Possible Effects of the Realignment of U.S. Highway 93 on Movements of Desert Bighorns in the Black Canyon Area

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Abstract. We collared 49 desert bighorns (*Ovis canadensis nelsoni*) adjacent to Hoover Dam in the Black Mountains of Arizona. We monitored their movements for up to 2 years to determine areas of importance, potential movement corridors, and reactions to U.S. Highway 93. Three separate ewe groups used distinct lambing and watering areas. One of the ewe groups will be most affected by realignment of U.S. Highway 93 because the ewes routinely cross Highway 93 and because their home ranges will be bisected by any one of the three considered highway alignments. Only the Promontory Point alignment would bisect home ranges of ewes in the other groups. We believe that the Gold Strike alignment would cause the most harm to local bighorns. Vehicle speed will probably increase on the finished highway on any of the alignments chosen, and the increased speed will increase bighorn deaths.

Key words: Arizona, bighorn sheep, Black Mountains, habitat fragmentation, highway, *Ovis canadensis*, vehicle collision.

Since the mid-nineteenth century, desert bighorns in Arizona declined from a statewide estimate of 35,000 (Buechner 1960) to a low of 2,500 in the 1950's (Russo 1956). Although bighorn numbers have increased under intensive management, many remaining populations in Arizona are physically separated by highways, fences (Leslie and Douglas 1979), railroads, cultivated ranches, canals, and housing developments (Gionfriddo and Krausman 1986). Habitat fragmentation is considered the most serious threat to biological diversity for all species and is the primary cause of the present extinction crisis (East 1983). Large mammals are especially vulnerable to habitat fragmentation because of their large body size, their large trophic needs, and their relatively large home ranges to meet these needs (Wilcox and Murphy 1985).

The habitat of the Black Mountain bighorn population near Hoover Dam is bisected by Highway 93, which crosses Hoover Dam at the south end of Lake Mead. This is the only crossing of the Colorado River between Lees Ferry and Davis Dam, a distance of approximately 550 km. Highway 93 carries major traffic from the east to Lake Mead or to Las Vegas, and traffic across the dam is reaching serious proportions. The crossing was designed to safely handle approximately 323 vehicles/h, but projections for peak-hour traffic across Hoover Dam in the year 2005 is 1,269 vehicles/h. Incomplete records indicate that more than 550 accidents have occurred on or near the dam since 1964. The Bureau of Reclamation (BR) seeks to remove traffic from the dam by rerouting traffic to a new steel-arch bridge that will require new highway approaches in both Arizona and Nevada.

The Arizona Game and Fish Department has expressed concern that the realignment might affect the estimated 100–150 bighorns that use the area. The concern involved obstruction of travel corridors that might result in segregation and potential increases in deaths from vehicle–bighorn collisions.

Bighorn movements are believed to occur within traditional corridors that are usually associated with adequate escape terrain. Travel corridors are considered critical habitat by managers (Desert Bighorn Council 1980). Travel corridors that are obstructed or not used for a period of time can be lost to the entire population (Giest 1971). The result may be that a subpopulation of bighorn sheep becomes isolated physically and genetically. The new highway could segregate the 100–150 bighorns on Mount Wilson from the larger contiguous population in the Black Mountains. Three processes that could affect the persistence time of a newly fragmented population are genetic stochasticity, population or demographic uncertainty, and environmental variation and catastrophes (Shaffer 1981).

The minimum number of individuals needed to maintain adequate genetic heterozygosity is difficult to determine; the most conservative estimate is that population size (N_e) must be more than 50, and it is generally advocated that N_e should be more than 500 (Franklin 1980). Although it seems the fragmented Mount Wilson population might be large enough to withstand variation in population size due to demographic or genetic stochasticity, the threshold size for large animals remains largely unknown (Brussard and Gilpin 1989). In contrast to demographic or genetic stochasticity, environmental stochasticity including populationwide changes related to variance in climate, disease, competition, predation, or resource availability (Brussard 1986) is independent of population size and can pose severe problems for population persistence. Berger (1990) examined the persistence of 122 varying sized bighorn populations in the Southwest over a 70-year period. He found that the populations with 50 or fewer animals went extinct within 50 years and that populations of 100 or more persisted for more than 70 years. Berger believed it unlikely that losses of populations were due to food shortages, severe weather, predation, or interspecific competition. He implicated diseases introduced from domestic stock. Disease or variations in environment seem more likely to threaten an isolated population on Mount Wilson.

Populations of many species may decline in numbers to where viability and reproduction are diminished for nongenetic reasons. There may be a threshold number of individuals in a population—known as the Allee effect—that is essential for the survival of the population. Caused by animals chemically or physically altering their environment, by social interaction, or by density-dependent mating, the Allee effect may force a population to extinction. Social animals like bighorn sheep (Giest 1971; Berger 1978; Berger et al. 1983) frequently increase their survival and foraging efficiency by group defense against predators. As population numbers diminish, the group may be too small for effective defense. The social interactions necessary for reproduction may be lacking, or it might be difficult to find a mate (Allee 1949).

Deaths from collisions between vehicles and bighorns are a recurring problem on U.S. Highway 93 near Hoover Dam. Arizona Game and Fish Department regional personnel estimate the annual loss to vehicle collisions to be 10 animals. Records of animals killed on the road indicate that most (80%) deaths occur between mileposts 1 and 4, near the planned construction site. The problem of deer–vehicle accidents has been addressed frequently (Bellis and Graves 1971; Puglisi et al. 1974; Reilly and Green 1974; Pojar et al. 1975; Reed et al. 1979; Ward et al. 1980; Reed and Woodward 1981; Reed et al. 1982; Bashore et al. 1985; Schafer and Penland 1985). Collisions or attempts to avoid collisions result in human lives lost, human injuries sustained, vehicles damaged, and wildlife lost.

Our purpose was to develop information on bighorn sheep movements near the Hoover Dam bypass highway construction site to minimize adverse effects to both motorists and bighorns. Our objectives were to identify

1. where specific travel corridors for bighorns are located,
2. to what extent the corridors are used,
3. what segments of the population use the corridors, and
4. how the use of the corridors might be affected if bisected by a new 4-lane highway.

Three alternative locations for the bypass were evaluated.

Study Area

Our study was conducted near Hoover Dam in the northern part of the Black Mountains in northwestern Arizona (Fig. 1). Hoover Dam is on the Colorado River approximately 113 km northwest of Kingman, Arizona, and 32 km southeast of Las Vegas, Nevada. We concentrated our efforts between Hoover Dam and the Willow Beach Fish Hatchery. The primary study site included the area from Hoover Dam southeast along U.S. Highway 93 to

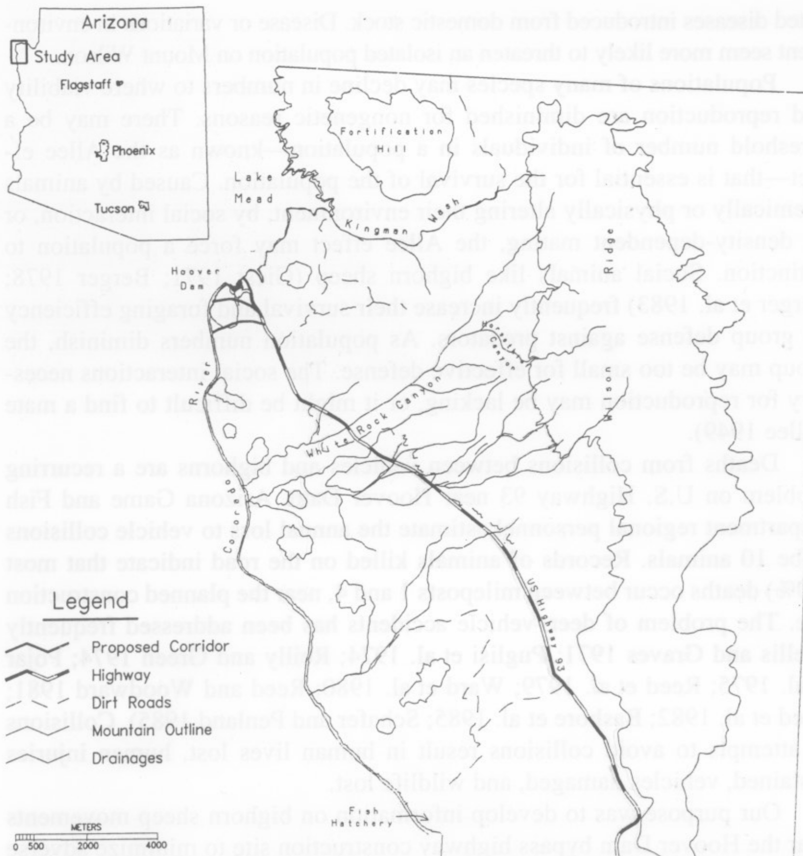

Fig. 1. Area of study in the Black Mountains.

White Rock Canyon, west to the Colorado River, and north along the river back to Hoover Dam. All three possible highway alignments were included, along with sufficient surrounding area to monitor all bighorns that might be affected by the construction.

The Gold Strike alignment (GSA), the preferred alternative for rerouting the highway at the onset of the study, veers off Highway 93 near milepost 1.8 and gradually curves into the first canyon approximately 1.6 km south of Hoover Dam (Fig. 2). It runs midway along the north side of this canyon for approximately 1.5 km to where the bridge would span the Colorado River. The Promontory Point alignment (PPA) would cross Lake Mead just north of Hoover Dam. The road would leave Highway 93 near milepost 1.8; four lanes and an access road to the dam would head almost straight north to the narrow part of Lake Mead just above the dam. The Sugarloaf alignment (SA) would

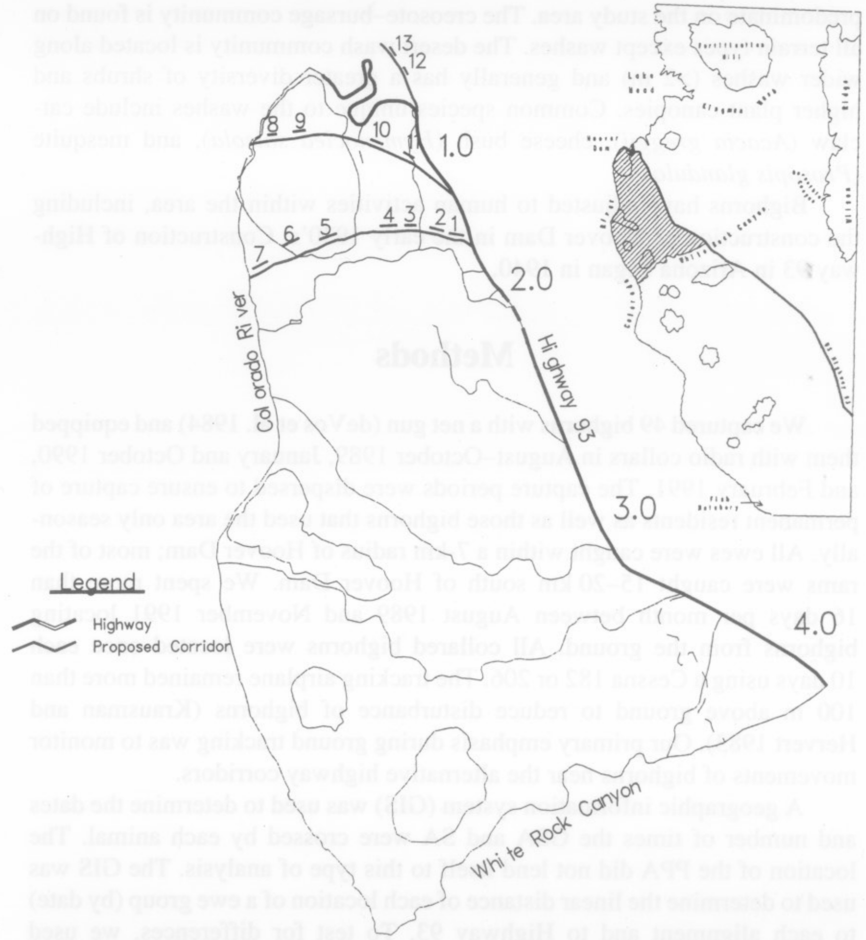

Fig. 2. Location of the three alignments, event recorders, and mile post designations. Top to bottom are the Promontory Point alignment (event recorders 12 and 13), the Sugarloaf alignment (event recorders 8–11), and the Gold Strike alignment (event recorders 1–7).

depart from Highway 93 near milepost 1.8 and bend west to just north of the sewage ponds and Sugarloaf Mountain before bridging the river at the narrows of Black Canyon just below Hoover Dam.

Elevations in the study area range from 194 m at the Colorado River to 1,511 m on top of Mount Wilson. Topography varies from mountainous terrain characterized by steep talus slopes and rugged cliffs broken by washes to rolling hills in alluvial drainages. Water for bighorns is abundant along the shoreline of Lake Mead; at the Colorado River; from several springs; and from the sewage ponds. The creosote–bursage (*Larrea tridentata* and *Ambrosia dumosa*) and the desert wash plant communities (Brown et al. 1979) predominate on the study area. The creosote–bursage community is found on all terrain types except washes. The desert wash community is located along wider washes (>2 m) and generally has a greater diversity of shrubs and higher plant canopies. Common species unique to the washes include catclaw (*Acacia greggii*), cheese bush (*Hymenoclea salsola*), and mesquite (*Prosopis glandulosa*).

Bighorns have adjusted to human activities within the area, including the construction of Hoover Dam in the early 1930's. Construction of Highway 93 in Arizona began in 1940.

Methods

We captured 49 bighorns with a net gun (deVos et al. 1984) and equipped them with radio collars in August–October 1989, January and October 1990, and February 1991. The capture periods were dispersed to ensure capture of permanent residents as well as those bighorns that used the area only seasonally. All ewes were caught within a 7-km radius of Hoover Dam; most of the rams were caught 15–20 km south of Hoover Dam. We spent more than 16 days per month between August 1989 and November 1991 locating bighorns from the ground. All collared bighorns were located once each 10 days using a Cessna 182 or 206. The tracking airplane remained more than 100 m above ground to reduce disturbance of bighorns (Krausman and Hervert 1983). Our primary emphasis during ground tracking was to monitor movements of bighorns near the alternative highway corridors.

A geographic information system (GIS) was used to determine the dates and number of times the GSA and SA were crossed by each animal. The location of the PPA did not lend itself to this type of analysis. The GIS was used to determine the linear distance of each location of a ewe group (by date) to each alignment and to Highway 93. To test for differences, we used Kruskal–Wallis one-way ANOVA. Any time a group of bighorns was seen within 0.5 km of any of the alignments, the group was watched for more than 1 h to record corridor crossings if they occurred. Crossings were marked on a 7.5-min quadrangle map. From May 1990 to February 1991, seven infrared beam recorders (Trailmaster) were monitored along the GSA. Date and time are recorded whenever the beam between sending and receiving units is interrupted. Beam recorders (5) were moved from GSA to SA (3) and PPA (2) in February 1991.

Results and Discussion

Areas of Importance

We were able to identify three separate ewe groups based on association level and home range areas. There was a high degree of association between ewes captured in the primary study area (primary ewes), but little association between these ewes and those captured east of Highway 93 (eastside ewes) or south of White Rock Canyon (southside ewes; Cunningham and Hanna 1990). Similarly, eastside ewes and southside ewes had a high degree of association with ewes captured nearby but not with ewes from the other areas. Because of this lack of association and because each group used separate watering and lambing areas, we considered each subgroup separately with respect to potential highway alignments and habitat use around Highway 93.

Ewes captured within the primary study area (primary ewes) had similar home range shapes and sizes and ranged from Hoover Dam to White Rock Canyon and east of Highway 93 between mileposts 2 and 4 for approximately 2 km. Primary ewes used the area east of the highway (also used by the eastside ewes), mostly in late summer and fall (August–December). During winter and spring, primary ewes shifted to steeper slopes along the river and rarely were found east of the highway. The home ranges of all primary ewes were bisected by both highway 93 and all proposed alignments (Fig. 3).

Ewes captured east of the highway (eastside ewes) were most frequently found on the slopes of Mount Wilson. During late summer and fall they used rolling hills near Lake Mead. As temperatures cooled, they gradually moved to the steep slopes of Mount Wilson and remained until the following summer when the springs on Mount Wilson dried. Eastside ewes then moved back to the hills near the lake. This seasonal movement pattern was observed both years. Only two instances on one occasion of eastside ewes crossing Highway 93 were recorded. Ewes captured south of White Rock Canyon (southside ewes) ranged from approximately 1 km north of White Rock Canyon south for approximately 6 km, primarily on the steep slopes near the river.

The majority (83%) of rams wintered west of the highway from approximately 3 km south of White Rock Canyon to Willow Beach. By 1 September 1990, most of the rams had moved north to be with the ewes when the rut started. Only one 2-year-old ram went south of Willow Beach even though there was a greater density of ewes in that direction. All other rams moved only north and east during the rut. All but 1 of the 18 collared rams crossed Highway 93 and were subsequently located near ewes on Mount Wilson. We captured three rams in or near the primary study area during October 1990. Two of these wintered on the east side of Mount Wilson. We believe that rams wintering north of Willow Beach and on Mount Wilson will move to areas near the proposed alignments and will cross Highway 93 to rut.

The main sources of water for the primary ewes were the sewage ponds just east of Sugarloaf Mountain ($n = 81$), an ephemeral pothole ($n = 49$) 4 km south of Hoover Dam and 2 km west of the river, and a hot spring just south of Sugarloaf and just below GSA ($n = 18$). We believe bighorns use the river occasionally for water, but much of the river is inaccessible even to bighorns (vertical cliffs >100 m). Seventy percent (99 of 149) of the locations of primary ewes at water sources was at the two sources within 0.5 km of GSA and SA. The sewage ponds are approximately 0.2 km from SA and 0.4 km

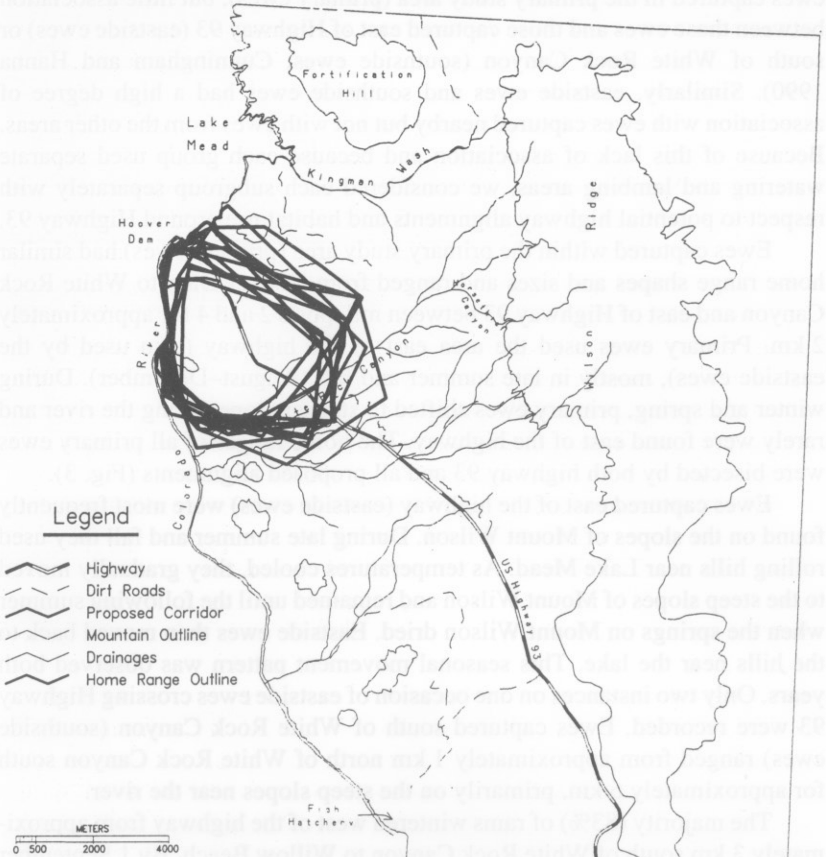

Fig. 3. Home range outlines for all ewes in the primary group.

from GSA. All bighorns approaching GSA from the south would have to cross GSA to get to the sewage ponds. The hot spring is located just below GSA (0.2 km) and approximately 0.5 km south of SA. Disturbance by human activity above bighorns at the hot spring (Hicks and Elder 1979; Cunningham 1982) could reduce the usefulness of the water source.

Eastside ewes used ephemeral water sources on Mount Wilson until the sources dried in late summer. The ewes then moved north and traveled back and forth to Lake Mead to drink. They frequently crossed and even fed in the rolling hills west of Mount Wilson and watered in a small isolated cove just east (about 400 m) of PPA. The core area of three of the eastside ewes included this cove. We located southside ewes most often adjacent to a hot spring near Ringbolt Rapids, but there are several accessible areas near the river this far south. We hesitate to say one area is more important than the other for this group.

No particular water source seemed important to rams. We observed rams at all important water sources for ewes during the rut and at various places along the river from Willow Beach north for 3–4 km in early summer. We occasionally found rams close to the river in winter.

Lambing occurred from February to June, with the majority of lambs appearing in late March and early April. We documented lambing activity by primary ewes in two contiguous blocks of steep habitat. We know three ewes lambed between GSA and SA in 1990, and one returned to lamb there in 1991 (the other two ewes died in fall 1990). During a 4-day, 24-h monitoring period, we documented that ewe 8 lambed close to midnight on 9 February 1990 about 200 m north of the planned route for GSA. She did not leave this general area (within 0.2 km) before we stopped monitoring 4 days later. In early March, we found ewes 10 and 12 with newborn lambs in the cliffs above the river between GSA and SA. They too were sedentary and stayed in this area for at least a week. On 23 March 1991 ewe 12 was again seen with a newborn lamb in this same general area. We also observed three uncollared ewes with lambs in this same area in 1990 and two in 1991. In 1990, we often located lambs near GSA and SA, as a large nursery group (10–12 ewes with lambs) often used this area frequently until July. We believe one ewe lambed on the steep slopes just west of the river about 2–3 km south of Hoover Dam in 1990 and four lambed there in 1991. As with other ewes with lambs, they were at first sedentary and solitary, but after a few weeks they were found in large nursery groups. Ewes with lambs rarely crossed Highway 93 until the lamb was older (mid-July) and frequently were found closer to the river on the steeper slopes.

Eastside ewes with lambs tended to stay higher on the slopes of Mount Wilson and use the rolling hills less frequently. We saw very young lambs (<1 week) in two general areas along Mount Wilson and Fortification Hill. We were unable to pinpoint where these lambs were born, but ewes with lambs could be found predictably in these areas. During the spring lambing season, southside ewes moved onto steep terrain approximately 7–11 km south of Hoover Dam and near the river. The ewes returned to this area each spring, but we found no specific lambing areas.

Effects of U.S. Highway 93

We documented more than 550 crossings of Highway 93 by ewes and rams. All primary ewes crossed the road several times and averaged 30 crossings/year (range = 15–52). The duration of monitoring and the number of crossings were correlated ($r^2 = 0.88$, $P < 0.00001$). Primary ewes were the only ewes that crossed Highway 93 consistently, and none showed more than mild caution when approaching Highway 93. They frequently fed along the edges during mild to heavy traffic, especially after rainstorms when the surface runoff caused a green-up adjacent to the highway. Only two of the eastside ewes and two of the southside ewes crossed Highway 93 once during the study. Seventeen of the 18 collared rams crossed Highway 93 during the study.

The largest number of crossings occurred during summer—ewes crossed back and forth to feed and water, and males increased movements to initiate rut. Crossings continued in fall during the rut. The lowest number of crossings was in spring when ewes were sedentary during lambing. Primary ewes were most often found near Highway 93 (Table). There were differences in distance between seasons, but the differences were small (0.2 km). Eastside ewes were most often found the furthest from Highway 93 (4.1–5.2 km), reflecting their preference for Mount Wilson. Southside ewes were found at intermediate distances from the highway (1.4–2.0 km); the greatest distance was in spring. Rams showed little seasonal variation and were most often located 2.0–2.4 km from the highway. All bighorns were found near the highway on occasion.

The above data reveal an interesting and important difference in behavior between ewes captured in different areas. The number of crossings by the primary ewes indicates that Highway 93 is not a barrier and that ewes have

Table. Mean and minimum distance (km) of locations of bighorn sheep (*Ovis canadensis*) to U.S. Highway 93, Gold Strike Alignment (GSA), Sugarloaf Alignment (SA), and the Promontory Point Alignment (PPA) by group and season.

	Highway 93		GSA		SA		PPA	
Group and season	$\bar{x}$	(Minimum)	$\bar{x}$	(Minimum)	$\bar{x}$	(Minimun)	$\bar{x}$	(Minimum)
Primary ewes								
Fall	0.8	(0)	2.4	(0.04)	2.7	(0.1)	3.3	(0.6)
Winter	0.8	(0)	2.0	(0)	2.4	(0.02)	2.9	(0.4)
Spring	0.7	(0)	1.4	(0)	1.6	(0)	2.2	(0.3)
Summer	0.6	(0)	1.7	(0)	1.9	(0.08)	2.5	(0.07)
Eastside ewes								
Fall	5.2	(0.05)	7.1	(0.8)	7.2	(0.5)	7.3	(0.5)
Winter	4.1	(0.1)	5.7	(0.1)	5.7	(0.3)	5.8	(0.1)
Spring	4.3	(0.05)	5.9	(0.6)	5.9	(0.1)	6.0	(0.3
Summer	4.3	(0.1)	6.0	(0.4)	6.1	(0.2)	6.3	(0.2)
Southside ewes								
Fall	1.4	(0.04)	4.8	(1.8)	5.2	(1.2)	5.8	(3.6)
Winter	1.7	(0.1)	4.8	(2.3)	5.2	(2.9)	5.7	(3.3)
Spring	2.0	(0.3)	5.2	(2.6)	5.5	(3.2)	6.1	(3.7)
Summer	1.5	(0.08)	4.8	(2.8)	5.1	(3.2)	5.8	(3.8)
Rams								
Fall	2.1	(0.06)	6.3	(0.1)	6.6	(0.5)	7.2	(0.9)
Winter	2.4	(0.1)	7.1	(0.4)	7.5	(0.4)	8.0	(0.8)
Spring	2.0	(0.04)	7.3	(1.0)	7.5	(1.4)	8.3	(1.8)
Summer	2.2	(0)	6.9	(0.06)	7.3	(0.1)	7.8	(0.2)

habituated to this disturbance. Home range outlines and number of crossings by the eastside and southside ewes suggest that the highway is a barrier. We commonly saw eastside or southside ewes adjacent to Highway 93, but we observed no crossings. Bighorn ewes are believed to learn their home range from their mothers whom they follow their first year (Giest 1968, 1971; Festa-Bianchet 1986). We assume that crossing Highway 93 was a learned behavior in the primary group area but not elsewhere. Therefore, we conclude that a highway may or may not be a barrier depending on the experience of the bighorns. The primary ewes might not accept mitigation measures and cease crossing the highway.

Almost all the observed crossings were in late summer and early fall. We observed the largest number of groups (19, totaling 102 bighorns) cross between mileposts 2.1 and 3.0. Ten crossings were seen at milepost 2.9, and another 7 were observed at milepost 3.1—48% of the observed crossings were in this general area (2.9–3.1). A trail—frequently used by bighorns when traveling from the bajada east of Highway 93 to the sewage ponds and back—intersected the highway in this vicinity. Two other general crossing areas occurred at mileposts 2.1 and 2.5. No obvious topographic features were evident at these locations. These three areas accounted for 75% of crossings we observed—the remainder seemed random.

A common feature of preferred crossing areas is a break in the guard rails on both sides of the highway. We observed groups crossing in areas where there is a guard rail on one side, but on each of the four occasions the bighorn got confused (particularly lambs) and ran back and forth across the road before finally jumping the guard rail to safety. Crossings were observed during all periods of the day, and two were at night. We observed a group of two rams cross under Highway 93 at milepost 5.1, and tracks indicated other bighorns had used this culvert.

We documented 25 deaths on Highway 93 during the study. Seven were beyond our primary study site (beyond milepost 5.0), and 18 were in areas we repeatedly monitored for sheep movements. Most deaths (20 of 24) occurred in late summer and fall (July–October) when the number of crossings was greatest. Deaths between mileposts 3 and 4 totaled seven, and four of the seven were at the major crossing area (milepost 2.9–3.1). Use of the crossing areas does not ensure safety. Two deaths each were recorded at crossings at miles 2.5 and 2.1. Deaths were lowest between mileposts 4 and 5 (2) and 2 and 3 (4). The long straightaways between these mileposts may reduce the number of bighorn–automobile collisions. Five deaths occurred between mileposts 1 and 2—three were near miles 1.4 and 1.5. Several tire marks were on the pavement from sudden stops in this area, and we documented that one burro was killed here.

It is probable that the traffic increase on the dam implies a traffic increase on Highway 93 in Arizona and that highway-caused mortality is also increasing. When these ewes first started crossing the highway regularly, mortality may have been lower with minimal demographic effect. If traffic and related mortality keep increasing, the subgroup that has learned to cross the highway could be extirpated without mitigation in some form.

Movements Around the Proposed Alignments

During the study, we documented 363 crossings of GSA. Rams (seven with collars) and primary ewes were the only bighorns documented crossing this or other alignments. The number of crossings by primary ewes ranged from 2 to 48 and averaged 27/year. The most common reason for crossing was sheep going to and from the sewage ponds in summer for water. A large nursery group used the area around GSA in 1990. Proportionally, there was a greater amount of use around GSA than SA, but utilization time was similar with spring and summer being equal (Fig. 4).

Infrared beam recorders were placed near suspected areas of crossing along GSA from 20 May 1990 to 1 March 1991. Sixty-nine percent (55 of 80) of recorded crossings occurred at the first two stations (Fig. 2). The area included several well worn trails to and from the sewage ponds. We documented bighorn crossings in a wash that rises from the bottom of the canyon but few crossings close to the river.

Of the 72 crossings of GSA we observed, 43 (60%) were adjacent to the highway (recorders 1 and 2) where sheep utilize well worn trails. We saw several groups bedded adjacent to the trails in the flat terrain. Fourteen groups (19%) went up the wash southeast of Sugarloaf Mountain (recorder 5). Many observations were of sheep feeding and moving slowly. Most (64%) of the movement was in areas of least relief (<10% slope). While bighorns are agile on steep terrain, we suggest that bighorns prefer to travel in areas of least resistance when possible.

The primary ewes were closer ($P < 0.00001$) to GSA than any of the other groups (Table). Mean distance varied from 1.4 to 2.4 km depending on the season. Primary ewes were found closest to GSA in spring and summer

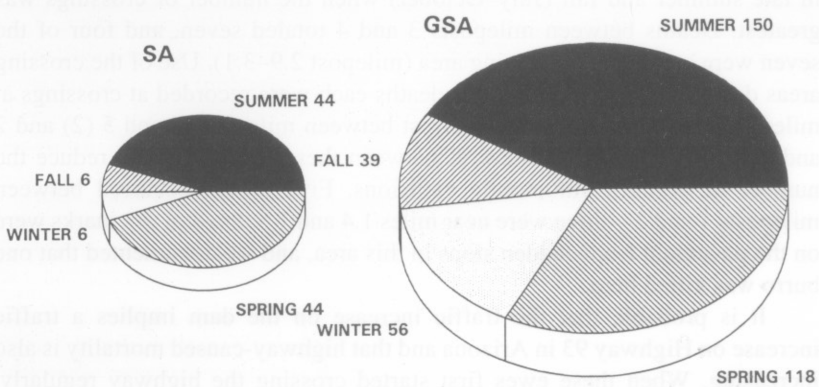

Fig. 4. Number of sheep crossings by season at the Gold Strike alignment (GSA) and the Sugarloaf alignment (SA).

when lambing activity and water needs were high. Eastside ewes and rams were next in closeness to GSA.

We documented 100 crossings of SA using GIS and successive locations. Only primary ewes crossed the alignment; no collared rams have been found north of SA. The highest number of crossings was in spring and summer. Data from event recorders showed almost equal use of the areas along the alignment. We observed more bighorn use in the areas on the east side of the alignment over the 2-year period, probably because of proximity to the sewage ponds. Of the 43 groups we observed on SA, use was highest near recorders 10 (19–44%), 11 (14–32%), 9 (6–14%), and 8 (4–9%). Of 317 bighorns seen along SA, 220 (69%) were ewes and 67 (21%) were lambs. Primary ewes were found closest to the SA over all seasons, and these ewes were closest to SA in spring and summer (Table). Eastside ewes and rams were found close to SA infrequently, but average distance was significantly farther ($P < 0.00001$) than primary ewes. Southside ewes never came closer than 1.2 km to SA.

Location of PPA did not lend itself to use of GIS to analyze crossings. We placed two event recorders along the alignment and recorded only one crossing in 4 months. We only sighted one group along this alignment during the study, and we found little sign while hiking the alignment. This is much lower than crossings recorded on other alignments, but a theft reduced the monitoring time by about 1 month.

Primary ewes had the shortest mean distance to PPA, but it was never less than 2.2 km. The minimum distance was less than 300 m on only one occasion. Other groups were significantly farther away ($P < 0.00001$) than primary ewes, but minimum distance revealed that the eastside ewes do use this area. A watering area frequented by eastside ewes (cove on Lake Mead) is only 0.4 km away.

Possible Effects of Alignments and Construction

We believe that alternate GSA has the most potential for disturbing local bighorns. If GSA were selected, either the highway construction or the presence of the 4-lane highway with no mitigation to permit passage could extirpate bighorns from approximately 4 km^2 of habitat in the Sugarloaf Mountain area. If extirpation would occur, the bighorns would lose a primary watering area, a lambing area, and up to 25% of general feeding and resting area. Displaced bighorns would be forced to compete with residents of adjacent habitats and could cause adjustments for unknown distances around the selected alignment. As density of bighorns increases, recruitment rates decrease (Leslie and Douglas 1982) to stabilize density. The opportunity for spread of diseases increases as density increases and widespread mortality could occur. In summary, we believe that if Sugarloaf and surrounding area are avoided (including important watering and lambing areas), there is a high probability of the local population declining and a low probability of widespread decline in the Black Mountains from increased disease transmission.

We suggest, if GSA or SA is selected, that a new, year-round water source be provided for the sheep. The watering source should be placed in a location central to sheep activity but far enough away from construction that the bighorns can drink undisturbed. The orders of preference for placement of waterholes as suggested by Werner (1989) should be followed. We also suggest developing the ephemeral pothole discussed earlier. The social behavior around waterholes is important, and availability of waterholes during critical drought months is essential (Olech 1979).

Bighorn use around SA was highest during the two most critical periods for bighorns—spring lambing and summer waterhole use. Summer use of the sewage ponds would be precluded by construction and use of SA (only 0.2 km away). Moving the sewage ponds 0.4 km south to the southern end of the bench would probably make them accessible to bighorns. With the availability of water in the sewage ponds and the hot springs, we believe the bighorns using the SA area would remain. Lambing and rearing in the area near construction might be reduced, but erection of adequate sight barriers during construction might not preclude postlambing use because ewes could still remain above the center of human activity.

The two specific concerns we have about the PPA is the close proximity to the Lake Mead cove frequently used for watering and that PPA will straighten the approach to the bighorn crossing and allow vehicles to increase speed. Southbound motorists will be traveling in two of the four lanes and will have a downhill run to milepost 1.8. The increased speed could be detrimental to bighorns and to motorists. The cove is not in sight of the proposed construction, but loud noises could affect bighorn use. Blasting only at night might reduce some of the noise effect. Both of our concerns must be considered if PPA is selected.

Some construction-related activities could affect local bighorns despite the alignment chosen. Increased traffic and daily human activities during construction and immediately postconstruction will increase bighorn and human encounters—we hypothesize increased general stress on bighorns, increased road kills, and an increased potential for poaching. Reactions of bighorns to disturbance can vary with habitat, distance to escape terrain, and distance from disturbance (Welch 1969; Olech 1979; Chilelli and Krausman 1981; Bates 1982; Hansen 1984). Generally, the closer the disturbance, the more pronounced the reaction, and the farther the movement by bighorns (Hicks and Elder 1979; Miller and Smith 1985).

The primary ewes have habituated to some human presence and structures. Gradual alteration in human activity may be received differently than a rapid acceleration of human activities associated with highway construction. We are unsure how the other ewes and rams will respond to increased human activity. During construction of the Palo Verde–Devers power line, Smith et al. (1986) found that fewer ram crossings occurred during the construction period in the New Water Mountains. Denying ram movements to traditional breeding areas for even a short time could reduce reproduction success by extending the breeding season and stressing both sexes. Extending the breeding season would force rams to increase movements. Ewes could breed late, and subsequent lambing would occur later in spring when environmental conditions are less favorable, and survival of lambs could be lower. Some ewes might go unbred (genetic isolation).

We suggest training of construction workers to avoid contact with bighorns and the placing of a 25-mph-or-less speed limit on construction vehicles to reduce noise and collisions with bighorns. We recommend use of water trucks and other methods to reduce dust during construction near Lake Mead. While monitoring the bighorn population during construction of a dam in Waterton Canyon, Colorado, Bailey (1986) documented a major die-off—from an estimated 78 to 13. The bighorns were diagnosed as dying from bronchopneumonia (Spraker et al. 1984), and necropsies indicated the pneumonia was associated with airborne dust caused by vehicle passage every 5–6 min. We feel that mitigation to redirect and prevent crossings by bighorns is needed in certain areas.

Each proposed approach road is planned as four lanes and is free of the existing hairpin curves to milepost 1.2 and the steep gradient beyond the crossing. Vehicles approaching the Colorado River from Nevada would not have to slow for the 4–6 km leading to the river, as they do now. The wider approaches on both sides of the river after construction will allow smaller vehicles to pass large trucks that presently travel at very slow speeds because of the grades (slopes) and hairpin curves. We documented many bighorn deaths between mileposts 1.0 and 5.0 and suspect that deaths will increase as the average speed increases following construction. Ewes whose home ranges are bisected by U.S. Highway 93 currently have a 25% chance of being killed while attempting to cross the existing highway each year.

The primary means of preventing crossings would be fencing. Reed (1981) found that a 2.44-m fence with basal closure and permanency (through continued maintenance) reduced accidents by about 75%. Fencing must extend well beyond the area of concern to prevent the sheep from moving around it—Ward et al. (1980) found that 19 mule deer (*Odocoileus hemionus*) were hit by vehicles after going around the end of a fence before it was completed.

Underpasses or overpasses should be built at locations of frequent crossings (Klein 1971; Reed et al. 1979; Singer and Doherty 1985). Mule deer, elk (*Cervus elaphus*), and moose (*Alces alces*) will use underpass crossings of highways and pipelines; but the degree of use depends on the location, dimensions, degree of visual barrier, and use of restrictive lead-in fencing (Van Ballenberghe 1978; Ward et al. 1980). Reed et al. (1979) reported that deer preferred overpasses; but Singer and Doherty (1985) found that mountain goats (*Oreamnos americanus*), behaviorally more similar to bighorns, readily used underpasses designed for mountain goats. Deer preferred underpass structures to culverts (Reed et al. 1979; Ward et al. 1980). Caribou (*Rangifer tarandus*) showed reluctance (Child 1974), and pronghorns

(*Antilocapra americana*) rarely used underpasses (Ward et al. 1980). We recommend underpass structures similar to those described for mountain goats because they would be less disturbing for bighorns. Singer and Doherty (1985) designed two underpasses for mountain goats that were sufficiently large (3–8 m high × 23 m wide × 11 m; and 3 m high × 3 m wide × 11 m) to allow an open view for the animal (no tunnel effect) and a comfortable distance from the roadway.

Finally, we recommend that the Arizona approach to Hoover Dam (current U.S Highway 93) be closed or speed reduced to 25 mph or less. A triangle of bighorn habitat—including thc primary watering site (sewage ponds) and prime lambing area—could be surrounded by high speed highway if the speed on the dam access road were not reduced. Closure or speed limits of 25 mph or less could reduce the probability of two or more bighorns being killed annually near milepost 1.8.

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