local law enforcement agencies. The research team identified predation by mountain lions based on sign at carcass sites, including presence of scats, tracks, caching of kill, drag-lines, canine punctures, hair plucked from kill, and feeding patterns.[(90)]

C. HIGHWAY CROSSINGS

The research team determined highway crossings by drawing lines connecting all consecutive GPS location fixes in a Geographic Information System (GIS), and inferred crossings where lines between fixes crossed Highway 93 through a given section of the highway. The research team compiled highway crossings by all collared animals, and compared crossings among all highway MPs, especially between MP 0 to 3 and 3 to 17.

D. HOME RANGE

The research team calculated home ranges of collared bighorns using minimum convex polygons (MCP), 100% MCP, and described home ranges of individuals qualitatively in relation to Highway 93.[(125)] Home range sizes differ depending on method of analysis, and the research team used MCP to enhance comparison of home range sizes in our study with the MCP method used in earlier research on our study area.[(17,28)]

E. TRACK BEDS

The research team developed 50 track beds along sides of the Highway 93 corridor to supplement data on presence and highway-related movements of bighorns obtained from telemetry collars and continual ground observations. The research team located track beds in areas of historically high vehicle collision frequencies (AGFD unpublished data) to help locate specific areas of highway crossings. The research team also located track beds in other areas of low historical vehicle collision frequencies and lower use by bighorns. The research team located track beds based on data obtained from ground observations and data downloaded from collars to determine if gaps in crossing data existed based on telemetry data from bighorns distributed throughout the Highway 93 alignment between MP 2.5 and 13.5. The research team counted track sets (single or multiple tracks on a track bed) at about 3-week intervals, and cleared and restructured track beds after each examination.

Track beds consisted of a layer of sand about 0.6 inches thick, 3 feet wide, and of variable length depending on terrain. The research team placed track beds between MP 2.5 and 13.5 in saddles, at the edges of guardrails, in culverts, on and below an out-jump at MP 2.0 (Appendix 2) associated with construction upgrades, and beneath two underpasses located at MP 4.1 and 8.0. Out-jumps are constructions of earth and rocks raised to the level of ROW fencing that allows bighorns to escape from inside the ROW but prevents entry into the ROW. Based on ground searches for bighorn sign, the research team believed pre-existing fencing on both sides of the highway between MP 13.5 and 17 precluded most bighorn crossings and made track beds unnecessary in this area. The research team placed no track beds between Hoover Dam and MP 1.5, because high human foot traffic in this area would tend to obliterate signs of bighorn use.

F. GROUND OBSERVATIONS

The research team conducted ground observations regularly, and recorded date, nearest milepost, group size, gender of adults, presence of lambs, and on which side of the highway (east or west) observations occurred. The research team often watched bighorns for prolonged periods in attempts to observe them crossing the highway. The research team incorporated all ground observation data and locations of guardrails along the highway alignment into a GIS database. The research team observed most bighorns from a vehicle during routine morning and evening surveys.

G. ESCAPE TERRAIN AND SLOPE

The research team calculated escape terrain on the study area following published procedure and incorporated data into a GIS database.[(89)] The research team calculated slopes of study area terrain between 0 and 100% by 10% slope categories using ArcGIS.

H. DATA ANALYSIS

The research team employed ArcGIS to analyze GPS data. The research team divided Highway 93 between MP 0 and 17 into 17 sequential 1-mile sections, and subdivided these sections into ¼-mile segments to quantify highway crossings and bighorn use in buffer zones that the research team developed contiguous with and parallel to the highway. Metric data were used in most analyses and are presented as such for statistical formulations, but otherwise have been presented using the English system, and using conversions of 1 meter = 3.29 feet, 1 centimeter = 0.39 inches, and 1 kilometer^2 = 0.396 mile^2. The research team identified buffer zones extending on both sides of the highway ≤328 feet and 328 to 820 feet from the highway to assess GPS fix distributions.[(36)] The research team developed random location points by locating the number of fixes observed within the range of each individual bighorn, and redistributing the same number of location points randomly within its range, thus providing realistic estimates of areas of relative use by collared bighorns.[(119)] The research team compared mean number of GPS fixes and random points in buffer zones using confidence intervals. The research team compared mean number of highway crossings and mean number of bighorns crossing the highway between MP 0 and 3, and MP 3 and 17, and compared mean number of highway crossings and mean number of females and males crossing the highway using confidence intervals. The research team determined relationships between MP and bighorn highway crossings using Spearman rank correlation. The research team used 2 X 2 contingency tables and Yates chi-square analysis to compare proportions of collared females and males crossing the highway.[(129)]

The research team determined centers of activity (COA) of each collared bighorn and grouped bighorns, defined COA as centrally-clustered locations of GPS fixes within an 820 foot buffer zone in relation to the highway, and analyzed individual and grouped animals by shared use areas. The research team calculated COAs for individual bighorns using the formula:

$$\Sigma(ab)/c,$$

where "a" is the number of ¼-mile highway segments occupied by an individual, "b" is the frequency of GPS fixes in each ¼-mile highway segment, and "c" is the total GPS fixes in all ¼-mile highway segments occupied by an individual. The research team calculated COAs for groups of bighorns using the formula:

$$A/B,$$

where "A" is the sum of individual COAs by ¼-mile segments in a shared area, and "B" is the number of bighorns in the shared area.

The research team calculated correlations between distances of individual COAs in relation to 164 feet, 328 feet, and 820 feet distances from physical landscape features (ridgelines) that extended across the highway using simple linear regression.[129] The research team defined ridgelines as those that involved continuous, elevated landmasses that connected both sides of the highway alignment and offered bighorns good visibility in relation to surrounding areas. The research team calculated mean distance of COAs of individual animals from ridgelines and compared mean distances to ridgelines using confidence intervals. The research team also determined geographic center for each grouped COA to help identify locations of potential highway crossing structures.

V. RESULTS

A. CAPTURES

The research team captured and collared 30 bighorns during each of two capture efforts, and combined data from the first and second bighorn captures for analyses. During the first capture, the research team deployed five spread spectrum collars (three females, two males) and 25 store-on-board collars (17 females, eight males). During the second capture effort, the research team captured six animals not previously captured, and deployed 15 spread spectrum and 15 store-on-board collars. The research team placed collars on six females and two males between MP 0 and 3, and 14 females and eight males between MP 3 and 17. Due to mortalities before and during captures, the research team obtained data from 34 collars placed on 23 females and 11 males. The research team thus placed radiocollars during captures on at least 15% of the number of adult bighorns counted on the study area during aerial surveys in 2004.(2)

B. HIGHWAY CROSSINGS

The research team conducted 21 fixed-wing over-flights to upload data from spread-spectrum collars and check mortality status of individuals. On April 16, 2006, 18 remaining collars dropped off, and the research team retrieved them and downloaded data. Thirty-four collared bighorns provided 73,496 usable GPS locations. Two collars failed to provide GPS data.

Distribution and movements of collared bighorns occurred throughout the study area (Figure 2), but the number of highway crossings by bighorns (Figure 3) and number of distinct bighorns that crossed the highway (Figure 4) varied between MP 0 and 17. The research team documented 345 crossings of Highway 93 by nine female and five male bighorns (41% of collared animals; Table 1). Thus, 59% of collared bighorns did not cross the highway. The research team documented 232 highway crossings by bighorns between MP 0 and 3 (50 beneath the Sugarloaf Mountain underpass), and 113 highway crossings between MP 3 and 17. Six collared bighorns crossed beneath the Sugarloaf Mountain underpass 33 times before highway construction essentially ended in October 2004, and six crossed 17 times after completion of construction. Six collared bighorns also crossed around or through ~7-foot ungulate-proof ROW fencing 177 times during bypass construction, and seven bighorns crossed the fencing 165 times after completion of construction.

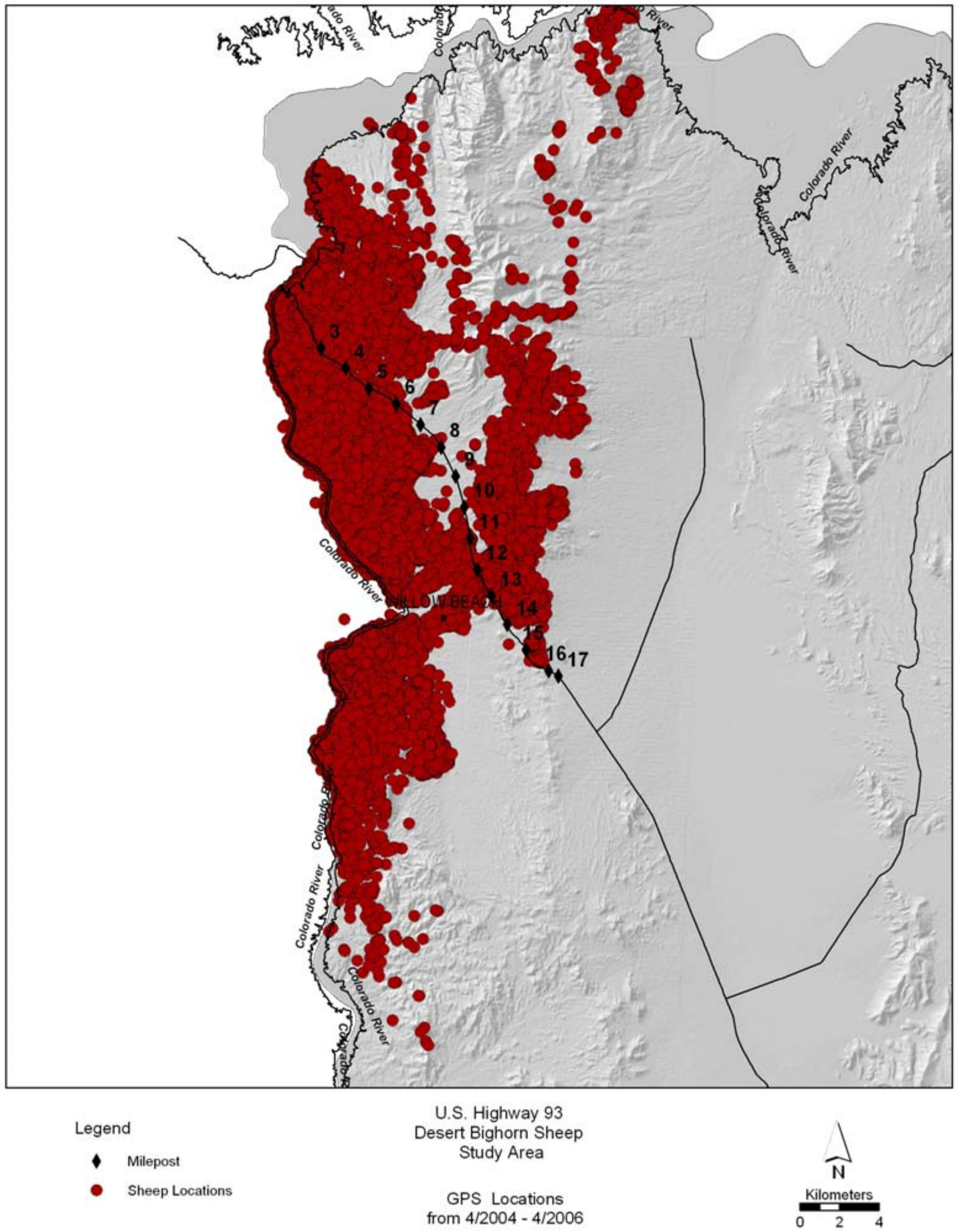

Figure 2. Distribution of collared bighorns on the Highway 93 study area, Arizona, 2004 to 2006

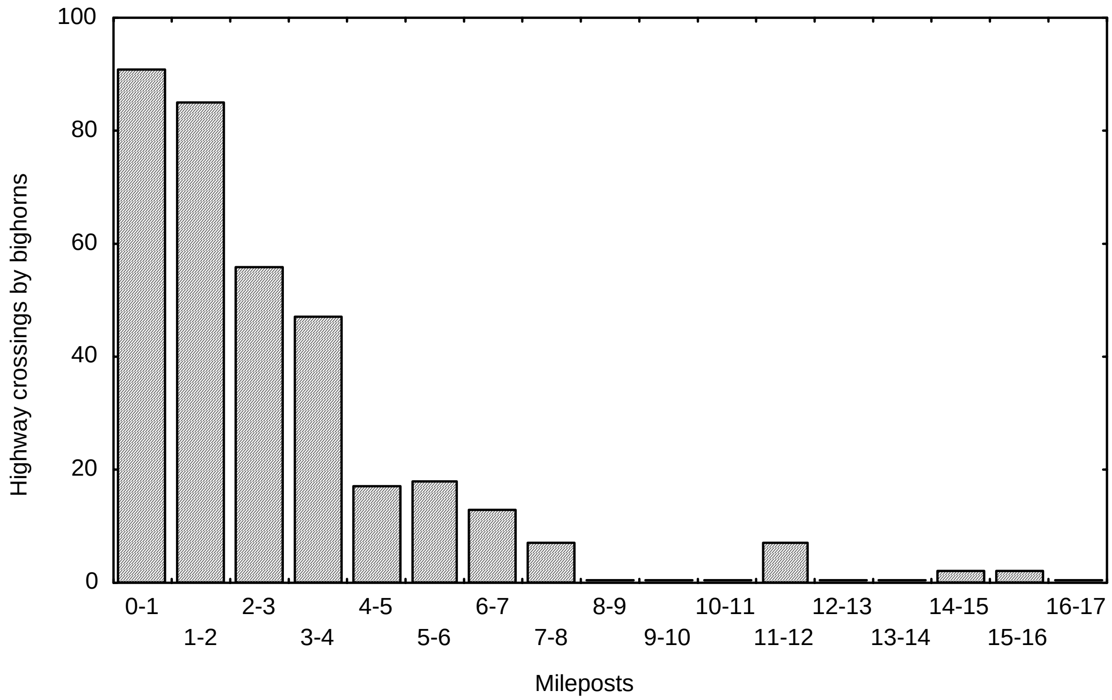

Figure 3. Number of Highway 93 crossings by collared bighorns per 1-mile highway segment, MP 0 to 17, Arizona, 2004 to 2006.

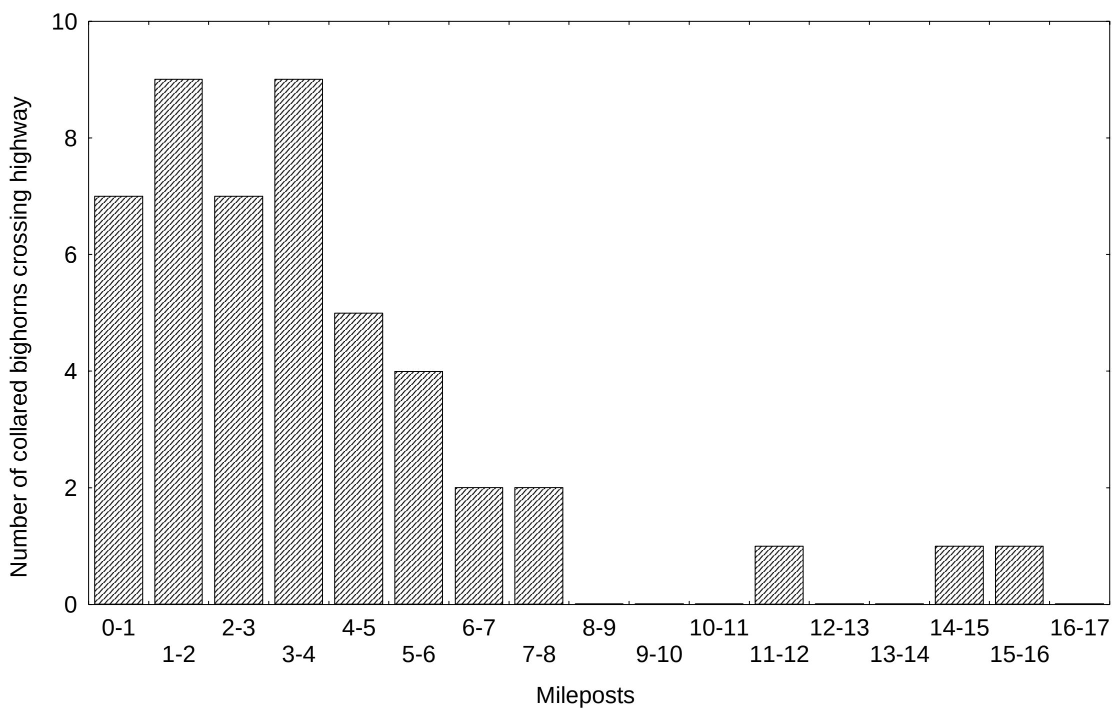

Figure 4. Number of collared bighorns crossing Highway 93 per 1-mile highway segment, MP 0 to 17, Arizona, 2004 to 2006.

Table 1. Collared (ID = animal number) female and male bighorn crossings at Highway 93, right of way (ROW) fences, and Sugarloaft Mountain underpass in Arizona, 2004 to 2006

ID	Sex	Highway 93	ROW fence	Sugarloaf Mountain
3252	Female	6	0	0
3253	Female	19	2	0
3254	Male	13	9	2
3255	Male	71	70	11
3257	Female	71	101	16
3261	Female	13	27	9
3262	Female	4	0	0
3263	Female	4	0	0
3265	Female	48	35	3
3268	Female	27	83	6
3273	Female	4	0	0
3274	Male	30	0	0
3278	Male	12	6	2
3279	Male	23	0	0
3308	Female	0	9	1
Total		345	342	50

The number of highway crossings (R = –0.8291, t_{15} = –5.7436, P < 0.001) and number of bighorns that crossed the highway (R = –0.8116, t_{15} = –5.381, P < 0.001) declined southward between MP 0 and 17. Mean highway crossings per mile (mean = 77.3, 18.72 SD, 95% CI = 30.8–123.8) and mean number of bighorns crossing the highway per mile (mean = 7.7, 1.2 SD, 95% CI = 4.8–10.5) were greater between MP 0 and 3, than mean highway crossings per mile (mean = 8.1, 13.0 SD, 95% CI = 0.6–15.6) and mean number of bighorns crossing the highway (mean = 1.8, 2.6 SD, 95% CI = 0.3–3.3) between MP 3 and 17. Most females (N = 8) and males (N = 5) crossed the highway between MP 0 and 5 and MP 0 and 8, respectively (Figure 5). Six females crossed the highway between MP 0 to 3, and seven crossed between MP 3 and 17. Four males crossed the highway between MP 0 to 3, and five crossed between MP 3 and 17. Bighorn crossings of the highway between MP 0 to 3 and 3 to 17 were 232 and 113, respectively.

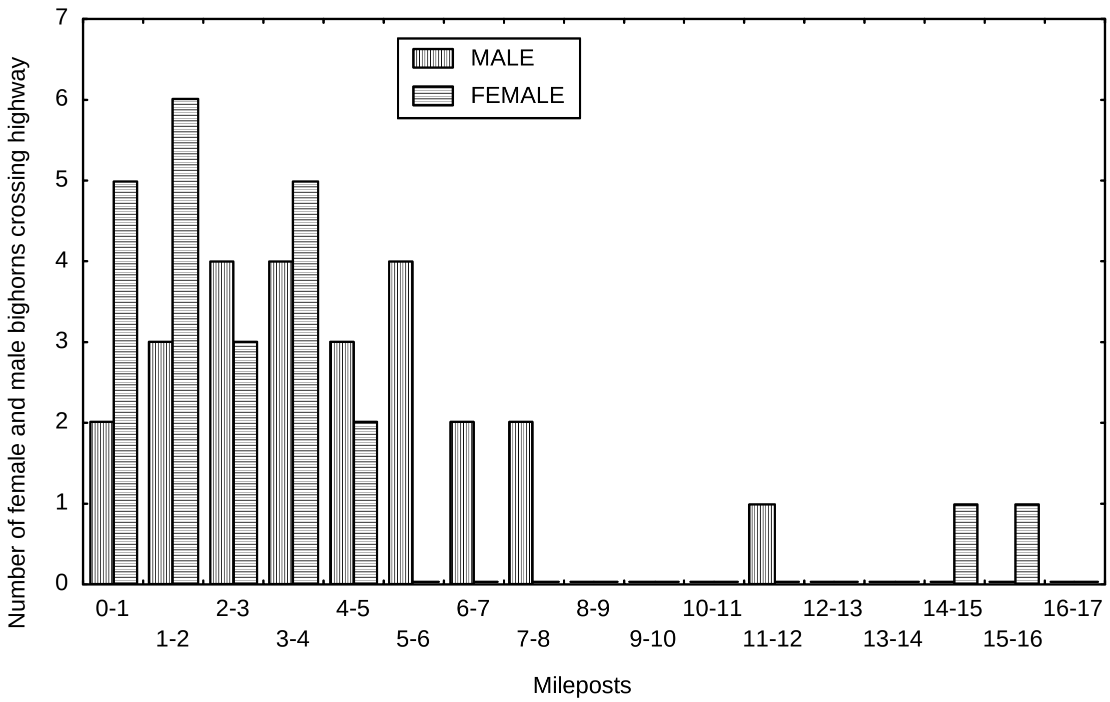

Figure 5. Comparison between collared male and female bighorns crossing Highway 93 per 1-mile highway segment, MP 0 to 17, Arizona, 2004 to 2006

The number of highway crossings and number of bighorns crossing tended to be higher for MP 3 to 4 than other highway segments between MP 3 and 17 (Figures 3, 4). Proportions of females and males that crossed the highway between MP 0 and 17 relative to total collared bighorns did not differ ($\chi^2 = 0.01$, $df = 1$, $P = 0.941$). The proportion of males and females that crossed the highway between MP 0 and 3 and between MP 3 and 17 also did not differ ($\chi^2 \leq 0.22$, $df = 1$, $P \geq 0.636$). Number of females ($R = -0.5868$, $t_{15} = -2.806$, $P = 0.013$) and males ($R = -0.8280$, $t_{15} = -5.720$, $P < 0.001$) that crossed the highway declined southward between MP 0 and 17 (Figure 5). Most collared bighorns tended to avoid the area near the roadway on the east side of the highway between about MP 6 and 11, and on the west side of the highway between about MP 8 and 11 (Figure 6). Collared bighorns that crossed (Figure 6) or did not cross (Figure 7) the highway were broadly distributed within the study area, and many that did not cross the highway approached the right-of-way (Figure 7).

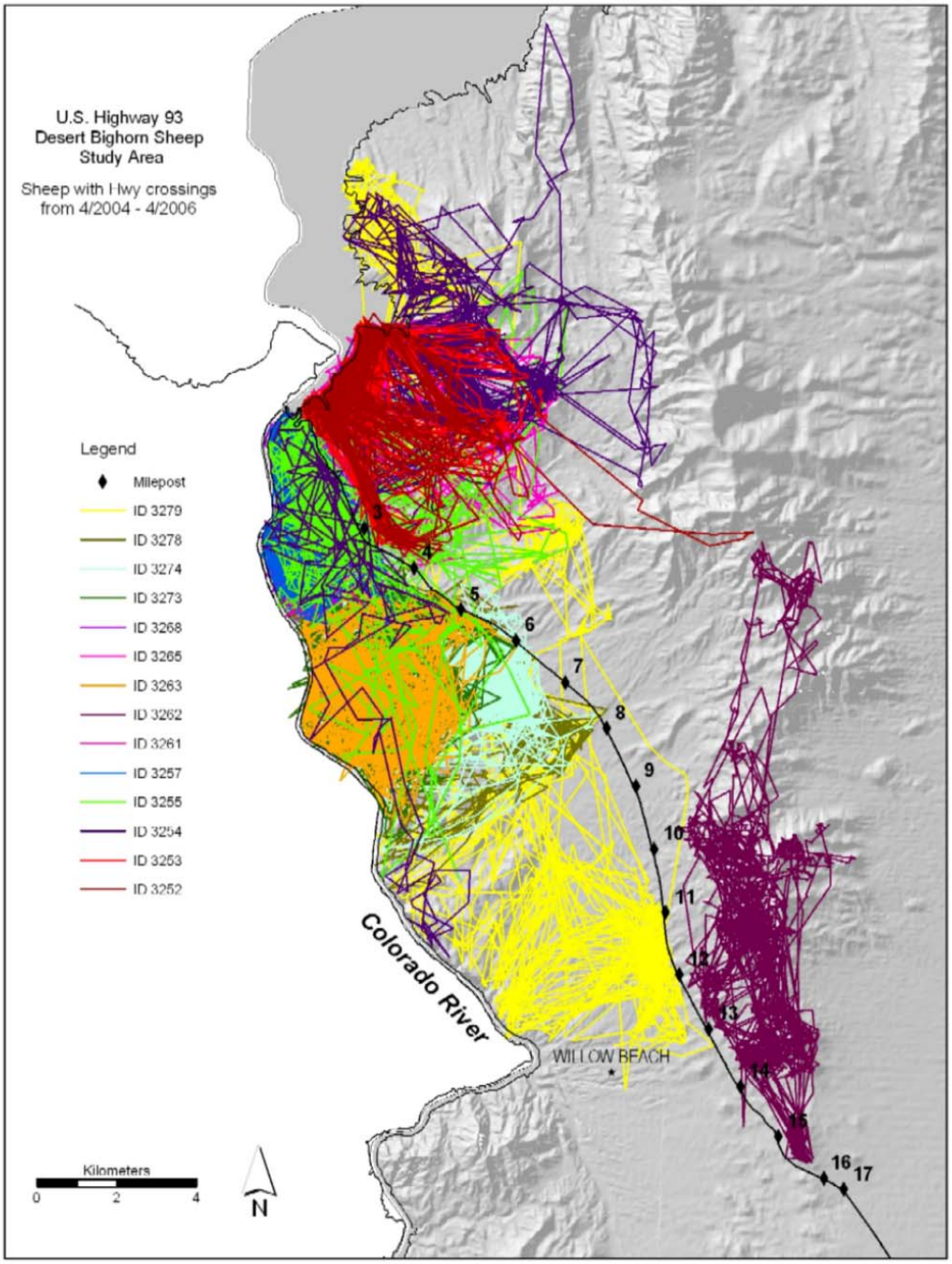

Figure 6. Distribution of collared bighorns that crossed Highway 93, Arizona, 2004 to 2006

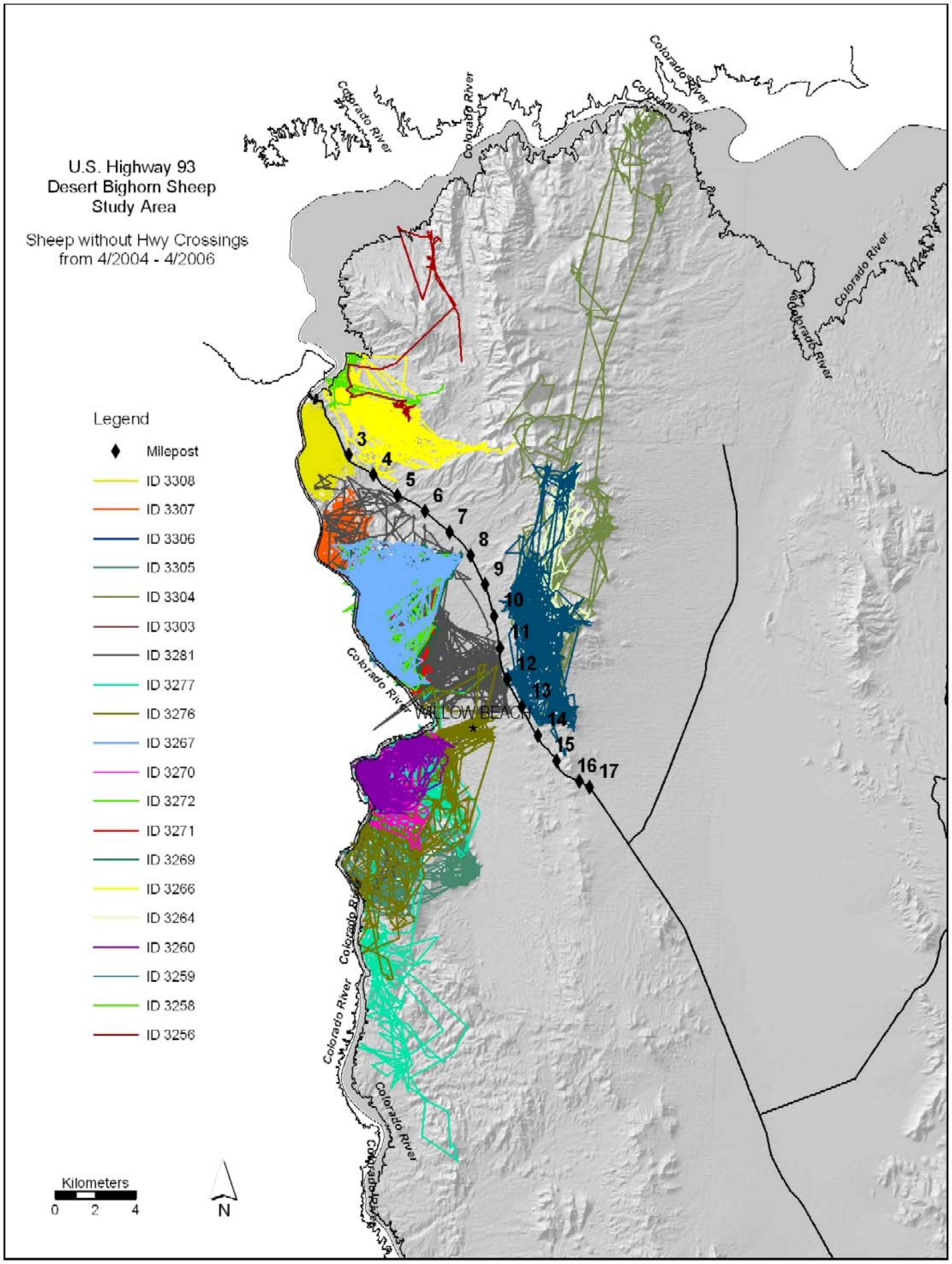

Figure 7. Distribution of collared bighorns that did not cross Highway 93, Arizona, 2004 to 2006

Within the buffered ≤328 feet zone, mean GPS fixes of collared bighorns (mean = 5.76 fixes/0.25 mile, 9.26 SD, 90% CI = 3.67–7.85) was lower than mean random point locations (mean = 13.44/0.25 mile, 19.19 SD, 90% CI = 9.11–17.77). Conversely, mean GPS fixes of collared bighorns within the 328–820 feet buffer zone (mean = 13.80/0.25 mile, 20.56 SD, 90% CI = 9.16–18.44) was not different from mean random point locations (mean = 21.91/0.25 mile, 31.14 SD, 90% CI = 14.88–28.94).

Bighorn sheep tended to approach and cross the roadway in predictable locations between MP 3 and 17. Of 113 highway crossings by bighorns between MP 3 and 17, 99 occurred within the following ¼-mile highway segments (Figure 8) extending successively southward from MP 3: 60 between segments 11–14 (MP 2.8 to 3.5), 22 between segments 19–22 (MP 4.8 to 5.5), six between segments 30–32 (MP 7.5 to 8.0), seven between segments 44–47 (MP 11 to 11.8), and four between segments 56–62 (MP 14 to 15.4).

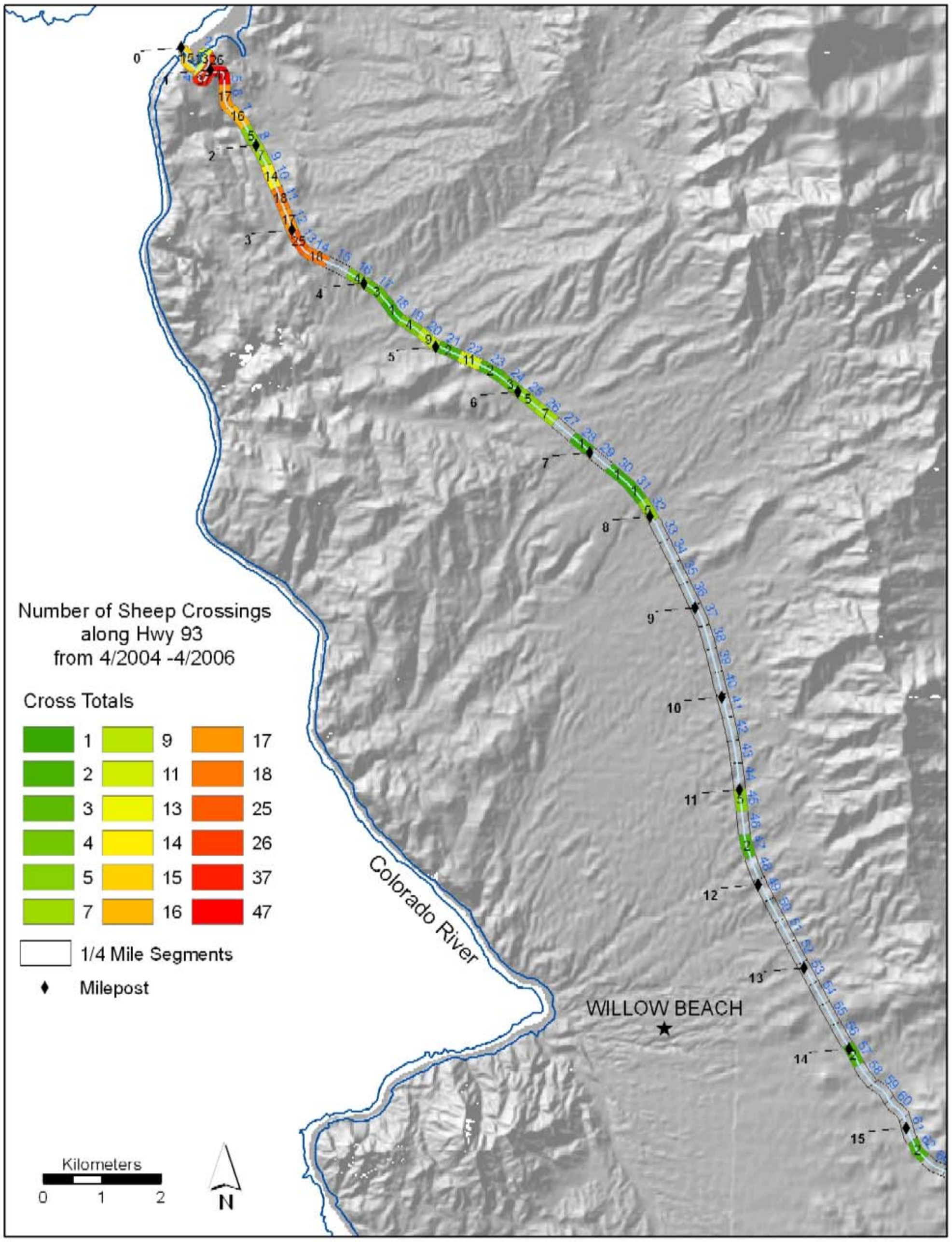

Figure 8. Quarter-mile highway segments and frequency of bighorn sheep crossings onthe Highway 93 study area, Arizona, 2004 to 2006

C. HOME RANGE

The research team calculated home ranges for 18 females and eight males that were alive for ≥12 months following captures. Mean home ranges for females and males were 10.6 $mile^2$ (mean =27.53 km^2, ± 11.97 SD, 95% CI = 21.58–33.49) and 49.0 $mile^2$, mean = 111.36 km^2, ± 41.73 SD, 95% CI = 76.47–146.25), respectively. Mean home ranges of females that crossed (10.9 $mile^2$; mean =28.36 km^2, ± 12.83 SD, 90% CI = 19.76–36.96) and those that did not cross (10.4 $mile^2$; mean = 26.87 km^2, ± 11.90 SD, 90% CI = 19.97–33.76) the highway did not differ. Mean home ranges of males that crossed (37.7 $mile^2$; mean = 97.55 km^2, ± 48.78 SD, 90% CI = 51.04–144.06) and those that did not cross (51.9 $mile^2$; mean = 134.37 km^2, ± 8.04 SD, 90% CI = 120.82–147.91) the highway did not differ.

D. TRACK BEDS

Thirty-four percent of track beds (17/50) registered bighorn track sets, excluding the track bed located at an out-jump at MP 2.0. Track beds at MP 3.2 to 3.3 registered 16 track sets, those at MP 5.3 to 5.6 registered 13 track sets, and those at MP 7.7 to 7.9 registered >16 track sets. Track beds in these locations accounted for 76% (45/59) of track sets, and other track beds within 1/4 mile of these locations accounted for 24% (14/59) of track sets. Track beds in the area between MP 11.0 and 13.5 did not register tracks. The research team placed track beds only in association with gaps between guardrails along the highway, except that the research team placed track beds on and below the out-jump at MP 2.0 west of the current highway alignment, in five culverts, and underneath underpasses at MP 4.2 and 8.0. Four track sets on the out-jump on the upper bed, and three track sets tracks on the lower bed, indicated some bighorns exited the ROW, but another animal remained in the ROW. The research team found no track sets at culverts, found no tracks at the underpass at MP 4.2, and found two track sets in each direction at the underpass at MP 8.0. Because the ROW fence was not yet functional, the research team placed no track beds at other out-jumps.

E. MORTALITY

Eighteen collared animals survived from captures to the end of the project. Collars recorded data for a mean of 17.0 months (± 7.73 SD**,** range = <1 to 24 months). The fate of one ram is unknown because the collar failed completely after release. One female was released without a replacement collar during the second capture effort because of neck injury from the radiocollar.[78]

Nearly 46% (16/35) of bighorns collared were known to have died during the study. Mountain lion predation caused 75% (12/16) of known mortalities that occurred on both east and west sides of the highway (Figure 9). Legal harvest (12.5%; 2/16), possible infection of neck due to collar (6.3%; 1/16), and capture (6.3%; 1/16) caused fewer deaths than mountain lions. Mortality of collared bighorn sheep due to vehicle collisions was significantly less during our study (N = 0) than during previous research on the study area in 1989–1991 (N = 5 or 6).[28] Total known mortalities of collared and unmarked bighorn sheep from vehicle collisions during our study was reduced as well (N = 1), compared to the previous study (*N* = 25).[28] A vehicle killed one lamb in June 2003 (prior to our study) in the vicinity of MP 1.2, and a vehicle reportedly killed a young ram in the vicinity of the MP 2.0 interchange during winter/spring 2006.

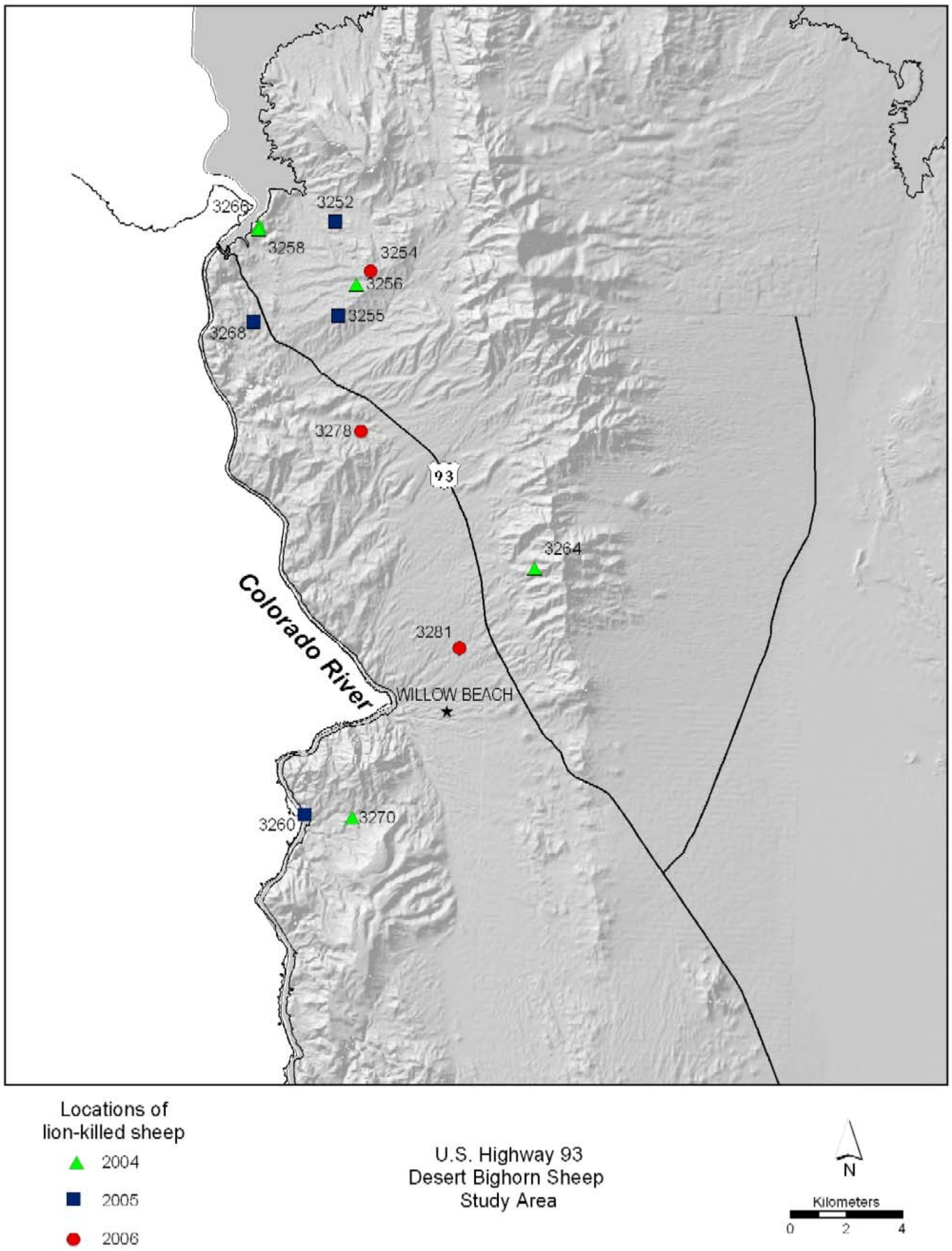

Figure 9. Locations of collared bighorns killed by mountain lions on the Highway 93 study area, Arizona, 2004 to 2006

F. GROUND OBSERVATIONS

The research team observed 574 bighorns throughout the study area during regular ground surveys, including unknown repetitive observations of animals (Figure 10). Data from telemetry, ground observations, and track beds confirmed the highest abundance of bighorns in the northern part of the study area, primarily north of about MP 6. Mean group size observed was 4.4 animals (± 3.6 SD, range = 1–19). The research team observed 33 single animals and 100 groups with $\geq$ two bighorns. The research team observed 427 bighorns adjacent to highway 93. The number of bighorns observed per mile declined ($R = -0.7196$, $t_{13} = -3.737$, $P = 0.002$) between MP 0 and 17. The research team observed the highest number of bighorns between MP 1 and 2.5 ($N = 245$), including 62 bighorns in close association with the Sugarloaf Mountain underpass. Other areas where the research team observed relatively high numbers of bighorns included MP 3.2 to 3.4 ($N = 63$), MP 5 to 6 ($N = 39$), MP 7.7 to 7.9 ($N = 10$), and MP 11 to 12 ($N = 28$). The research team observed 23 highway crossings by bighorns within the first 4 miles from Hoover Dam, and observed seven highway crossings in the vicinity of MP 1.1 to 1.2, 12 crossings at MP 1.9, and four at MP 3.2 to 3.4. Most observed highway crossings occurred in gaps between guardrails. The research team observed bighorn sheep at MP 3.2 to 3.4 and MP 7.7 to 7.9 that often appeared to attempt crossing but were driven back by curious motorists that stopped to photograph the animals.

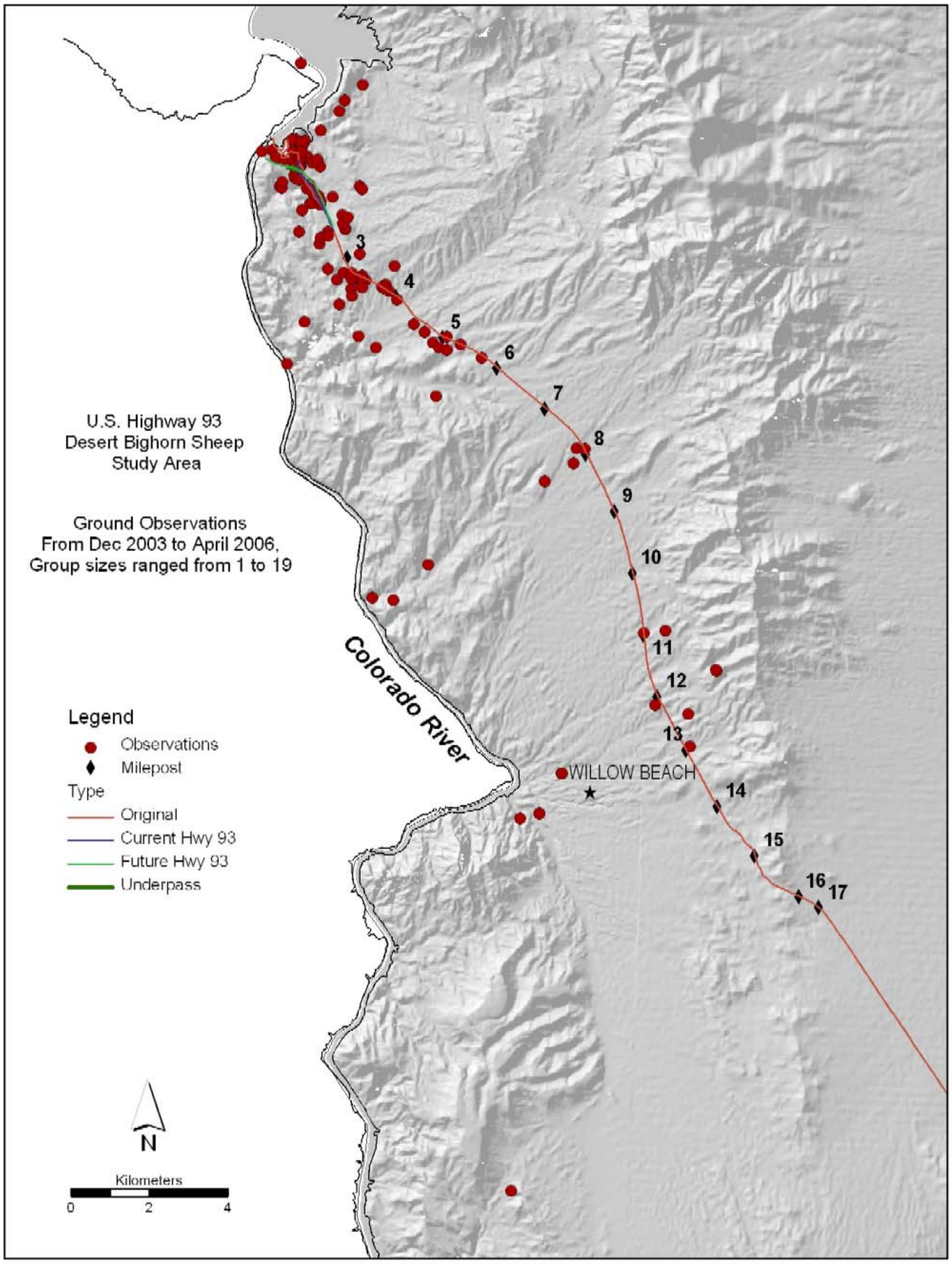

Figure 10. Ground observations of bighorn sheep by field personnel on the Highway 93 study area, Arizona, 2003 to 2006

G. ESCAPE TERRAIN AND SLOPE

Limited areas of escape terrain occurred near the highway, primarily west of MP 0 to 3 and MP 5 to 6, and east of MP 0 to 1.5, MP 10 to 14, and MP 15 to 16 (Figure 11). Bighorns appeared to occupy and move through habitats with and without escape terrain (Figures 6, 7, 11). Highway crossings by bighorns appeared to associate most closely with escape terrain between MP 0 and 3 and about MP 5 to 6 (Figures 3, 4, 6, 11). Slopes in the study area ranged from shallow to very steep, and bighorns appeared primarily to cross the highway particularly between MP 3 and 17 in areas of contiguous moderate slopes (Figures 3–6, 11, 12). The research team identified five major ridgelines that extended across the highway alignment between MP 3 and 17 that were separated from each other by a mean distance of 3.2 miles (± 1.0 SD, range 1.9–4.4 miles). Mean distances of COAs of individuals within grouped bighorns from ridgelines were associated with and did not differ among three ridgelines at MP 3.3 (mean = 0.24 miles; mean = 394.2 m, 282.4 SD, 95% CI = 192.2–596.2 m), 5.1 (mean = 0.21 miles; mean = 344.5 m, 318.7 SD, 95% CI = 10.09–678.9 m), and 12.2 (mean = 0.54 miles; mean = 871.3 m, 285.5 SD, 95% CI = 417.0–1.325.5 m). The COA of one individual at MP 15.3 was 580 feet from the ridgeline. As distances of individual bighorn COAs from ridgelines in 164, 328, and 820 feet increments increased, the number of individual bighorn COAs declined ($F_{1, 4\text{-}24} \geq 7.87$, $r^2 \geq 0.2470$, $P \leq 0.014$, $b \geq -0.92$). Four of five ridgelines showed COAs for bighorns, and all but one of these areas registered multiple tracks on track beds.

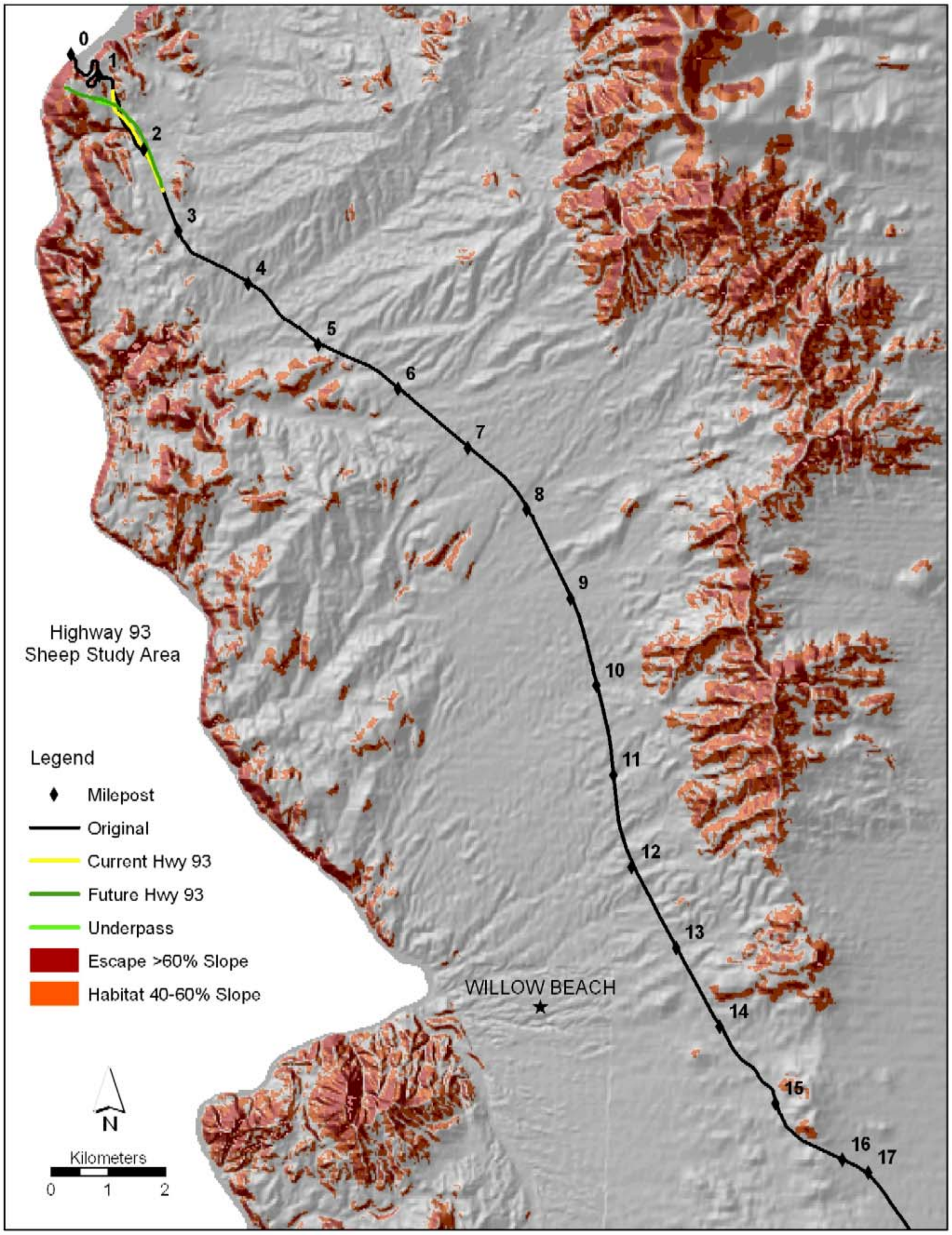

Figure 11. Escape terrain on the Highway 93 study area, Arizona

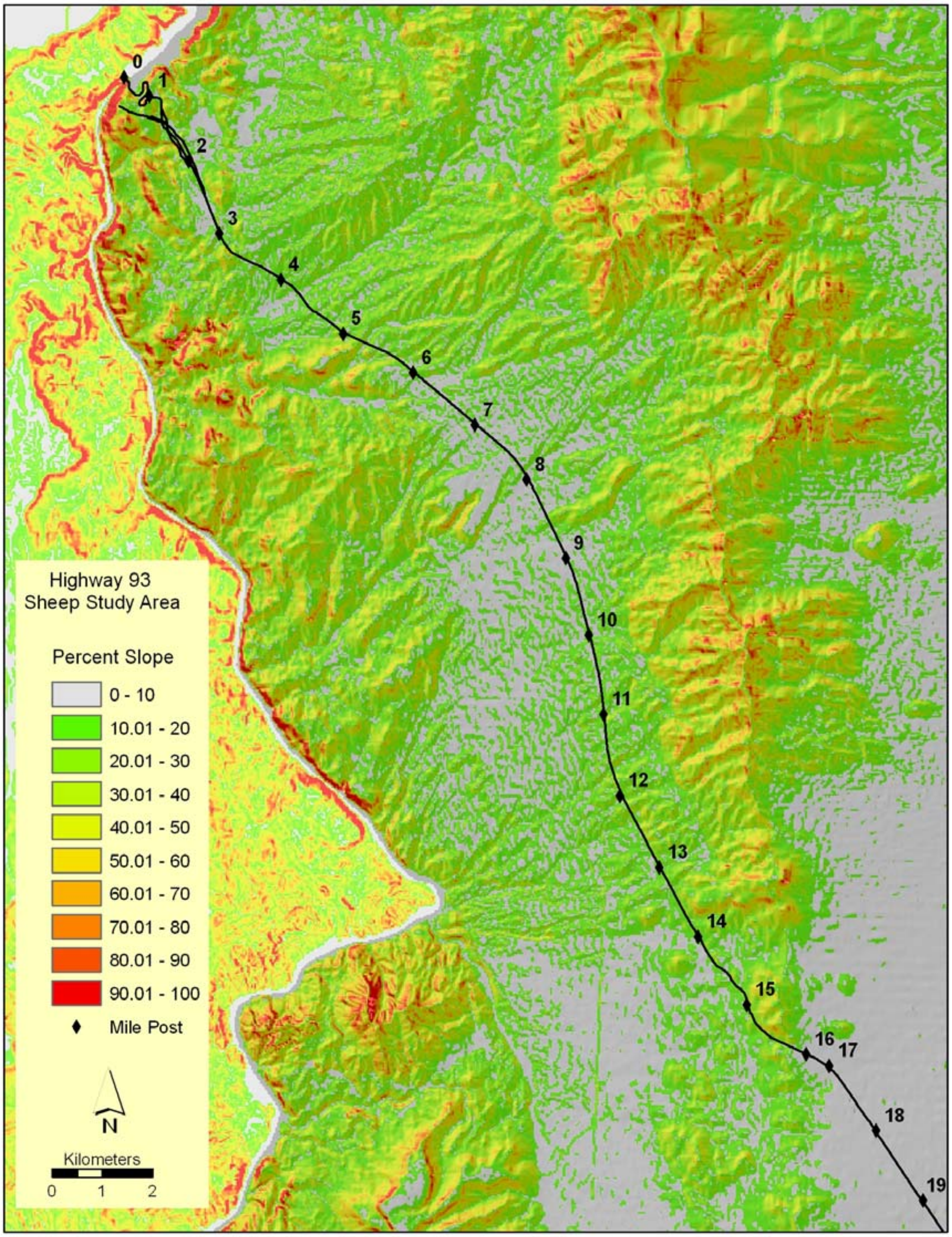

Figure 12. Terrain slope on the Highway 93 study area, Arizona

VI. DATA EVALUATION AND ANALYSIS

Ever since there have been modern roadways, there have likely been deleterious effects on wildlife, such as vehicle collisions and direct mortality, habitat fragmentation, loss and degradation, road avoidance, increased human activities, reduced biodiversity, genetic isolation, chemical contamination, reduced access to vital habitat, and disruption of life cycle processes and the food chain.(21,45,112) Habitat fragmentation is considered the most serious threat to biological diversity for all species and is the primary cause of the present extinction crisis.(40) Large mammals are especially vulnerable to habitat fragmentation because of large body size, high level of trophic needs, and relatively large home ranges.(126) Because many species of special concern are long-lived and have low reproductive rates, any harmful indirect effects of highways are most likely incremental and cumulative, and many years of research will be required to assess these effects.(21)

Distribution of desert bighorn sheep in Arizona was more extensive in the past than today.(128) Combined effects of ecological and sociological barriers governed ancestral movements of individuals between mountain ranges.(16,108) Travel corridors are preferred routes through marginal and low use habitats that connect adjacent areas of higher quality habitat, and are considered critical habitat.(94,127) Bighorn movements are believed to occur within traditional corridors usually associated with adequate escape terrain.(29) Strong social ties between offspring and parents promote a highly traditional pattern of seasonal movements by bighorn sheep.(42,59,65) Social systems of bighorn sheep appear to have been shaped by anti-predator and foraging strategies that rely upon learned traditions, and travel corridors that are obstructed or not used for a period of time can be lost to the entire population.(52,59) Keeping travel corridors permeable is necessary to ensure adequate gene flow, access to seasonal breeding, feeding and lambing areas, and access to water and escape terrain. Denying movements by bighorn rams to traditional breeding areas for even a short time could reduce reproductive success by extending the breeding season and stressing both sexes.(29) Gregariousness likely plays a key role in affecting dispersion by individual rams, and the tendency to follow conspecifics at some times of the year may be greater than that to return to the same seasonal range.(49) Lack of extreme rigidity in seasonal dispersion would be advantageous when new habitat is created, or when appropriate mitigation measures are in place to allow permeability across roadways.(49) Management policies and decisions should be directed toward identifying and preserving traditional routes of movement by bighorn rams, an essential factor that contributes to stability of a desert bighorn population.(128)

The bighorn population in the Black Mountains of Arizona is one of the largest extant populations in the Southwest. Since 1979, the Black Mountains population has provided multiple transplants involving more than 580 desert bighorn sheep to several states. The importance of this herd's health cannot be overstated from a local and regional biological perspective. During our study, the number of bighorns counted during aerial surveys in 2004 was >50% lower than the number counted in aerial surveys during previous research on the study area in 1991.(2) Nonetheless, collared bighorns in our study were distributed and moved throughout the study area. Home ranges of females were smaller than those of males, whether or not they crossed the highway, and home ranges of ewes and rams were comparable between our study and pre-construction research during 1989 to 1991.[28] An abundance of bighorns was highest in northern portions of the study area, particularly north of about MP 6. Bighorn sheep need access to an array of habitats to carry out life processes and maintain herd vigor. Construction of an unmitigated (no crossing structures), 4-lane, divided highway with ungulate-proof ROW fencing potentially would disrupt or halt many or all movements of bighorns to vital habitat areas and reduce viability of populations.

Bighorn-vehicle collisions have been a major concern to transportation authorities and wildlife managers. Records indicate an average of more than three bighorns per year were killed by vehicles on Highway 93 during the 22-year span from 1980–2002; AGFD (unpublished) estimated vehicle-related deaths were closer to10 animals/year. Desert bighorn sheep are highly sought trophies by the hunting community and are valuable to wildlife enthusiasts, managers, and conservationists. Few human fatalities have resulted from vehicle collisions with bighorns, but human deaths and substantial property damage can occur and bighorn populations can be affected negatively.[29] Deer (*O. hemionus*, *O. virginianus*) are implicated in 90% of wildlife-vehicle collisions in North America, and associated costs can reach about $2 billion annually for an estimated 700,000 annual collisions.[70,95,97] High costs, ecological impacts of roads, and the sheer amount of land affected by the system of public roads (estimated at 20% of the U.S. land area). have many state and federal highway and wildlife agencies concerned about safety of motorists and long-term well-being of wildlife populations.[54]

One factor that has hindered the ability of state agencies to deal with highway-wildlife issues is a lack of accepted methodologies for evaluating potential impacts of roadways on wildlife and habitats and developing mitigation strategies.[91] States also have problems justifying habitat and wildlife mitigation that is not associated with a listed species, because there is no legal imperative.[97] Until recently, there has been little collaboration between biologists and engineers to solve mutual wildlife-highway dilemmas.

Historically, mitigations for wildlife along roadways included night-time speed reduction zones, installation of special roadside headlight reflectors, adding “rumble” strips to the road surface, highway lighting, one-way gates, cattle guards, mirrors, lighted animated deer crossing signs, and fencing.[46,79,96] (See references 99 and 106) Most of these strategies met with mixed success, and only fencing appears to have universal applicability, but this is true only when fencing is constructed with appropriate specifications relative to the species in question [23] Fences at least 7.9 feet high were effective for deer, and fences 8.2 feet high were effective for elk.[99] Pronghorn (*Antilocapra americana*) seldom jump 3.8 feet fences.[45] Vehicle collisions with deer declined 80% after right-of-way fencing was installed, and remaining collisions were associated with ends of the fence.[106] Black bears also moved parallel to fencing until reaching its end and entering a right-of-way.[107]

Although fencing can be effective in preventing trans-roadway movements by wildlife, reducing wildlife-vehicle collisions is but one concern relative to wildlife and the public. Creating a road or highway that is safe, yet permeable to wildlife, benefits the public and wildlife. Highway permeability is key to maintaining life cycles and populations of wildlife in an environment dominated by man-made obstacles. Animal-proof fencing can also funnel trans-highway movements of wildlife through safe passageways.(92,106)

Recently, underpasses and, to a lesser extent, overpasses have been installed along roadways to enhance permeability to wildlife. Underpasses developed from the notion that some animals use culverts to cross under roadways, rather than at grade. Culverts, originally designed to manage water flow, are typically long and narrow with limited visibility, which many species find unattractive. Previous studies indicated that mule deer were wary of using underpasses narrower than 23 feet and lower than about 8 feet.(100) Mule deer were reluctant to use an underpass even after 10 years (Reed 1981), and studies suggested a learning curve with respect to use of underpasses.(21,79,98)

Construction of highway crossing structures is costly, particularly for large mammals, and underpasses may be affordable only on major roads.(21,97) Underpasses have been used as mitigation for highway crossings for amphibians and desert tortoises (*Gopherus agassizii*).(13,72) They have been constructed for ungulates such as mountain goats, elk, deer, and pronghorn.(21,22,45) (See reference 113) They also have been built for grizzly bears and Florida panthers (*Puma concolor*).(57,60,79) (See reference 112) The research team found only two published references of culvert use by bighorn sheep.(29,128)

Overpasses are a highway mitigation option that has been used successfully in Europe and Canada, but overpasses are largely overlooked in the United States. European and Canadian transportation agencies address natural resource mitigation issues by emphasizing larger landscape planning that provides wildlife habitat and related measures to compliment transportation system planning.(91) Overpasses tend to be more state-of-the-art and more expensive than underpasses. However, overpasses may prove to be useful for bighorn sheep, because bighorns appear often to traverse ridgelines during trans-highway movements. Wider overpasses tend to be more effective than narrower ones, and overpasses for large mammals in Canada are about 165 feet wide.(47)

Few rigorous evaluations have been carried out regarding design, placement, and effectiveness of highway crossing structures.(23,36,97) Their placement necessary to benefit wildlife is poorly understood.(23) Some studies have claimed success with underpasses for certain species.(57,100,120) Results of other studies were equivocal or demonstrated no use.(45,70,100) Confounding the problem of which species will use what kind of crossing structure is that a certain variation of a single type of structure may be more enticing than another. For example, elk in Arizona readily use an underpass with sloping sides more than one adjacent to it with vertical sides, but white-tailed deer (*O. virginianus*) shun both types of underpasses and prefer to go around a right-of-way fence and cross at grade (N. Dodd and J. Gagnon, AGFD, pers. comm.). Locations of underpasses also seem to be critical. Location is more important than design of underpasses for the Florida panther and wildlife in Canada.(21,79) Regardless of dimensions and shape, an underpass or overpass generally is of little value as a wildlife corridor if it does not connect suitable habitat.[92] Dimensions of crossing structures significantly influenced passage by ungulates, including underpass openness, width, and distance from movement corridors.[68,92,98] The research team suggests these variables are critical in constructing highway crossing structures for bighorn sheep.

With regard to types of crossing structures that might be used in construction on Highway 93, our study indicates that underpasses are promising as mitigation features for bighorn sheep if they conform to ridgelines and known crossing areas, avoid washes, and provide good visibility from both sides for approaching bighorns. It is apparent that bighorn sheep rarely use culverts, will use large underpasses with directive ROW fencing, and might also use overpasses with directive fencing. Bighorns already have become accustomed to using the newly constructed underpass at MP 1.5. Despite presence of an access road beneath the underpass, its construction bodes well for the future of bighorns relative to realignment of the Highway 93 right-of-way. Bighorns have used the underpass frequently, even during construction, and they have been filmed sleeping in shade of the underpass. In contrast, bighorns avoided underpasses constructed at a highway interchange on Highway 93 at MP 2.0, and at MP 4.2 and 8.0 (Figure 8). The research team suggests bighorns avoided the traffic interchange constructed at MP 2.0 because eight lanes of road, a parking area, and high human activity might have intimidated them. The interchange as constructed is markedly different from that proposed in the Record of Decision, in that it originally was proposed to be only a bighorn sheep underpass structure.[48] Perhaps after traffic has been re-routed onto the bypass, the interchange underpass may be more appealing to bighorn sheep, but the research team expects it will take some time for bighorns in the area to become familiar with the structure.[21,79] The research team suggests bighorns avoided underpasses at MP 4.2 and 8.0 because they are constructed in wide washes, and added slope fill contiguous with bridge abutments consists of large rocks covered with retaining fencing. Our observations indicate these fill areas and retaining fencing (riprap) hamper travel by bighorns. Although covering fill areas and retaining fencing with soil might improve use of these underpasses by bighorns, the research team believes placement of underpasses in washes still is problematic because bighorns seldom travel in washes.

Although overpasses are unproven for bighorn sheep, bighorns from a behavioral standpoint are feasible candidates for using overpasses, because they tended in our study to focus on ridgelines in their movements to approach and cross Highway 93. The research team suggests that construction of overpasses, rather than underpasses, merit consideration in some of these areas, and they likely would be appropriate to benefit highway crossings by bighorns if they are sufficiently wide (e.g., $\geq$164 feet). Moreover, they would provide good, broad visibility to bighorns. Strategically located underpasses and overpasses with acceptable dimensions and characteristics provided relatively safe passage for deer.[92,101] After construction of two underpasses in Glacier National Park, mountain goats used them in 99.6% (1204/1209) of highway crossings.[113] Bighorn sheep in many ways are similar to and behave like mountain goats, and likely prefer highway crossings with high visibility and natural substrate underneath to provide a more familiar setting.[107,113]

Use of GPS and GIS technology allows detailed analysis of effects of highways on wildlife at an accuracy level not previously possible.[112] Since the removal of Selective Availability by the Department of Defense in May 2000, GPS receivers used in wildlife research have been found to be accurate to <130 feet and have the potential for accuracy of ≤33 feet.[32,35,71] (See references 81 and 124) This level of accuracy is necessary in order to correctly determine points along a highway where bighorn sheep cross. Pinpointing bighorn crossing areas is a key prerequisite if engineers are to develop functional highway crossing mitigation features.

Even with such advances in technology, there are limitations. The GPS collars deployed in this study were programmed to provide a fix every 5 hours, thus optimizing the frequency of fixes and providing duration of battery life for a 2-year study. Desert bighorn sheep have the capability to move large distances in the span of 5 hours, and the research team has witnessed them cross and re-cross Highway 93 without these events registering with GPS collars. Some animals that appeared only to have approached the highway may have crossed and re-crossed, but GPS receivers registered only approaches. In 25 instances involving two ewes (ID #s 3252 and 3253; Table 1, Figure 6), collar data registered crossings in the vicinity of MP 1. The research team believes these animals remained on the same side of the alignment but moved along it, and that curves in the highway at this location resulted in apparent crossings when consecutive fixes were connected on a map. These ewes belonged to a group on the east side of the highway in the vicinity of Hoover Dam, a group that the research team never observed to cross the highway, although the research team frequently observed them along the highway. Previous research referred to this group as "eastside" ewes, and researchers observed only two animals from this group crossing the highway, once each.[28] The high crossing frequency ($N = 91$) the research team documented for MP 0 to 1 was an artifact of curves in that highway segment and frequency of successful collar location fixes. The research team directly observed no bighorns during our study that crossed the highway between MP 0 and 1, a finding identical to previous research.[28] Error also likely occurred when a successful fix was obtained and followed by an unsuccessful attempt at a fix, resulting in the line connecting consecutive fixes ignoring movements that actually occurred between successful fixes.

Most bighorn-vehicle collisions occurred within the first 5 miles from Hoover Dam in earlier studies.[28] Prior to our study, a lamb was killed in June 2003, and a young ram was killed during the winter/spring of 2006 during our study; both deaths occurred within the first 2 miles from the dam. In comparison, about 25 bighorns died from collisions with vehicles during earlier research.[27,28] Reasons for diminished mortality of sheep due to sheep-vehicle collisions in our study remain speculative, but likely relate to at least three factors: (1) The reduction in population level in the northern end of the Black Mountains likely reduced the opportunity for bighorn-vehicle interaction; (2) Because of security issues after terrorists attacks of 9/11/2001, commercial traffic across Hoover Dam was re-routed. Only large trucks carrying supplies and fill for the Hoover Dam Bypass Project were allowed on the highway. Although the research team did not measure traffic flow, this likely significantly reduced the number of large vehicles that might be unable to avoid a bighorn sheep in the roadway; (3) Reduced speed limits in the vicinity of the bypass construction probably influenced drivers' reaction times and ability to avoid collisions with bighorn sheep.

A. MP 0–3

Our study started after initiation of construction, and therefore lacks data from a pre-construction phase. Thus, the research team cannot quantify associations between immediate pre- and post-construction periods and general use of the Sugarloaf Mountain area by bighorns. Nonetheless, numbers of highway crossings by bighorns were similar between our study ($N = 345$, MP 0 to 17) and research in 1989 to 1991 ($N > 550$) that focused on MP 0 to 4.[28,29] Fewer crossings in our study corresponded to fewer bighorns collared and the decline in bighorn numbers. Given these considerations, the research team suggests that permeability of Highway 93 to crossing by bighorns was clearly apparent and probably was comparable during pre- and post-construction periods. Sugarloaf Mountain just west of the bypass area was believed to be an important lambing and watering area (sewage ponds) during 1989-1991, prior to proposed construction activities.[28,29] Although no collared ewes in our study lambed on Sugarloaf Mountain, the research team cannot relate the lack of lambing there to bypass construction. Sewage ponds on Sugarloaf Mountain adjacent to the bypass alignment were maintained at a full level through October 2004, when bypass construction activities terminated. Since then, one pond dried completely, and the other fluctuated from nearly dry to a water level of about two feet. The research team found little indication that bighorns used the ponds during our study, and observed only two bighorn sheep at the sewage ponds that were frightened off before drinking. Modification of bighorn behavior in relation to disturbance at water sources is well documented and may have been affected by construction activities.[19,83]

An interim report by HDR Engineering, Inc. provided to Federal Highway Administration (FHWA) stated that a temporary supplemental water source was installed near the sewage ponds away from construction from August to mid-November 2003 because few sheep were seen watering at the sewage ponds.[38] Although precipitation in 2005 was above average, natural tinajas (ephemeral pools of water in rocks) and springs in the vicinity of the highway bypass have dried up, and bighorns may use the sewage pond near the construction area less frequently and be forced to seek water sources elsewhere, unless supplemental water is provided. If bighorns are forced to concentrate on other water sources, recruitment might decline, and adult mortality and spread of infectious diseases might increase.[19,28,74] The present reduction in population size is likely attributable, at least in part, to prolonged drought in the Southwest.[88,90] Moreover, predation by mountain lions (Figure 9) and bypass construction activities might have contributed to relatively low use of the Sugarloaf Mountain area, compared to earlier studies.[27,28,29] The research team suggests that an offsite water source be developed and maintained in the Sugarloaf Mountain area at least until highway construction activities are terminated.

Dust from vehicles likely caused a major bighorn sheep die-off due to bronchopneumonia in Colorado, and construction-related dust in the Hoover Dam bypass construction area might pose a problem.[3,115] However, the research team observed no sick or dead bighorns in the vicinity of the Hoover Dam bypass construction area, possibly reflecting effective dust abatement during and after construction.

The research team documented 50 crossings by bighorns underneath the Sugarloaf Mountain underpass at MP 1.5, indicating that the bypass construction area was permeable to bighorn sheep. Permeability of the highway between MP 0 and 2.5 in the construction area to crossings by bighorns appears adequate, because rams and ewes both crossed the highway in this area throughout our study. The ROW fence was intentionally manipulated to allow animal movement across the highway until traffic was re-routed onto the Hoover Dam bypass (342 crossings of the fence), but there was substantial movement through the Sugarloaf Mountain underpass. The research team observed bighorns underneath the bypass structure during construction and observed bighorn sheep beds below the underpass at the southeast abutment. The research team speculates there may be an increase in movement across the current alignment by bighorns in the Sugarloaf Mountain area, once traffic is precluded or reduced after completion of bypass and bridge construction. East-side ewes, which seldom crossed the highway in the present and earlier studies, might also increase highway crossings in the Sugarloaf Mountain area once vehicle traffic is reduced or prevented.[29]

Use of the bypass underpass and crossing rates of the ROW fence by bighorns was higher during the first 6 months of our study (April to October 2004) than during the subsequent 18 months. Construction of the bypass approach was nearly complete except for alignment paving by October 2004. Although six collared bighorns used the underpass before and during and six used it after construction, crossing activity diminished after most construction activity ended. Reduced crossing of the ROW fence might partially be explained by more complete closure of the ROW fence as October 2004 approached, resulting in fewer places to breach the fence. Seasonal movement patterns may have affected crossing rates by bighorns, but the research team has no certain explanation for diminished use of the underpass after construction.

The ROW ungulate-proof fence has not been tested fully in the area of bypass construction, but it appears to funnel sheep appropriately; numerous “holes” in the fence (some necessary for construction and sheep movement purposes) prevented final determination of its effectiveness. Height of the fence seems to be adequate on level ground, but in rough country (e.g., Sugarloaf Mountain), rocks may allow animals to leap over the fence, and higher fencing is needed. Hard substrate in some areas prevents basal closure of the fence, and gaps need to be sealed with rocks to prevent sheep from crawling under the fence. The ROW fence should be monitored regularly following completion of construction, because erosion from thunderstorms can regularly destroy fence segments, such as the research team observed at MP 2.1. Photographic records (unpublished data) suggested all presently constructed out-jumps are too low to preclude bighorns jumping into the ROW; they require higher fencing and at least an additional 2 feet of fill to control bighorn movements effectively.

B. MP 3–17

Highway mitigation measures have been designed to increase permeability and habitat connectivity for wildlife living around crossing transportation corridors.[21] The Arizona Department of Transportation (ADOT) and Arizona Game and Fish Department (AGFD) are in a unique position to use empirical data to develop, evaluate, and fuse mitigation features into highway design to maintain and enhance desert bighorn sheep permeability and habitat connectivity prior to expansion of a major travel corridor to reduce traffic congestion.

A perceived barrier (e.g., roadways) can manifest itself in similar ways to actual barriers, such as fencing.[73] The barrier effect of Highway 93 was apparent on bighorns that crossed and those that did not cross the highway (Figures 6, 7). The research team documented lower activities (telemetry fixes) of bighorns within 100 meters of Highway 93 than farther away, suggesting the highway influenced distribution of bighorns and comprised a barrier to movements. However, the roadway did not preclude trans-highway movements, in that 41% of radiocollared bighorns crossed the highway right-of-way. Ewes and rams both crossed the highway between MP 3 and 17, as well as between MP 0 and 3. Broad movements by rams are critical to maintaining genetic heterozygosity of a population, indicating importance of maintaining highway permeability between Highway 93 MP 3 and 17.[94,128] Collared ewes south of Willow Beach seemed to be largely unaffected by the highway, because they never approached the highway right-of-way, possibly due to the distance and gentle terrain that separated this group from the roadway.

General areas of comparatively high highway crossing activity have been called "conflict zones," because animals on the roadway in such areas risk being hit by vehicles, creating a safety hazard for animals and humans.[4] Crossing zones are "hotspots" of trans-highway movements within highway segments that have the highest rates of crossing, relative to conflict zones.[4] Our study demonstrated that highway crossing and conflict zones did not occur randomly on Highway 93. Data from ground observations and track beds were consistent with telemetry results in specifying locations of highway crossings by bighorns, and identifying locations of crossings within conflict zones. Bighorn sheep tended to approach and cross the roadway at predictable locations between about MP 3 and 17, specifically between MP 2.8 and 3.5, MP 4.8 and 5.5, MP 7.5 and 8.0, MP 11 and 11.8, and MP 14 and 15.4, and the research team designated these areas as conflict zones. Sections of highway between these locations were largely devoid of crossing activities, except that locations between MP 5.5 and 6.5 maintained moderate levels of crossing by rams (Figures 3–6).

Throughout the study, the research team often observed bighorns on and near elevated ridgeline areas with moderate (50–70%) slopes that extended across the highway. The research team believes many bighorns used these continuous ridgelines to approach the ROW; such topographic features have been designated as "linear guide-ways."[4] Centers of activity of grouped and individual bighorns confirmed that activities of animals tended to concentrate near these ridgelines when approaching the highway. Many ridgelines approached or crossed the highway alignment, but only a few provided CLEGs that extended across the right-of-way and connected habitats on both sides of the highway. On a smaller scale, bighorns most often negotiated a highway crossing where there were breaks in the guardrail and where part of a CLEG bisected the highway alignment. Based on highway crossing and center-of-activity data for individual and grouped collared bighorns, as well as ground observations and track bed surveys, the research team concludes highway crossings by bighorns were closely linked to the use of CLEGs. References are common in the literature regarding bighorns favoring elevated, precipitous terrain.[51,59,82] Increased visibility and proximity to escape terrain are related to higher bighorn foraging efficiency.[103]

The research team identified five CLEGs (Appendixes 3 to 7) between MP 3 and 17 that corresponded with increased ROW crossing activities by bighorns. The highest number of crossings and number of animals crossing the highway occurred near the ridgeline at MP 3.3. Four ewes and four rams crossed 60 times at this location. This finding is likely conservative because the research team also observed numerous unmarked bighorns in this area. Ground observations (Figure 10), track beds, and COA data for grouped bighorns indicated highest use by bighorns in a saddle, 144 feet south of the CLEG, where bighorns often appeared to stage before crossings to the east side of the highway. Observations also indicated that bighorns crossing the highway from east to west often did so down a steep cut in the road directly in line with the CLEG. The area between the Hoover Dam and the CLEG at MP 3.3 (Appendix 3) represented the highest numbers of bighorns crossing along the entire MP 0 to 17 corridor. This area also represented one of two locations between MP 3 and 17 where collared ewes frequently crossed. The ridgeline at MP 3.3 provided circuitous connections among lambing grounds and escape terrain near the Colorado River, the ridge that borders White Rock Canyon to the south, hills east of the highway, and northward to Lake Mead. Ewes from the west side of the highway and rams crossed eastward and westward at the MP 3.3 CLEG, but ewes from the east side of the highway did not cross westward. Thus, the circuitous connection of the CLEG at MP 3.3 allowed continual movement patterns among areas that connected bighorns on east and west sides of the highway.

The second CLEG was located at MP 5.1 (Appendix 4), and it connected escape terrain near the Colorado River to the ridge that borders White Rock Canyon to the north, which in turn connected to Wilson Ridge to the east. Among collared bighorns, four rams and two ewes crossed the highway at this location 22 times. Track beds and COA data of grouped bighorns showed higher activity at 1,130 feet south of the CLEG, possibly because more rams than ewes crossed in the area. The distance of the COA from the ridgeline likely reflects a preference of rams for more gentle terrain that existed near escape terrain provided by the CLEG.[9,29] In contrast to rams, ewes tend to occupy and use areas in or close to escape terrain and tended to cross the highway on steeper slopes provided on the CLEG (Figures 6, 11, 12).[12] Most bighorns that crossed in the vicinity of MP 5.1 generally occupied areas west of the highway, but rams in particular used the ridge and associated hills east of the highway.

The third CLEG, known locally as Black Mesa, is located at MP 7.7 (Appendix 5). Two collared rams crossed the highway six times in this area, and two other collared rams approached the highway in this area. The research team also observed 10 unmarked rams and found >16 track sets on tracking beds at this ridgeline area, suggesting the CLEG might be a more important highway crossing area than indicated by telemetry data. Track sets and ground observations indicated the highest use at 210 feet south of the ridgeline of this CLEG. Although the research team documented no COAs for bighorns at this CLEG, it was the only location at which ewes south of MP 5.1 approached the highway from the west. Five collared ewes approached to within 0.6 mile of the highway in this area, but did not cross the ROW. Multiple sheep beds on ledges above the alignment (Appendix 8) also are consistent with comparatively high activities in this area. The research team observed that bighorn rams in particular avoided an underpass in a wash just south of the CLEG at MP 8.0, and attempted to cross the highway at the CLEG. Each time the research team observed bighorns in the area, they were on the CLEG and attempting to cross at the southern edge of the mesa (Appendix 9). Each apparent crossing attempt failed as curious motorists taking photographs frightened the animals. The research team also detected bighorn tracks on one occasion at the present underpass at MP 8.0 (bridge over Crane's Nest Wash). The research team documented no highway crossings by females at the MP 7.7 CLEG, but this does not diminish the potential importance of this ridgeline as a crossing area for ewes. Recent drought conditions likely contributed to population decline, and the population in the Black Mountains probably will increase in abundance and distribution when rainfall returns to more normal levels.[88,90] The research team suggests that if a highway crossing mitigation feature is not developed at this CLEG, a substantial portion of bighorn range east of the proposed highway alignment between MP 3 and 17 might be lost or diminished.

The fourth CLEG is located at MP 12.2 (Appendixes 6, 10) and is characterized by a ridge extending westward between Wilson Ridge and Willow Beach. The present highway alignment cuts into and bisects the ridgeline. Although the GPS collars registered seven crossings in the area by only one ram (¼ to ¾ mile north of the CLEG), the research team identified a COA for grouped bighorns ($N = 2$ rams and $N = 2$ ewes) 290 feet south of the CLEG. The CLEG represents the most direct route from Wilson Ridge to the rest of the Black Mountains south of Willow Beach.

The fifth CLEG, located at MP 15.3 (Appendix 7), was 580 feet north of the COA of one ewe that crossed the highway four times. This ewe registered 66 fixes within ¾ mile from the CLEG and within 820 feet of the highway. The research team believes a 4 foot high fence erected previously to exclude burros, prevented the ewe from crossing the highway. Despite data for only one ewe, the research team suggests that the ridgeline at MP 15.3 merits consideration for construction of a feature to mitigate highway crossings by bighorns. Several studies indicate that ewes do not select habitat independently of one another, supporting the notion that the ridgeline area likely is used by multiple bighorns.[30,50] The COAs and highway crossings by bighorns and subjective evaluation of ground observations of bighorns (Figure 10) on the MP 15.3 and other CLEGs tended to be high, relative to adjacent locations away from the elevated ridges.

VII. CONCLUSIONS AND RECOMMENDATIONS

A. MP 0–3

1) The recently constructed Sugarloaf Mountain underpass at MP 1.5 provides adequate permeability to bighorns relative to the future highway upgrade alignment. However, bighorns appear to be avoiding current water sources in the Sugarloaf Mountain sewage ponds. The research team recommends development of a permanent or temporary water source or sources further removed from construction activities, at least until construction is completed.
2) Present dimensions of out-jumps are inadequate to prevent entry of bighorns into the highway right-of-way. The research team recommends addition of at least 2 feet of fencing and fill on current and future out-jumps. These changes should be adequate to prevent entering, but still allow exiting, the right-of–way.
3) Regularly monitor the ungulate-proof right-of-way fence in order to repair as needed, particularly following rainstorms. Additional height or realignment of right-of-way fencing is needed in some areas to prevent the possibility of bighorns jumping over it from adjacent rocks, particularly in the Sugarloaf Mountain area. Basal closure of the fence should be improved to prevent breaching by bighorns into the right-of-way.
4) The interchange underpass at MP 2.0 may prove to be problematic in enhancing trans-highway movements by bighorns, and should be monitored to evaluate its effectiveness. Future modifications of the interchange to improve bighorn permeability may not be possible, but monitoring should enhance our understanding of necessary attributes of underpass construction design.

B. MP 3–17

1) The research team identified five areas that bighorns crossed in this section of Highway 93, specifically in areas associated with MP 3 to 3.5, MP 5 to 5.5, MP 7.5 to 8, MP 11.3 to 11.8, and MP 14.3 to 15.5. The research team recommends construction of crossing mitigation features in the first four of these areas, and consideration of a crossing feature in the fifth area.
2) Highway crossing zones used by bighorns were closely linked to ridgelines that provide CLEGs in each of the above locations. These CLEGs provide critical linkages to bighorn habitat and populations on both sides of the highway, and the research team recommends placement of overpasses and underpasses on or adjacent to CLEGs.
3) Design and placement of mitigation features will influence highway permeability to bighorns, and the research team suggests more natural structures connecting areas of suitable bighorn habitat will increase effectiveness. 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. Visibility through underpasses or across overpasses is critical for animals approaching structures. Our observations and photographic evidence indicate bighorns prefer to cross

through an underpass on the sides below the abutments rather than in the middle where there often may be a drainage. Sloped sides that are too loose, too steep, or use fence riprap to stabilize the sides may impede use of underpasses. A shelf below and extending the length of underpass abutments may provide easier access and a feeling of security to bighorns (Appendix 11). Natural substrate with short, low-density vegetation throughout the crossing structure may enhance permeability. The research team suggests that bighorns require open span underpasses at least 43 feet wide and 13 feet high extending beneath a divided highway (T. Clevenger, Western Transportation Institute, pers. comm.). Right-of-way fencing should join abutments of mitigation features to funnel bighorns and facilitate trans-highway movements.

4) Overpasses need to connect elevated habitats on both sides of the highway. Although the proper width for overpasses has not been defined for desert bighorn sheep, overpasses in Banff National Park in Canada measuring 160 feet wide have been used successfully by ungulates and large carnivores, and likely would be adequate for bighorns. The overpasses incorporated pre-cast arches, were self-irrigating, had roughly 6 feet of topsoil covering the structures to promote growth of native vegetation, and earthen berms along the outer edges to minimize noise and visual disturbance from the roadway. The research team suggests that overpasses designed with these characteristics would have a high probability of being used regularly by bighorns.

5) The research team recommends construction of an overpass adjacent to a saddle on the south side of the CLEG at MP 3.3. Most collared bighorn ewes that crossed the highway did so at this CLEG, but rams also crossed here.

6) The research team recommends construction of an underpass at the southern end of the CLEG at MP 5.1 to incorporate the slope of the CLEG where it meets a drainage. The highway alignment in this location might need to be elevated to increase openness of the underpass. Bighorn ewes and rams crossed the highway on or near this CLEG, and both likely would use this underpass. Construction of an underpass away from this CLEG would likely limit or prevent highway crossings by ewes.

7) The research team recommends construction of an overpass on the southern edge of the CLEG at MP 7.7. Although this CLEG had no COAs for collared bighorns, rams used the area extensively, suggesting potential importance of the location for highway crossings. Moreover, this was the only area where ewes approached the highway south of the MP 5.1 CLEG. Bighorns avoided the existing underpass in Crane's Nest Wash at MP 8, indicating ineffectiveness of the present structure, and the research team believes directive fencing would be inadequate to ensure bighorn use because of its location in the wash.

8) The research team recommends construction of a highway underpass on the southern edge of the CLEG at MP 12.2 (Appendix 10). An underpass located near MP 11.65 would likely function well if slopes of adjoining hills are included within the underpass, existing fill is removed, and adequate fencing is provided to direct movements.

9) The research team knows of only two collared ewes that frequented the area near the CLEG at MP 15.3, and only one ewe crossed the highway here. The research team recommends consideration of construction of an overpass or underpass on or near this CLEG, because the ridge connects Wilson Ridge on the east to about 23 square miles of habitat associated with Fire Mountain to the south of the highway.

10) The research team recommends that construction of highway mitigation features be given priority near the three CLEGs at MP 3.3, 5.1, and 12.2. Eighty-two percent (93/113) of highway crossings by bighorns between MP 3 and 17 occurred at these locations. Regardless of this assessment, the research team believes crossing structures at the other CLEG locations would be valuable in ensuring sufficient highway permeability to maintain genetic heterogeneity of the Black Mountains desert bighorn sheep population and maintain population vigor.

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APPENDIXES:

SELECTED FEATURES FROM THE PROJECT STUDY AREA

Appendix 1. Sugarloaf Mountain underpass, Highway 93, Arizona

Appendix 2. Out-jump located at MP 2.0, Highway 93, Arizona

Appendix 3. Continuous, linear, elevated guide-way (CLEG) located at MP 3.3, Highway 93, Arizona

Appendix 4. Continuous, linear, elevated guide-way (CLEG) located at MP 5.1, Highway 93, Arizona

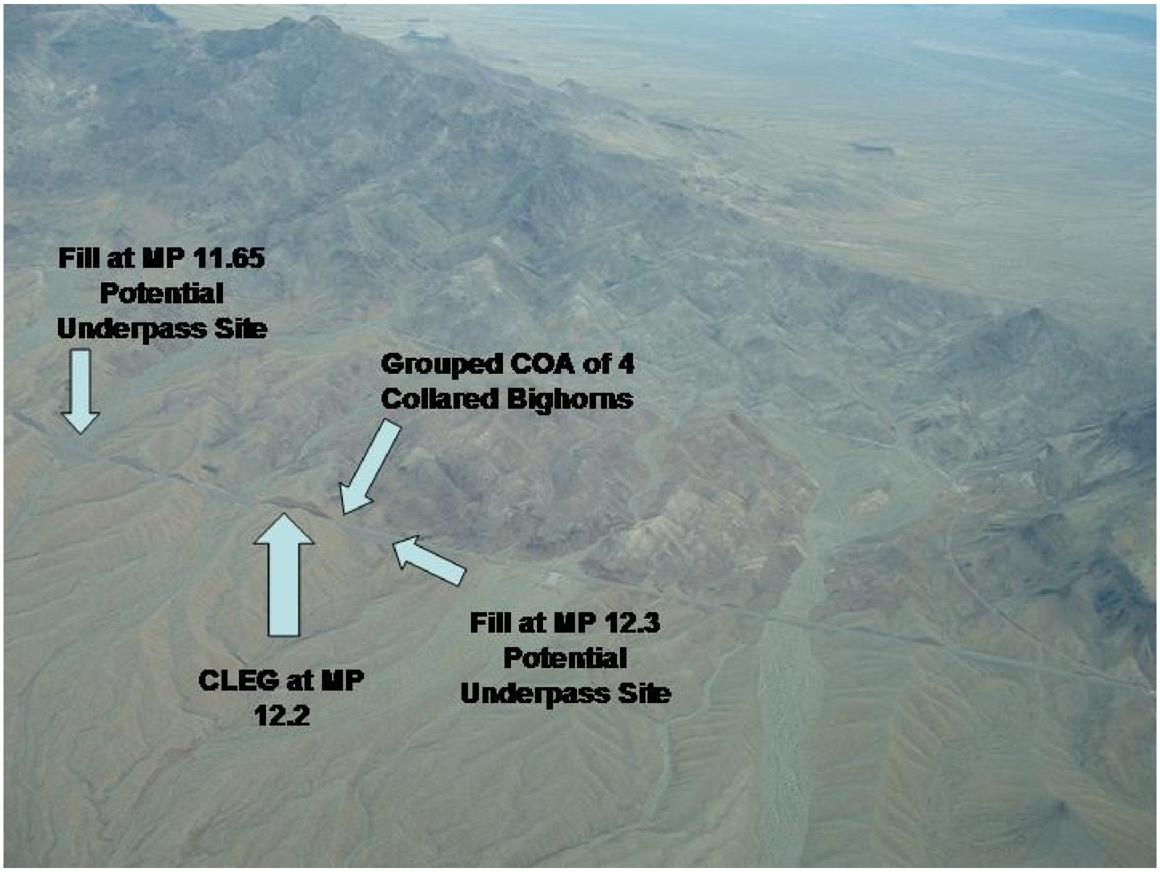
Appendix 5. Continuous, linear, elevated guide-way (CLEG) located at MP 7.7, Highway 93, Arizona

Appendix 6. Continuous, linear, elevated guide-way (CLEG) located at MP 12.2, Highway 93, Arizona

Appendix 7. Continuous, linear, elevated guide-way (CLEG) located at MP 15.3, Highway 93, Arizona

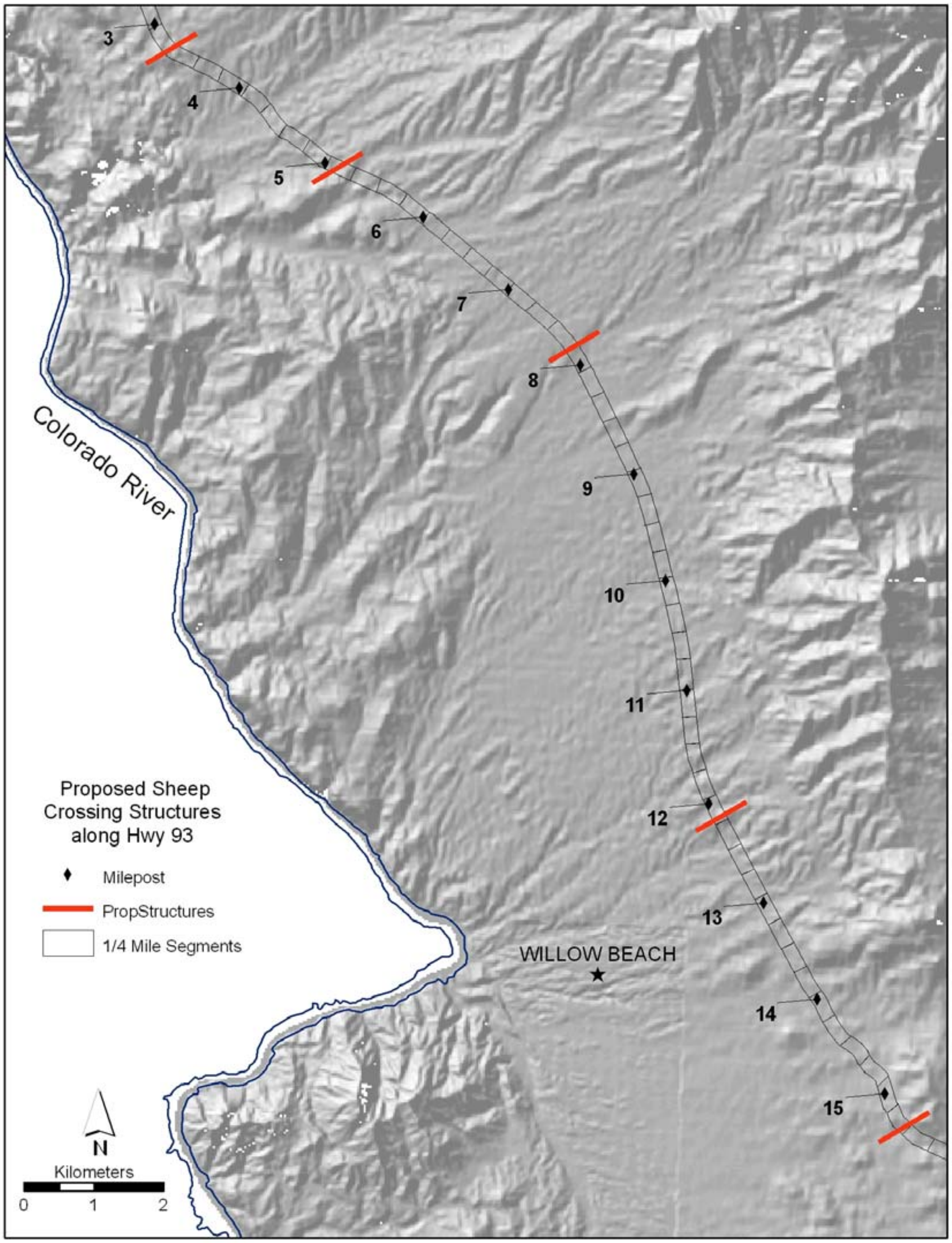
Appendix 8. Bighorn sheep beds located on continuous, linear, elevated guide-way (CLEG) at MP 7.7, Highway 93, Arizona

Appendix 9. Bighorn sheep on continuous, linear, elevated guide-way (CLEG) at MP 7.8, Highway 93, Arizona



Appendix 10. Aerial view of continuous, linear, elevated guide-way (CLEG) at MP 12.2, Highway 93, Arizona

Appendix 11. Shelf below abutment at an underpass, Highway 93, Nevada



Appendix 12. Locations of Proposed Crossing Structures along US 93 Highway