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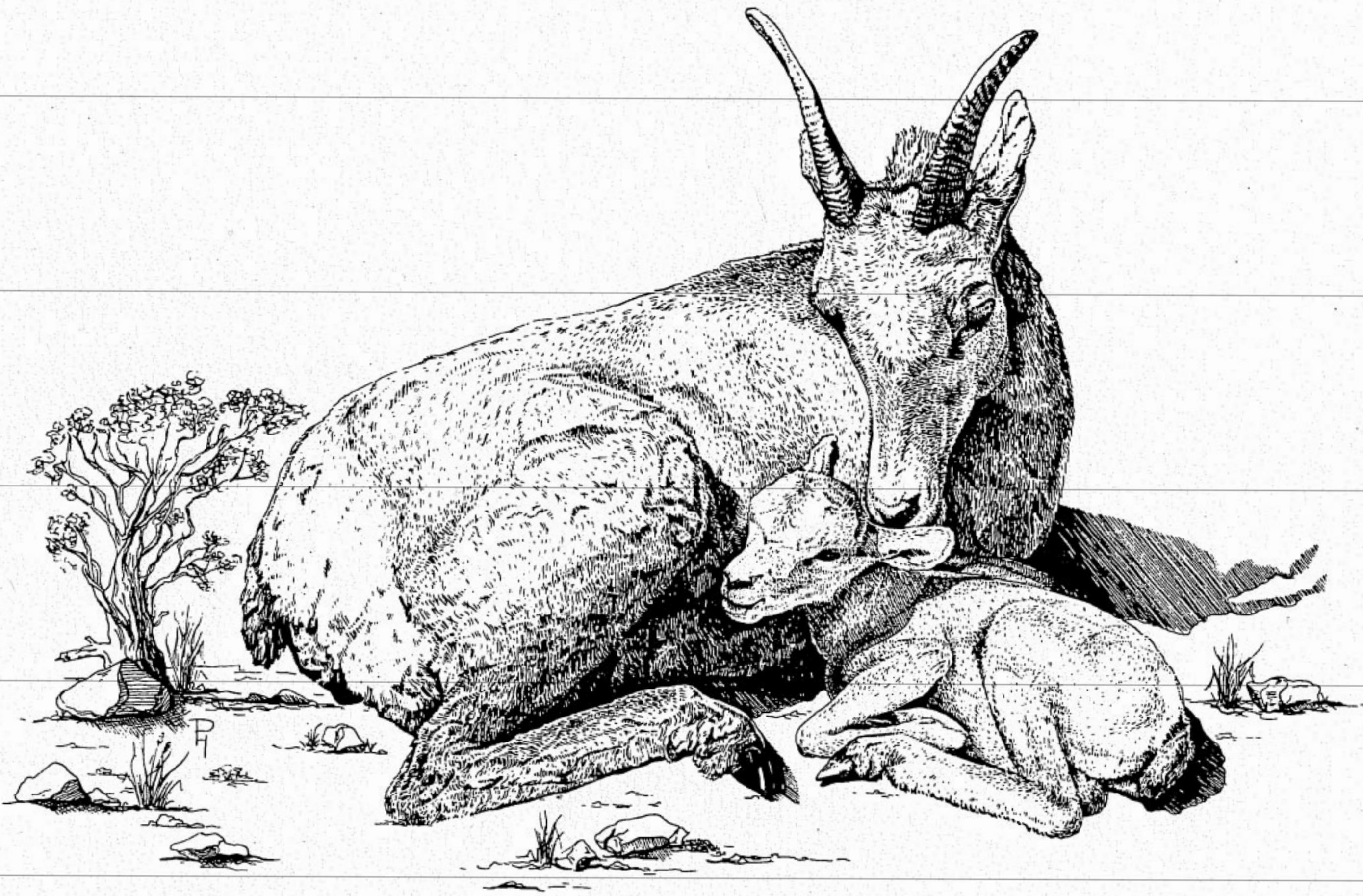

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GENETIC VARIATION IN DESERT BIGHORN SHEEP

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Abstract: Genetic variation at 10 highly variable microsatellite loci was characterized for 279 bighorn sheep in 13 study sites in Arizona, southern California, New Mexico, and Canada. All study sites contained a substantial amount of genetic variation. Genetic differences between study sites were large and roughly proportional to geographic distance. The significance of this to desert bighorn sheep taxonomy and management is discussed.

Key words: Genetic variation, desert bighorn sheep, taxonomy, evolution

INTRODUCTION

Bighorn sheep occupied most of the desert mountain ranges in Arizona, California, and New Mexico until human settlement led to the extirpation of sheep from much of their historic range. Existing bighom sheep populations occupy fragments of historic range (Bleich et al. 1995). Bighorn sheep management has focused on improving the viability of existing populations and reintroducing sheep to their previous range, and these efforts have become increasingly successful. This success has been due, in part, to research that has improved our understanding of bighorn sheep populations. Now, recent advances in molecular genetic methods offer a perspective of the evolution of bighorn sheep in the Southwest that should be valuable for bighorn sheep management.

Genetic data can address 2 issues pertinent to bighorn sheep management. First, a genetic survey can directly measure the amount of genetic variation in bighorn sheep populations. There has been concern that population isolation might lead to inbreeding and population decline (DeForge et al. 1979), and each component in this scenario has received some support. For example, Bleich et al. (1995) showed that modem bighorn sheep populations have lost historic connections to adjacent populations. Ramey (1995) showed bighorn sheep populations have low levels of mitochondrial DNA diversity. Sausman (1984) showed inbreeding increased lamb mortality in captivity. Berger (1990) showed that small populations of bighorn sheep have had a high extinction rate. Quantifying the amount of genetic variation in populations will help evaluate how likely this scenario is, and will permit managers to use genetic information during bighorn sheep management.

Second, recognizing historic patterns of genetic variation in bighorn sheep populations is required to preserve evolutionary relationships during translocation programs. Translocation of bighorn sheep has been a valuable part of bighorn sheep recovery effort and should not disrupt natural patterns of genetic differentiation. Combining genetically different populations of bighom sheep could alter adaptations to local environments and lower the fitness of populations.

We will address these issues by examining genetic variation in bighorn sheep from across the Southwest. Of the many genetic markers now available, microsatellite loci are best suited for these questions (e.g. Ashley and Dow 1994, Jarne and Lagoda 1996). Microsatellites are DNA sequences composed of a variable number (typically 5 to 40) of tandem repeats, such as CACACACA. Specific loci (locations in the genome) are defined by unique DNA sequences that flank the repeated units, and individuals are characterized by the number of repeats at that location. Sequences with more than 40 repeat units are uncommon (Valdes et al. 1993), but the mechanism constraining the number of repeated units is not known. Microsatellite loci have become popular genetic markers for evolutionary studies because they have a high mutation rate and are considered selectively neutral. Mutation changes the number of repeats at a locus, and the high mutation rate creates variation quickly. This allows recent evolutionary events to be detected. Neutrality ensures that the number of repeats at a particular locus will not affect the fitness of the individual. As a result, the amount of genetic differentiation at microsatellite loci for 2 isolated populations is proportional to the length of time they have been separated. If 2 populations have been exchanging members, the amount of genetic differentiation will be inversely proportional to the migration rate between the populations.

STUDY AREA

We obtained blood, tissue, or DNA samples from 279 sheep at the 13 locations in Anzona, California, New Mexico, and Canada listed in Table 1. Arizona Game and Fish Department provided 98 blood samples fiom sheep captured in Arizona, including samples fiom the Kofa Mountains, Castle Dome Mountains, Stewart Mountain, Mt. Davis, Lost Cabin, and Mt. Nutt. In addition, the Department provided 4 liver samples from the Kofa Mountains which had been collected by hunters. This study also includes 122 DNA samples previously analyzed at 3 microsatellite loci by Boyce et al. (1996) from bighom sheep at San Ysidro, San Gorgonio, Eagle, and Wheeler Peak. Lastly, Stephen Forbes provided data and DNA fiom 55 bighorn sheep in Alberta, Canada. Figure 1 shows the location of the 9 study sites in Arizona and California.

These study sites are composed of native sheep, except for the Stewart Mountain, Wheeler Peak, and Red Rock Wildlife Area study sites. The Stewart Mountain sheep were transplanted fiom the Kofa Mountains of Anzona; the Wheeler Peak sheep were transplanted fiom Alberta, Canada; and the Red Rock Wildlife Area sheep were captured in the San Andres Mountains of New Mexico.

METHODS

We genotyped all individuals at 10 dinucleotide microsatellite loci: FCB11, FCB128, FCB266, FCB304, MAF33, MAF36, MAF48, MAF65, MAF209, and DS52 (Buchanan et al. 1993; Crawford et al. 1994; Steffen et al. 1993). These loci were chosen because they have been informative in previous studies of genetic variability in bighorn sheep (Forbes et al. 1995; Boyce et al. 1996).

We began our data analysis by testing whether the data at each study site was consistent with random mating with respect to the 10 genetic markers in our analysis. This was accomplished by testing the data for agreement with Hardy-Weinberg proportions using GENEPOP 3.0 (Raymond and Rousset 1995). We tested each locus, each study site, and each locus at each study site, using the Bonferroni adjustment for multiple comparisons as criteria for statistical significance (Sokal and Rohlf 1995). Next, we calculated 2 sets of summary statistics. First, we calculated an unbiased estimate of the gene diversity (mean expected heterozygosity), $\hat{H}$, at each study site (e.g. Nei 1977). This statistic is a measure of the amount of genetic variation present at each location and is independent of sample size. Confidence intervals for estimates of gene diversity were obtained using the *t*-distribution. Second, we calculated the genetic distance of Nei (1977) between each pair of study sites. This statistic is a measure of genetic differentiation for pairs of populations and equals zero when the 2 populations are identical and infinity when the 2 populations share no genetic markers. Randomization was used to test for the statistical significance of each genetic distance.

Genetic distances between study sites were summarized with 2 methods. First, we used PHYLIP (Felsenstein 1993) to construct a UPGMA phylogenetic tree of the 13 sampling sites. The significance of the nodes in the tree was tested by bootstrapping over loci using the DISPAN software package (Ota 1993). Second, we compared the genetic distance between each pair of study sites with the geographic distance measured in kilometers. Geographic distances were obtained from the geographic information system program ARCVIEW 3.0 (E.S.R.I. 1998). For the 3 study sites of transplanted sheep (Stewart Mountain, Wheeler Peak, and Red Rock), we used the original location of the source sheep to calculate geographic distances. We used a Mantel test (Sokal and Rohlf 1995) to test for correlation between genetic and geographic distances.

RESULTS

There was considerable genetic variation at all of the sampling locations (see Table 1). There was variation at each locus and in each population. With only a few exceptions, each sample contained more than 1 microsatellite variant at each locus. None of the loci or study sites differed significantly from Hardy-Weinberg proportions, indicating mating apparently was random with respect to these loci. The average gene diversity was 0.51 for the 11 desert study sites, 0.57 for the 2 Rocky Mountain sites, and 0.52 overall. The 3 most genetically variable sampling locations were Eagle, Kofa, and Alberta; the 3 least genetically variable sampling locations were Red Rock, Mt. Nutt, and Old Dad. The confidence intervals for the gene diversity at each location indicate that the lowest heterozygosities are significantly lower than the highest; however, all 13 study sites have a substantial amount of genetic variation, and none of them can be considered genetically impoverished.

The genetic distance between each pair of sampling locations ranged from a minimum of 0.020 between Mt. Davis and Lost Cabin to a maximum of 0.87 between San Ysidro and Alberta (Gutierrez-Espeleta et al. 1998). All genetic distances were highly statistically significant ($p < 0.001$), except for the 2 shortest genetic distances ($D_{Davis.Cabin} = 0.02$, $\hat{p} = 0.06$; $D_{Kofa,Castle} = 0.04$, $\hat{p} = 0.05$). This indicates that each pair of study sites is genetically different, except for the 2 pair just mentioned.

The phylogenetic tree depicted in Figure 2 provides 1 method of summarizing the genetic differences between study sites. The values shown at the nodes of the tree estimate the probability of obtaining the indicated clusters of study sites if the study was repeated with 10 randomly chosen loci. As can be seen, only 2 clusters of study sites received reasonable support fiom the data: the 3 study sites in the Black Mountains of Arizona (Lost Cabin, Mt. Davis, and Mt. Nutt) and the 3 study sites with bighom sheep in or from southern Arizona (Kofa, Castle Dome, and Stewart). These 2 clusters are composed of neighboring locations, and both of these well supported clusters are at the tips of the phylogenetic tree. The major structure of the tree can not be considered reliable.

Figure 3 shows that genetic differences between study sites are proportional to geographic separation. A Mantel test found this relationship to be significantly different from random ($\hat{p} < 0.001$). The relationship is roughly linear for distances up to 300 lalometers, and then appears to asymptote, with genetic distances between 0.25 and 0.75 for study sites more distantly separated. If currently recognized subspecies definitions have a biological basis, we would expect a higher rate of genetic differentiation with distance when comparing locations across subspecies lines than within subspecies. This expectation is not met.

DISCUSSION

Our data has interesting similarities and differences to comparable data in Rocky Mountain bighom sheep. Eight of the 10 loci included in this study were previously analyzed by Forbes et al. (1995) in 5 populations of Rocky Mountain bighom sheep. Comparing the

2 data sets reveals that the rate of genetic differentiation as a function of geographic distance is much steeper among desert bighorn than Rocky Mountain bighorn. This could be explained by larger population sizes for Rocky Mountain bighorn, higher migration rates, or by similarities between populations in the Rocky Mountain bighorn remaining from post-Pleistocene colonization. If desert populations have historically been more isolated than Rocky Mountain populations, we would expect to find less genetic variation in the desert populations than in the Roclues. This expectation is not convincingly met. The gene diversity in Rocky Mountain sheep ranged from 0.43 to 0.60, with an average of 0.55 (Forbes et al. 1995) compared to an average gene diversity in the 11 desert locations in this current study of 0.49 at the 8 loci in common.

This data set complements the mitochondrial data of Ramey (1995) to provide a comparison between male and female migration rates. Ramey examined mitochondrial DNA (mtDNA) sequences at 26 locations in the Southwest (including Old Dad, Eagle, San Gorgonio, Kofa, and Red Rock) and found lower levels of genetic variation and greater differences between adjoining populations than in our study. Because mtDNA is only inherited maternally, mtDNA variation reflects only the evolutionary history of females. The low levels of mtDNA variation and high level of population differentiation indicate that the dispersal rate for ewes has been low. In contrast to mtDNA, microsatellite DNA is inherited both maternally and paternally. The higher level of genetic variation and less extreme genetic differentiation at microsatellite loci probably reflects higher dispersal rates among rams.

The relatively high gene diversity in desert bighorn populations shows that desert sheep populations have been large and/or well connected during recent evolutionary history. These gene diversities, however, probably do not reflect disturbances associated with human development during the past few centuries. Current population sizes and dispersal rates may or may not be adequate to retain existing genetic variation for an extended period. Retention of genetic variation within populations is maximized by high dispersal rates to and from other populations and minimized by low dispersal rates. Fortunately, dispersal rates as low as 1 migrant per generation are effective in preventing loss of genetic variation caused by fragmentation. Schwartz et al. (1986) have used this reasoning to argue that excessive loss of genetic variation is unlikely for large metapopulations of sheep. We agree. The recommendation (Bleich et al. 1990) that corridors between sheep populations be protected for bighorn movement is also sound.

Assigning biological significance to the genetic differences between populations found in this study is difficult. Populations with similar microsatellite variation may still have adaptively important differences maintained by natural selection. In addition, populations with differing microsatellite markers may share adaptively important traits. Evidence has been found for both of these situations (Karhu et al. 1996; Scheffer et al. 1998). Microsatellite differentiation only reflects the opportunity for other traits to evolve independently in each population. So, very similar populations such as Mt. Davis and Lost Cabin have had virtually no opportunity for independent evolution. In fact, these 2 locations practically constitute a single population. They, perhaps, should be considered sub-units of a metapopulation. The same is true for the Kofa and Castle Dome locations. In contrast, the large genetic differences between the 3 northern Arizona locations (Mt. Davis, Lost Cabin, Mt. Nutt) and the 3 southern Arizona locations (Kofa, Stewart, Castle Dome) imply a relatively long separation between these regions with opportunity for independent evolution and adaptation to local environments. Because we can not evaluate the biological significance of genetic differences between locations, and because genetic differences are roughly proportional to geographic distances, the most conservative method of selecting stock for translocations would be to choose the closest available population.

The genetic relationships estimated by this analysis, unfortunately, can not easily be used to produce a taxonomy of desert bighorn sheep.

Fairly strong genetic Qfferentiation exists in southwestern populations of bighorn sheep. However, genetic Qfferences appear to be associated with geographic distance rather than any specific boundary. If existing subspecies boundaries have biological meaning, we would expect to find increased genetic differences when comparing populations across subspecies boundaries. Because we find no evidence for this in our data, we conclude that we have no support for current subspecies designation. Rather, this analysis appears to support the view of Ramey (1995) that desert bighorn sheep are a polytypic subspecies.

However, we emphatically acknowledge that this study has not provided a strong test of the existing taxonomy. For example, we have included only 1 location (San Ysidro) from the Peninsular Ranges. The genetic distance between San Ysidro and San Gorgonio to the north was fairly high (0.35) considering the 2 locations are separated by only 42 lulometers, but apparently within the range expected for that distance. Examining the putative subspecies boundary between the Peninsular Ranges and the adjacent ranges in the Mojave Desert would require more sampling locations in order to detect a potential transition zone. Similarly, examining the putative subspecies boundary between Nelson and Mexican bighorn sheep in Arizona would require study sites closer to the potential boundary. Future research would also benefit from additional loci in order to decrease the width of confidence intervals for genetic distances (data not shown) and increase the statistical significance of clusters in the phylogenetic tree. However, the inability of this analysis to establish a taxonomy for desert bighorn sheep may reflect the inappropriateness of the subspecies concept as much as limitations in our data.

ACKNOWLEDGEMENTS

This study would not have been possible without the support of the Arizona Game and Fish Department. We thank Raymond Lee for providing blood samples and the Heritage Program for funding. We also thank Karen Parker for technical support and Stephen Forbes for providing data and samples fi-om Alberta sheep.

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Table 1. Location, currently recognized subspecies, number of individuals sampled (N), and gene diversity (H and 95% confidence interval for $\hat{H}$) of the 13 study sites included in this study.

Location	Subspecies	N	$\hat{H}$ (min, max)
Northern Arizona			
Mt. Davis	*O. c. nelsoni*	15	0.54 (0.49, 0.59)
Lost Cabin	*O. c. nelsoni*	16	0.55 (0.51, 0.58)
Mt. Nutt	*O. c. nelsoni*	28	0.44 (0.39, 0.49)
Southern Arizona			
Kofa Mountains	*O. c. mexicana*	9	0.60 (0.55, 0.64)
Stewart Mountain	*O. c. mexicana*	14	0.54 (0.50, 0.58)
Castle Dome Mountains	*O. c. mexicana*	20	0.58 (0.55, 0.62)
Southern California			
Old Dad Mountains	*O. c. nelsoni*	23	0.45 (0.41, 0.50)
Eagle Mountains	*O. c. nelsoni*	23	0.63 (0.60, 0.66)
San Gorgonio	*O. c. nelsoni*	22	0.46 (0.41, 0.51)
San Ysidro	*O. c. cremnobates*	22	0.49 (0.45, 0.53)
New Mexico			
Red Rock Refuge	*O. c. mexicana*	25	0.36 (0.30, 0.42)
Rocky Mountains			
Wheeler Peak, N.M.	*O. c. canadensis*	7	0.55 (0.51, 0.58)
Alberta, Canada	*O. c. canadensis*	55	0.59 (0.56, 0.63)

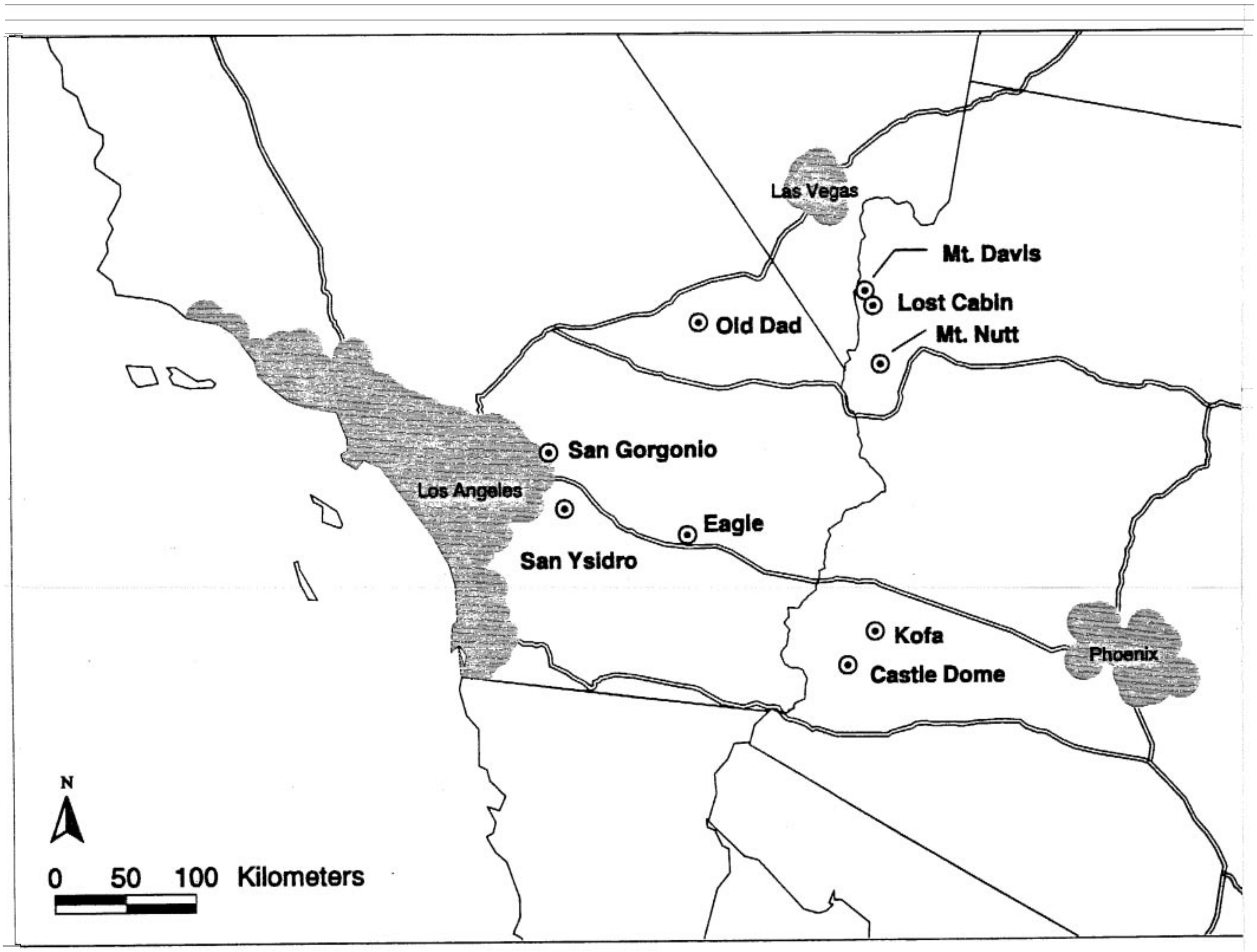

Figure 1. Location of study sites in Arizona and California. Not shown are the locations of Stewart Mountain (AZ), Wheeler Peak (NM), Red Rock (NM), and Sheep River (Canada).

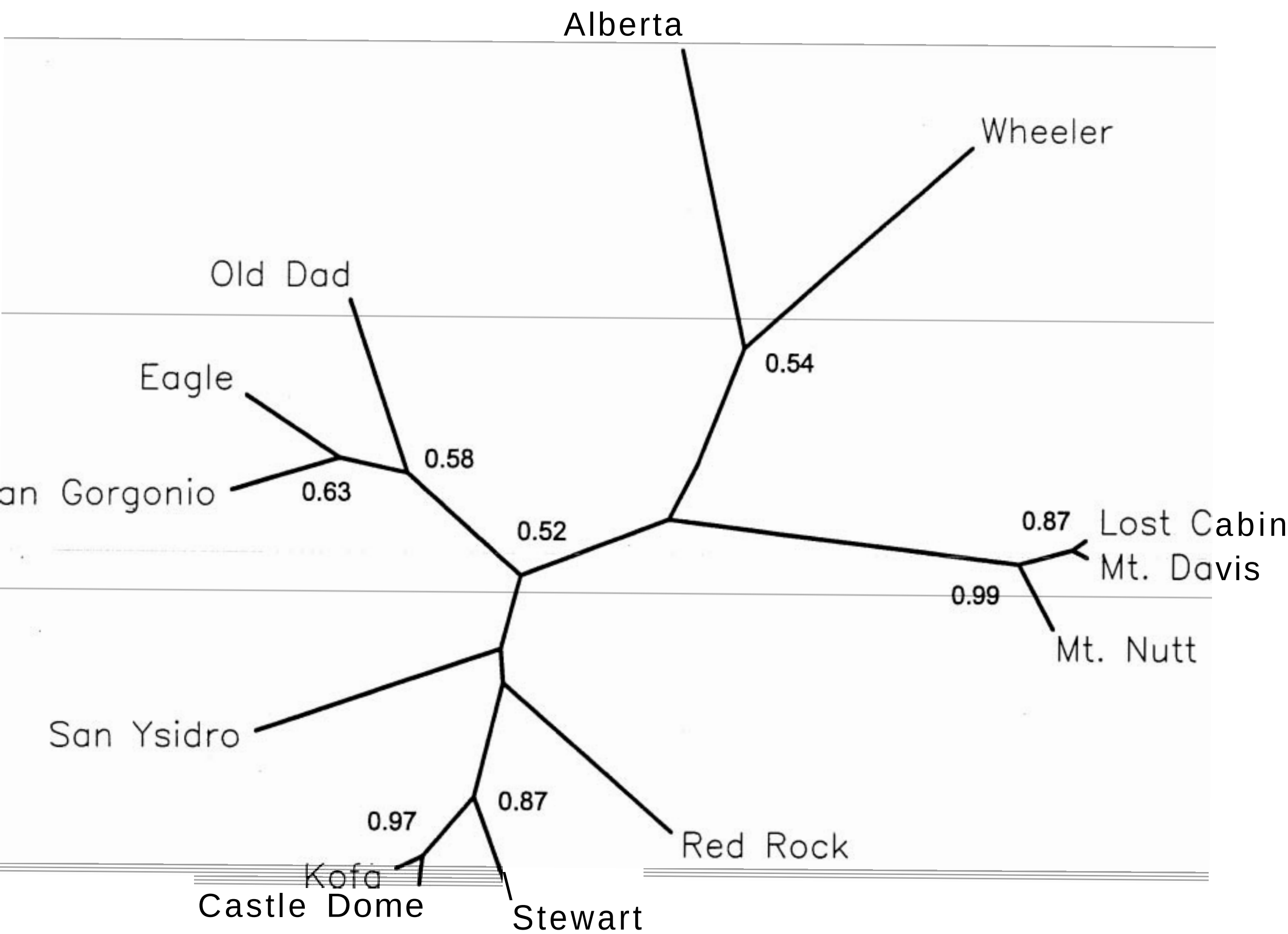

Figure 2. UPGMA phylogenetic tree. Numbers indicate the percentage of bootstrap replicates sharing the labeled node.

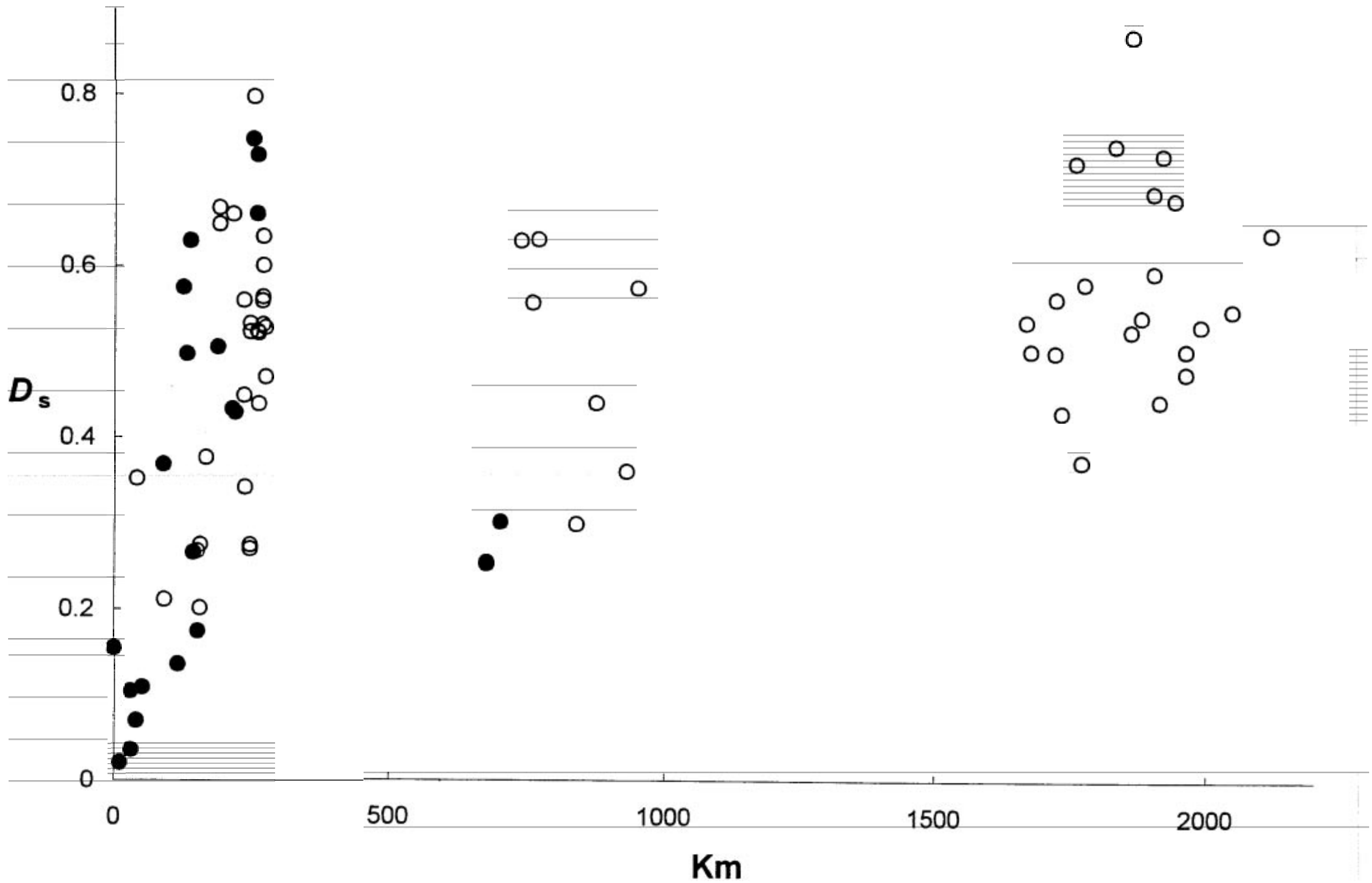

Figure 3. Genetic distance plotted against geographic distance. Comparisons between and within currently accepted subspecies are indicated by filled and open symbols, respectively.

SIGHTING RATES OF BIGHORN SHEEP DURING HELICOPTER SURVEYS ON THE KOFA NATIONAL WILDLIFE REFUGE, ARIZONA

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Abstract: Visibility bias limits the ability to precisely estimate the size of bighorn sheep (*Ovis* canadensis) populations from aerial surveys. We used radiocollars to mark desert bighorn sheep in the Kofa National Wildlife Refuge (KNWR), Arizona, then conducted 7 independent resight surveys to derive a population estimator and to measure the variance associated with the estimator. The average probability of sighting a marked group was 0.46 with a 90% confidence interval of 0.37 to 0.55. We also conducted surveys using sheep visually marked by ground observers and derived a similar resight rate of 0.45. We observed that the average group size of marked animals seen on surveys was significantly greater than the size of marked groups missed, which can lead to an overestimate of the true population size. We developed an alternative estimator that reduces this group size bias.

Key Words: Aerial survey, Arizona, bighom sheep, group size, helicopter, *Ovis* canadensis, population estimate, visibility bias

INTRODUCTION

The Arizona Game and Fish Department and the U. S. Fish and Wildlife Service have been cooperating on studies of techniques for conducting aerial surveys of desert bighorn sheep on the KNWR since 1980. Studies using 2-helicopter double-count, simultaneous double-count, and mark-resight methods (Furlow et al. 1981, Miller et al. 1985, Samuel et al. 1987, Lee et al. 1992) have been conducted to determine sighting rates for helicopter surveys and to increase the accuracy of survey-derived population estimates. The various test surveys produced sighting rates ranging from 0.25 to 0.63.

Helicopter survey of bighorn sheep populations is a common management practice. Interpretation of survey data is hindered by a lack of understanding of variables that affect the numbers of animals seen during an aerial survey and the associated variability inherent to methods of sampling. As a consequence, managers are not confident of the efficiency, accuracy, or precision of each survey conducted. Investigations of survey methods and interpretation of survey data have been ongoing.

The first strategy we used to improve surveys was the standardization of the areas flown and the level of effort in each survey block. However, even though standardized methods of aerial survey have been in use on the KNWR since 1985, interpretation of the survey results remains difficult. Assumptions regarding variables that affect the sighting rate are not well understood (Stemhorst and Samuel 1989). Several investigations into the sighting rates of aerial surveys of bighom sheep have been conducted (Furlow et al. 1981; Leslie and Douglas 1979; Miller et al. 1985; Neal et al. 1993). Although insight into variables that affect aerial surveys is provided in these studies, application of the reported sighting rates to other areas may be limited by these and other variables. Comparison of sighting rates among these studies is not possible because of different or unreported levels of effort. Since standardizing survey methodologies, we have tried several additional methods for estimating bighorn sheep populations. A 2-helicopter double-count was conducted in 1985 on the KNWR. An overall sighting rate of 0.49 was derived during this effort. However, the 2-helicopter double-count is flawed by the lack of independence between the 2 surveys. Another method, the simultaneous double-count (Graham and Bell 1989), has been tested in all game management units in southwestern Anzona. Another recent investigation used ground observers to visually mark groups of bighom sheep. These groups were compared with those seen from a helicopter. This method was outlined by Pollock and Kendall (1987). Small sample size from each trial has limited this method. Over time, an adequate sample size can be obtained by combining the results of several surveys, but a measure of the variance associated with the resulting estimator is difficult to derive.

While each investigation has led to a better understanding of survey results, many assumptions were left untested. Radiocollared animals provide an opportunity to test assumptions and determine the level of variation associated with aerial surveys of desert bighorn sheep. We used radiocollared bighorn sheep on the KNWR to investigate sighting rates during helicopter surveys. We let the following hypotheses guide our investigation:

H_0 : Sighting rates are constant.
H_a : Sighting rates are variable, due to factors which do not remain constant over time.

H_0 : Group size does not influence sighting rates.
H_a : There is a visibility bias caused by group size.

In addition to the listed hypotheses, we developed the following objectives:

1. Develop comparison estimates of sighting rate, and variance, in relation to simultaneous double-count, double-count using 2 helicopters, ground/helicopter observations, and mark/resight methods using the Lincoln-Petersen estimate.

2. Compare the areas thought to be bighorn sheep habitat with the actual locations of radiocollared sheep to test the validity of our survey polygons.

STUDY AREA AND METHODS

The study area encompassed 89.8 km^2 of the Kofa Mountains within the 2,693 km^2 KNWR in southwestern Anzona. Elevations range from 207 m to 1,487 m. Topography consists of rolling bajadas to deep, narrow canyons and tall, rugged peaks. Vegetation consists of Sonoran desertscrub classified as Anzona Upland Subdivision (Brown et al. 1979). Mean annual precipitation is 17.4 cm. Seasonal temperatures range from winter lows of 0 C to summer highs of 45 C. The Plomosa and New Water mountain ranges are located 20 km to the north of KNWR and have similar topography and vegetation. All flights were in Bell 206BIII helicopters with a pilot and 3 observers on board.

A total of 50 radiocollars (30 in 1993 and 20 in 1995) were fitted on bighorn sheep (44 females and 6 males). Animals selected for capture were spotted from ground stations to minimize any bias associated with using individuals for a helicopter sighting rate study that were originally selected with a helicopter. We speculated that there are some individuals that are more likely to run from the approaching helicopter, making them easier to see. These individuals could therefore be over-represented in the sample, resulting in an over-estimation of the sighting rate. Surveys were conducted 1 year after the radiocollars were placed on bighom sheep to reduce bias associated with the capture. The second capture effort was required due to high natural mortality among the initial sample of bighom.

Helicopter surveys of the area were conducted during October and November of each year. Standardized survey polygons in use since 1985 were used to delineate blocks of habitat (Fig. 1). The study area consisted of 13 survey polygons ranging in size from 3.8 km^2 to 13.4 km^2 with a mean size of 6.9 km^2. Polygons were delineated based on natural boundaries such as ridges, canyons, and washes. Survey polygons used for each survey included the majority of marked animals. We maintained a standardized survey intensity of 2.9 minutes per km^2.

We located all marked animals no more than 24 hours prior to each helicopter survey using radiotelemetry with a fixed-wing aircraft. Locations were recorded using a Global Positioning System data recorder. These observations were used to determine the marked sample for the following day's resight survey by helicopter. The observer on the fixed-winged flight was not used as an observer on the resight survey to eliminate bias associated with observer knowledge of-marked animal locations.

All groups of sheep observed during these surveys were classified by age and sex, number of animals in the group, and presence or absence of radiocollars. If the group contained a sheep with a collar, we identified that individual using an on board radio receiver. After each survey, each of the radiocollared sheep that was not seen was subsequently located and the size and sex-age composition of its group were recorded.

Sighting Probability Surveys

The mark-resight method that we used to calculate sighting probabilities (sometimes called visibility bias) of bighorn sheep is similar to the methods used in a classic Lincoln-Petersen population estimate (Seber 1973). The number of marked groups in the study area varied over time, due to mortality and movement. A marked group was one that contained at least 1 animal with a radiocollar. Groups containing collared sheep were classified as being either seen or missed during surveys. If a group had more than 1 collared animal it was counted only once as being a seen or missed group in order to maintain independence of sample observations.

The overall sighting probability of marked sheep during each survey was calculated as the simple proportion of marked groups available (as determined by the pre-survey fixed-wing telemetry flight) that were seen during the helicopter survey. Repeat surveys were conducted in order to obtain a mean sighting rate and to measure the variability of the statistic. Before pooling the data collected in different years, we had to test for equal means of the 2 data sets. We used a t-test to compare the means of each year's sighting rates. The Kolmogorov-Smirnov test was used to test for normality of the data and the Levene Median test was used to test for equal variances before the t-test was run.

A variation of the mark-resight method uses observers on the ground to visually mark groups of bighorn sheep that are subsequently seen or missed by observers in a helicopter flying a standardized survey route (Bodie et al. 1995). We used this method during surveys in 1991-94 in the Kofa, Plomosa, and New Water mountains. Ground observers were placed at locations with a view of mountain areas that would be transected by the helicopter survey. Using binoculars and spotting scopes, they located any sheep that were visible and recorded time, location, group size and composition, and what behavior the sheep exhibited when the survey helicopter approached. The helicopter crew did not communicate with the ground observers, but flew a normal survey route. After completion of the survey, helicopter and ground observers compared data to determine which groups of sheep that were marked by the ground observers were subsequently seen (resighted or "recaptured) by the helicopter crew, and which groups were not seen.

A third method was used to calculate sighting probabilities that did not make use of the radiocollared animals. This method, called the simultaneous double-count, is a variation of the Lincoln-Petersen estimator in which each of 2 observers on the same side of the aircraft simultaneously marks animals for the other observer to resight (Graham and Bell 1989, Marsh and Sinclair 1989). Each observer sees and records animals independently, so that a group of sheep may be seen by observer 1 or by observer 2, or by both observers. We used the following equations, taken from Graham and Bell (1989):

$$P = \frac{B(S_1+S_2+B)}{(S_1+B)(S_2+B)} \qquad P_1 = \frac{B}{(S_2+B)} \qquad P_2 = \frac{B}{(S_1+B)}$$

where P is the probability that a group will be detected by either observer on a side, P_1 is the probability for just the front observer, P_2 is the probability for the rear observer, S_1 is the number of groups detected by the front observer only, S_2 the number seen by the rear observer only, and B the number of groups seen by both. The simultaneous double-count is a conservative estimator in that it is correcting for visibility bias for only those animals that are available to be observed. In other words, animals that cannot be seen for some reason, such as those that are hidden in a cave, are not considered as part of the equation and are never accounted for.

Home Range

We estimated home range size for each animal monitored using the minimum convex polygon (Mohr 1947) and the adaptive kernel (Worton 1989) methods. We used the software program CALHOME (Kie et al. 1994) to perform home range calculations. All data points for a given animal were incorporated into the calculation; as a result, there is a wide range in the number and temporal distribution of locations. Animals were monitored for widely different periods of time dependent on the times of an individual's capture and mortality. Home ranges were calculated regardless of sample size. Calculations of mean home range size or comparisons of home range size with other studies should use only a subset of the home ranges calculated.

The minimum convex polygon has been widely used in past studies for describing home ranges. While probably not the best method of describing an animal's home range, it does allow for comparison between studies. In addition, the minimum convex polygon is easily represented graphically. We calculated both 100% and 90% minimum convex polygons for comparisons of home ranges, with some outliers excluded.

An animal's location during a period of its lifetime can be described by a bivariate probability distribution (Kie et al. 1994). The adaptive kernel is a non-parametric method that represents a home range as the smallest area that contains a specified percentage of the probability distribution. The adaptive kemel probably provides a more realistic representation of an animal's home range than the minimum convex polygon. We calculated 90% and 60% adaptive kemel probability distributions. When running the program, grid cell size was set at 50 x 50. We let CALHOME calculate the optimum bandwidth.

RESULTS

Kofa radiocollar mark-resight

Seven surveys were conducted to measure sighting probability rates of bighorn sheep. Four surveys were flown between October 17 and November 15, 1994, and 3 more were flown between October 17 and November 14, 1996 (Table 1). Surveys were always flown at least a week apart. Helicopter flight times ranged from 9.0 to 9.7 hours in 1994 and from 7.4 to 7.8 hours in 1996. The study area was changed somewhat for the 1996 surveys by dropping 2 unproductive blocks and adding 1 block. Total number of sheep observed on surveys in 1994 ranged from 104 to 115 and in the 1996 surveys from 77 to 100. Severe drought conditions during this time period may have caused an overall decline in sheep population size. This likely accounted for the decline in the number of sheep observed during the 2 years.

Each of the survey flights resulted in a separate estimate of sighting rate. These estimates ranged from 0.35 to 0.56 in 1994 and 0.35 to 0.67 in 1996 (Table 1). Mean estimates for each year were 0.49 and 0.44. There was no significant difference in the 2 years' meanvalues ($t = 0.456$, 5 df, $P = 0.667$), so the results of both years were pooled, resulting in an overall sighting rate of 0.46 (SD = 0.118, median = 0.44, 90% CI = ± 0.09). The 90% confidence interval is 0.37 to 0.55.

Since we always knew which marked (i.e. radiocollared) animals were in the study area at the time of each survey, individual sighting probabilities could be calculated (Fig. 2). The high values at each end of the distribution represent marked animals that were either never seen (resighted) on survey, or were seen every time. Neal et al. (1993) found that the distribution of sighting probabilities of mountain sheep on their study area in Colorado was best fit by a bell shaped curve. However, they had 14 resight occasions. Many of the individuals in our study whose probabilities fall into the tails of the distribution were available for only a few resight occasions because of mortality or emigration. If we look at only those animals that were available for a minimum of 4 surveys, the distribution tends more toward a bell shape, though the sample size is reduced from 40 to 15. It is difficult to conclude what the true distribution of our data would be without having more animals available for a larger number of resight chances.

During the 7 survey occasions, 354 groups of sheep were seen and classified. Of these, 60 groups were marked (had at least 1 radiocollared sheep). Seventy-one other groups containing marked animals were missed on surveys, and 60 of these were subsequently located and classified. Group sizes ranged from 1 to 9. The distribution of group sizes was skewed heavily toward single animals, which made up 53% of the total groups seen (Fig. 3). The average group size of all sheep seen on surveys was 2.0. The average group size of the radiocollared sheep was somewhat higher at 2.3. There was a significant difference (Mann-Whitney Rank Sum Test, P = 0.006) between the average group sizes of marked sheep seen (2.9) and marked sheep that were missed on surveys (1.8). The root cause of this "group size bias" can be seen if sighting probabilities are calculated for each group size category (Table 2). In our sample, groups of size 1 and 2 had the lowest probability of being spotted and had resight rates that were nearly equal at 0.40. Groups larger than or equal to 5 had a very high probability, though not certainty, of being seen. Sample sizes of these larger groups were small. If the data for all groups of 5 or larger are pooled, the average resight rate is 0.88. Sighting probabilities for groups of 3 or 4 are intermediate. Lumping these 2 group sizes yields an average resight rate of 0.64.

Ground observer mark-resight

Seven helicopter surveys using ground observers were conducted in the Plomosa, New Water and Kofa mountains (Table 3). The sightingrate for the combined data equaled 0.45. During the 7 survey occasions, 62 groups (147 bighorn sheep) were seen and classified. Sighting rates for discrete group sizes ranged from 0.32 to 1.00 (Table 4).

Simultaneous double-count

Data sufficient for calculating the parameters of the simultaneous double-count were collected during the 7 aerial surveys in the Kofa Mountains. Results are presented in Table 5. The sighting probabilities for the front seat observer (p_1) were highly variable, ranging fiom 0.33 to 0.76, with a mean of 0.63. Those for the back seat observer (p_2) were less variable, but had a lower average of 0.46. The probability that at least 1 of the 2 left side observers will spot a group of sheep (p) ranged fiom 0.58 to 0.88 with a mean of 0.80. The configuration of observers in the helicopters currently used for surveys has 2 observers on the left side of the aircraft, and a single observer on the right side, sitting in the rear seat. The pilot sits in the right front seat position and is not used as an observer. The sighting probability that was calculated for a single observer in the left rear seat (p) is assigned to the right rear seat observer. Data collected from the 2 sides of the aircraft during a survey can be kept separate and differential observation rates applied to each side's data. In theory, if sheep in the wild are distributed equally on either side of the surveying helicopter, then an overall ship's observation rate can be calculated as the average of the left and right sides' rates: $(p + p_2) / 2 = (0.80 + 0.46)12 = 0.63$.

Immigration / emigration and habitat use

We obtained 1504 telemetry locations of 50 marked bighorn sheep (Fig. 4). Nineteen (1.26%) locations fell outside of survey polygons. Survey polygons were originally drawn to include all habitat believed to be used by bighorn sheep. Results of our radiotelemetry indicate that survey polygons do include nearly all of the habitat used by bighorn sheep. Our study area often did not contain all of the marked bighorn. Movements by bighorn sheep toward the eastern portion of the Kofa Mountains precluded some animals (24% over the course of 7 surveys) fiom being sampled in the mark-resight trials.

Home range estimates using adaptive kernel and minimum convex polygon methods for all radiocollared bighorn sheep are presented in Table 6. No tests for adequate sample size or independence of locations were made. Results are presented here to allow comparisons with other studies.

DISCUSSION

Methods by which bighorn sheep surveys are conducted have been improved largely through standardization. In order to further our understanding and interpretation of survey data, investigation of factors that are believed to influence sighting rates should continue. This study attempted to address the level of variation associated with survey data.

The observed sighting rates for individual surveys ranged from 0.35 to 0.67 for the marked sub-population. However, the level of variation appears to be less when the total number of sheep observed per survey is examined (Table 1). The small sample size of radiocollared animals may explain the observed difference in variability between the 2 data sets. Direct comparison of the level of variation associated with the sighting rates and the total number of bighorn sheep observed is not offered because of a suspected decline in the number of animals available from 1994 to 1996. We documented 20 mortalities among the radiocollared sample during the course of the study. A prolonged drought is believed to have caused the rate of mortality observed in the population.

The results of the Lincoln-Petersen estimate yields an overall estimate of 0.46 (90% C.I. $\pm$ 0.09). This estimate of visibility bias can be used to estimate population size fiom the total number of animals observed on a standardized survey (Table 7). We attempted to control as many variables (survey area, observers, time of year, survey intensity) through standardization of the survey. However, there are other variables (group size, behavior, topography, vegetation) over which we have no control. These variables (both controlled and uncontrolled) can lead to bias when this observation rate (0.46) is applied elsewhere.

One of the assumptions of our population estimator is that animals observed during the survey are representative of the population. However, in this study we observed that the average group size of the marked animals seen on surveys was significantly larger than the average group size of marked animals missed on surveys. This difference can be explained by the observed probabilities for discrete group sizes. More small groups are missed by observers than large groups. This group size bias can greatly influence the accuracy of the population estimate. This method derived the estimate of 0.46 from the number of groups of bighorn sheep detected during the survey. Since the detected group size is biased towards larger groups, the resulting estimate of population size is inflated.

However, we can correct for this bias. The group size specific observation probabilities can be used in an alternative population estimator:

$$\sum_{1}^{n} (s_i / r_i) i,$$

where s_i is the number of groups of size i in the survey, and r_i is the specific observation rate for groups of size i.

This estimator corrects for group size bias and is more conservative than the simple visibility bias estimator. Using the 7 Kofa surveys as examples, this method lowered population estimates an average of 11% (range 4% to 15%) fiom the estimates obtained by using the derived correction factor of 0.46 (Table 7).

We also detected the group size bias in data fiom surveys that used ground observer-marked bighorn sheep (Table 5). This method yielded similar results as the method using radiocollars in the Kofa mountains (Table 2) for groups ranging in size fiom 1 to 4. Since the average group size observed during aerial surveys on the KNWR equaled 2.0, we believe further refinement of the sighting rate probabilities should be focused on small groups (1 to 4). Adjustments for bias among the small group sizes will have the greatest impact on the population estimate.

Because of the effect of group size bias on our surveys, the actual average group size of bighorn sheep on KNWR is not known. We attempted to obtain a sample of marked groups that was representative of the distribution of group sizes in the population, but our data suggested that we may have sampled individuals more likely to be found in larger than average groups (average of 2.3 in the marked sample and 2.0 in the marked and unmarked samples combined). This may be due in part to the manner in which individuals were selected for capture. Although we used ground observers to locate bighorn sheep for capture, the same visibility bias associated with helicopter surveys and group size may have influenced the sampled (marked) group size detected by ground observers. In addition, we had a preponderance of females in the sample due to the initial under-sampling of males and radiocollar failure among the male sample (4 of 6 radio transmitters on males failed after the first year). Our data indicates male only groups (1.2) tend to be smaller than female only groups (1.4). Therefore, the under-sampling of males could result in a higher than expected average marked group size.

Our results are based on use of the Lincoln-Petersen model. This model has several assumptions that must be met to obtain unbiased estimates. The assumption of closure (immigration/emigration, and/or mortality) was not believed to be violated because all radiocollared animals were located (marked) the day before each of the 7 resight surveys. Another assumption is that all animals have an equal probability of recapture. Although Neal et al. (1993) demonstrated that heterogeneity of recapture probability was not a problem in their study population, our data were inconclusive. However, examination of our data suggested that additional surveys would result in a more homogeneous distribution.

We offered 3 models for comparison: Lincoln-Petersen sighting rate derived from combining all groups, sighting rates derived from discrete group sizes, and the simultaneous double-count. We believe the discrete group size sighting rates derived from the radiocollared sample yielded the best estimate of the population because this method addresses group size bias. The 2-helicopter double-count and the combined Lincoln-Petersen estimate do not account for the sample bias associated with group size, possibly resulting in an over-estimation of population size. The simultaneous double-count yields an overly conservative estimate.

We advise using caution when applying the group size sighting rates derived here in habitats that differ significantly from the KNWR. In other habitats, the simultaneous double-count and ground observer mark-resight methods could be used as inexpensive alternatives to putting radiocollars on bighorn sheep and should yield useful results when their known biases are taken into account.

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Table 1. Results of bighorn sheep resight surveys in the Kofa Mountains, Anzona, 1994 and 1996.

Survey Date	Sheep Observed	Flight Time(hr)	Sheep/hr	Marked Groups Seen	Marked Groups Avail	Sighting Rate
10117/94	107	9.0	11.9	7	20	0.35
10124194	109	9.7	11.2	7	18	0.39
11/01194	115	9.1	12.6	9	19	0.47
11/15/94	104	9.2	11.3	10	18	0.56
10116/96	93	7.4	12.6	7	20	0.35
10128196	100	7.8	12.8	12	18	0.67
11/14/96	77	7.4	10.4	8	18	0.44

Table 2. Resight probabilities for different group sizes among marked sheep during aerial surveys in the Kofa Mountains: Anzona, 1994 and 1996.

Group Size	Resight Rate	Sample Size (n)		Group Size	Resight Rate	Sample Size (n)
1	0.40	52		5	0.83	6
2	0.39	31		6	1.00	3
3	0.67	15		7	1.00	3
4	0.57	7		8	0.67	3

Table 3. Results of surveys using ground observer marked groups of bighorn sheep in the Plomosa, Kofa, and New Water Mountains, Anzona.

Survey Year	Marked Groups Seen	Marked Groups Avail	Sighting Rate
1991-94[1]	20	44	0.45
1992[2]	8	18	0.44
Combined	**28**	**62**	0.45

[1] Plomosa Mountains
[2] Kofa Mountains and New Water Mountains

Table 4. Resight probabilities for different group sizes among bighorn sheep observed from ground stations in the Plomosa, New Water, and Kofa mountains, Arizona.

Group Size	Resight Rate	Sample Size (n)		Group Size	Resight Rate	Sample Size (n)
1	0.32	25		5	0.33	3
2	0.41	17		6	1.00	3
3	0.63	8		7	1.00	1
4	0.75	4		9	0.00	1

Table 5. Survey results and observation rates based on simultaneous double-count estimation procedures.

	S_1	S_2	B	n	p_1	p_2	p
10117/94	5	6	3	14	0.33	0.38	0.58
10124194	12	7	11	30	0.61	0.48	0.80
11101/94	10	4	10	24	0.71	0.50	0.86
11115194	7	7	4	18	0.36	0.36	0.60
10116/96	18	4	12	34	0.75	0.40	0.85
10/28/96	15	5	16	36	0.76	0.52	0.88
11/13/96	5	3	6	14	0.67	0.55	0.85
TOTAL	**72**	**36**	**62**	**170**	**0.63**	**0.46**	**0.80**

S_1 = groups seen by front observer only; p_1 = probability of front observer seeing a group
S_2 = groups seen by rear observer only; p_2 = probability of rear observer seeing a group
B = groups seen by both observers; p = probability of either observer seeing a group
n = sample size

Table 6. Home range size for bighorn sheep on the Kofa National Wildlife Refuge, Yuma County, Arizona, 1994-1997.

		HOME RANGE ESTIMATOR			
Animal		Adaptive Kernal (ha)		Minimum Convex Polygon (ha)	
No.[1]	n	90%	60%	100%	90%
1	33	3915	1563	4837	1912
2	39	1093	488	2366	629
3	25	570	156	676	272
4	53	1557	366	3991	829
5	54	1066	436	1115	734
6	54	3159	824	3131	2078
8	47	1001	338	1346	722
9	24	504	138	358	250
10	56	2351	746	2418	1550
11	54	1009	380	1136	713
12	48	4455	997	3671	2031
13	24	1152	324	2056	1002
15	2	-	-	-	-
15A	54	1339	336	1323	798
16	42	987	415	1141	651
17	17	413	101	450	213
18	52	3295	686	5544	1941
19	55	1044	339	3201	697
20	35	2254	921	3008	1987
21	55	581	254	822	433
22	56	630	205	969	435
22A	34	3603	1380	3438	1781
23	22	1850	582	1016	690
24	54	2596	648	3004	1447
25	16	814	233	659	468
26	7	1584	1070	593	593
27	16	1037	387	912	550
28	7	535	265	545	545
29	16	1206	232	869	564
30	16	614	188	529	293
31	16	1057	125	872	688
32	16	799	145	623	411
33	16	1387	262	1536	1146
34	16	1302	442	833	587
35	16	80	44	50	45
36	8	653	419	310	310
37	16	983	249	599	455
38	14	1962	417	1233	804
39	10	2734	963	1373	842
40	14	1567	884	1288	1028
41	16	5815	1000	5183	3793
42	15	1174	260	773	545

Table 6. (Cont.) Home range size for bighorn sheep on the Kofa National Wildlife Refuge, Yuma County, Arizona, 1994-1997.

Animal No.[1]	n	HOME RANGE ESTIMATOR Adaptive Kernal (ha) 90%	60%	Minimum Convex Polygon (ha) 100%	90%
43	8	-	154	404	404
44	16	2353	587	1519	1343
R1	30	7288	2338	5973	4134
R2	36	3845	2151	5680	2584
R3	29	19820	7373	22680	17870
R4	35	13230	2011	12660	5471
R5	53	2313	995	2417	1556
R7	35	2128	444	2007	1044

[1] Numbers beginning with “R” signify males

Table 7. Population estimates for the Kofa Mountains study area derived from 3 Qfferent estimators.

Survey Date	Estimator #1	90% CI	Estimator #2	Estimator #3
10/17/94	232	(195-289)	216	170
10/24/94	237	(198-295)	201	173
11/01/94	250	(209-311)	239	183
11/15/94	226	(189-281)	200	165
10/16/96	202	(169-251)	177	148
10/28/96	217	(182-270)	196	159
11/14/96	167	(140-208)	142	122

Estimator #1 is the Visibility Bias estimator using radiocollared sheep

Estimator #2 is the Group Size Bias estimator using separate group size sighting rates

Estimator #3 is the Simultaneous Double-count estimator

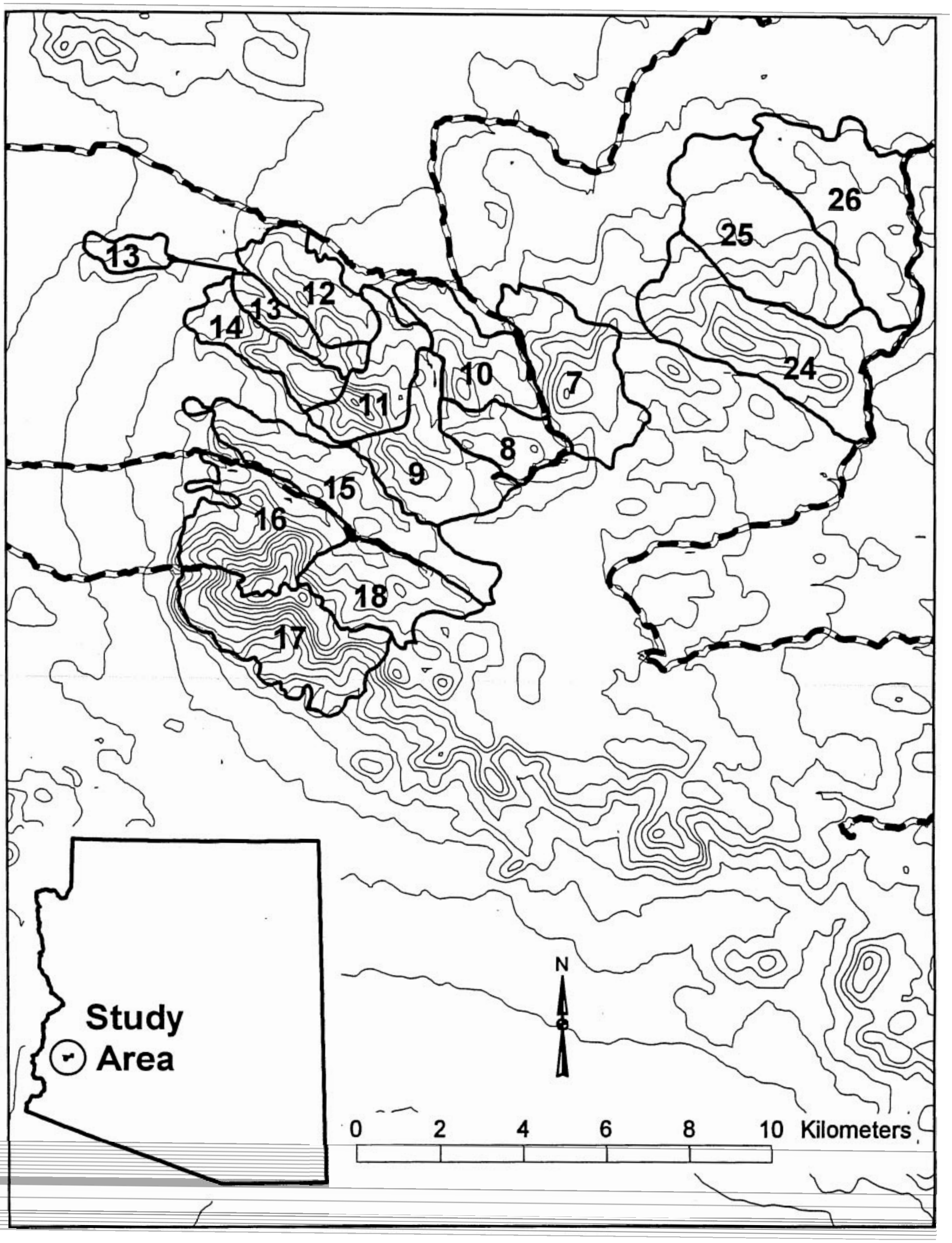


Figure 1. Study area in Kofa Mountains, Kofa National Wildlife Refuge. Standardized survey polygons are indicated by numbered blocks overlying topographical features.

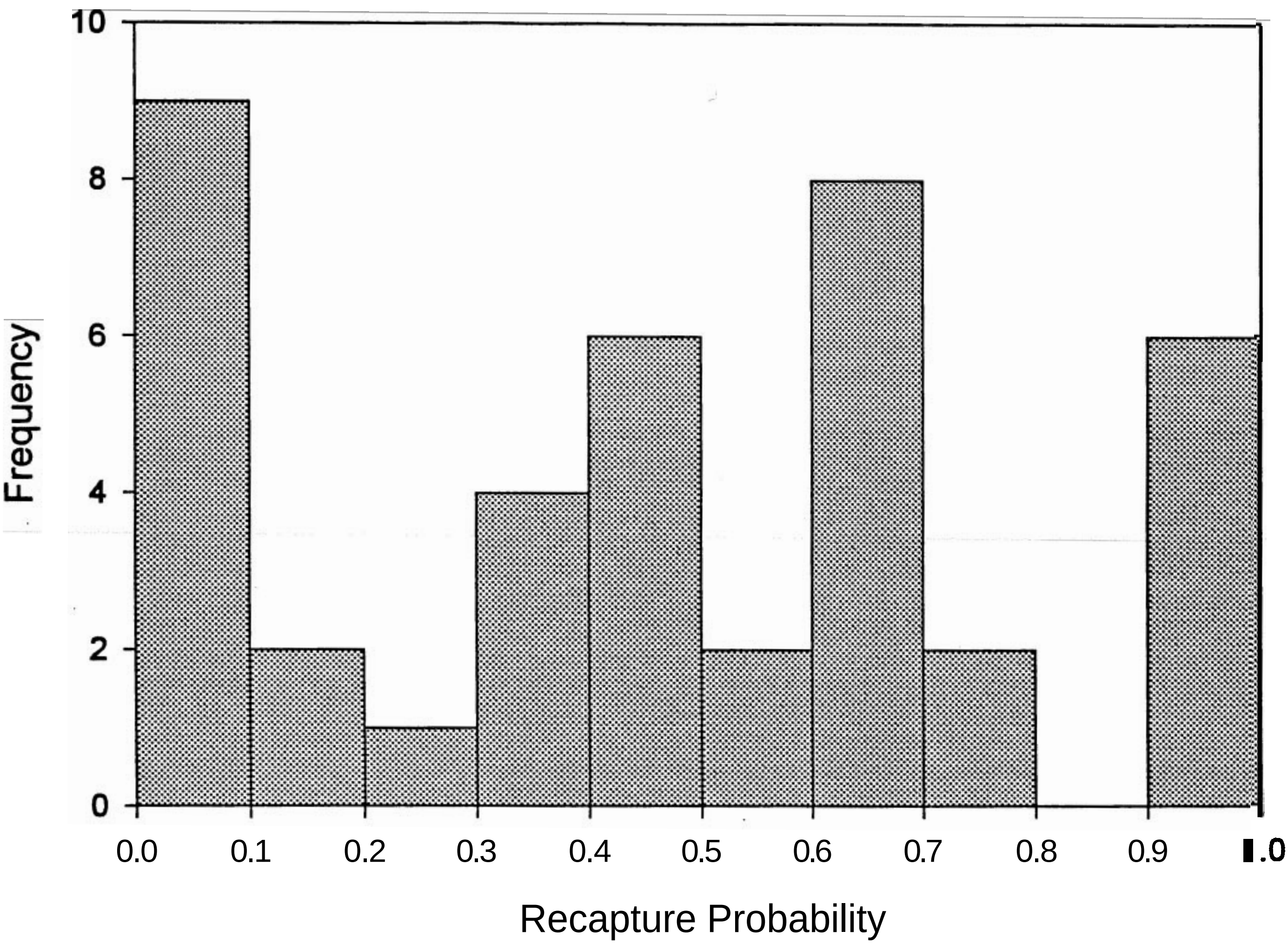
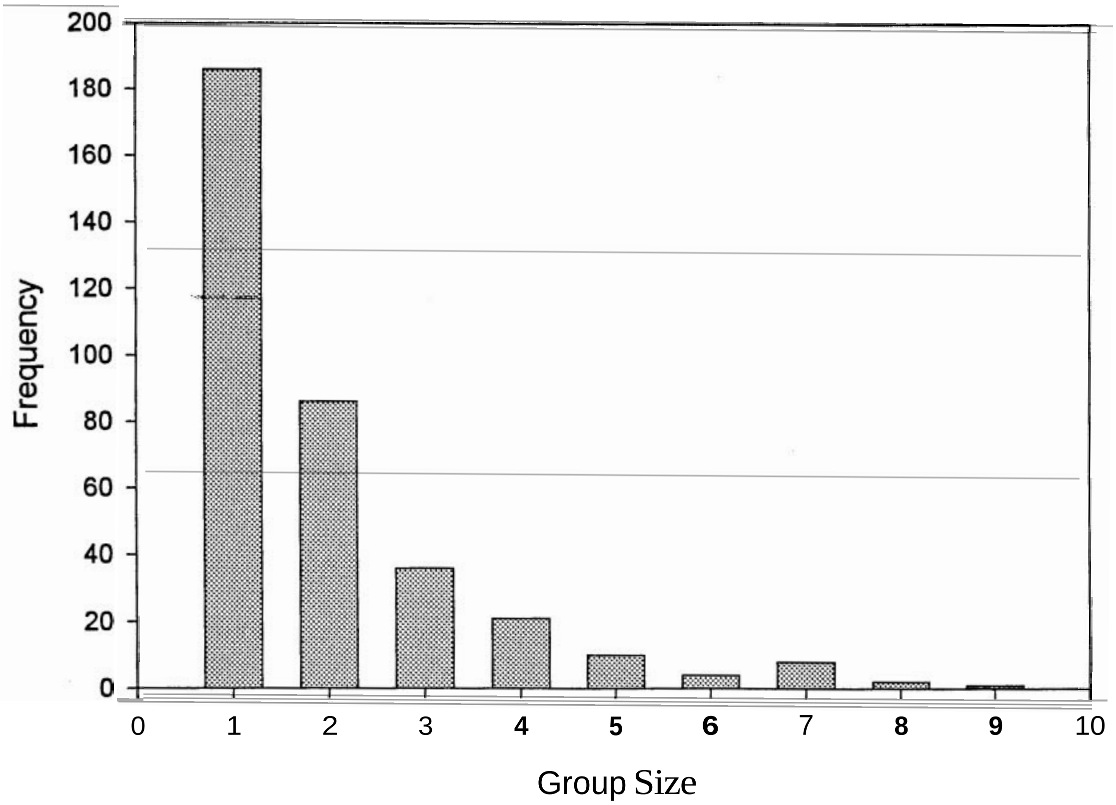


Figure 2. Frequency of individual recapture probabilities during 7 aerial surveys in the Kofa Mountains, Arizona, 1994 and 1996. Individual sheep were available for 1 to 7 resight occasions.



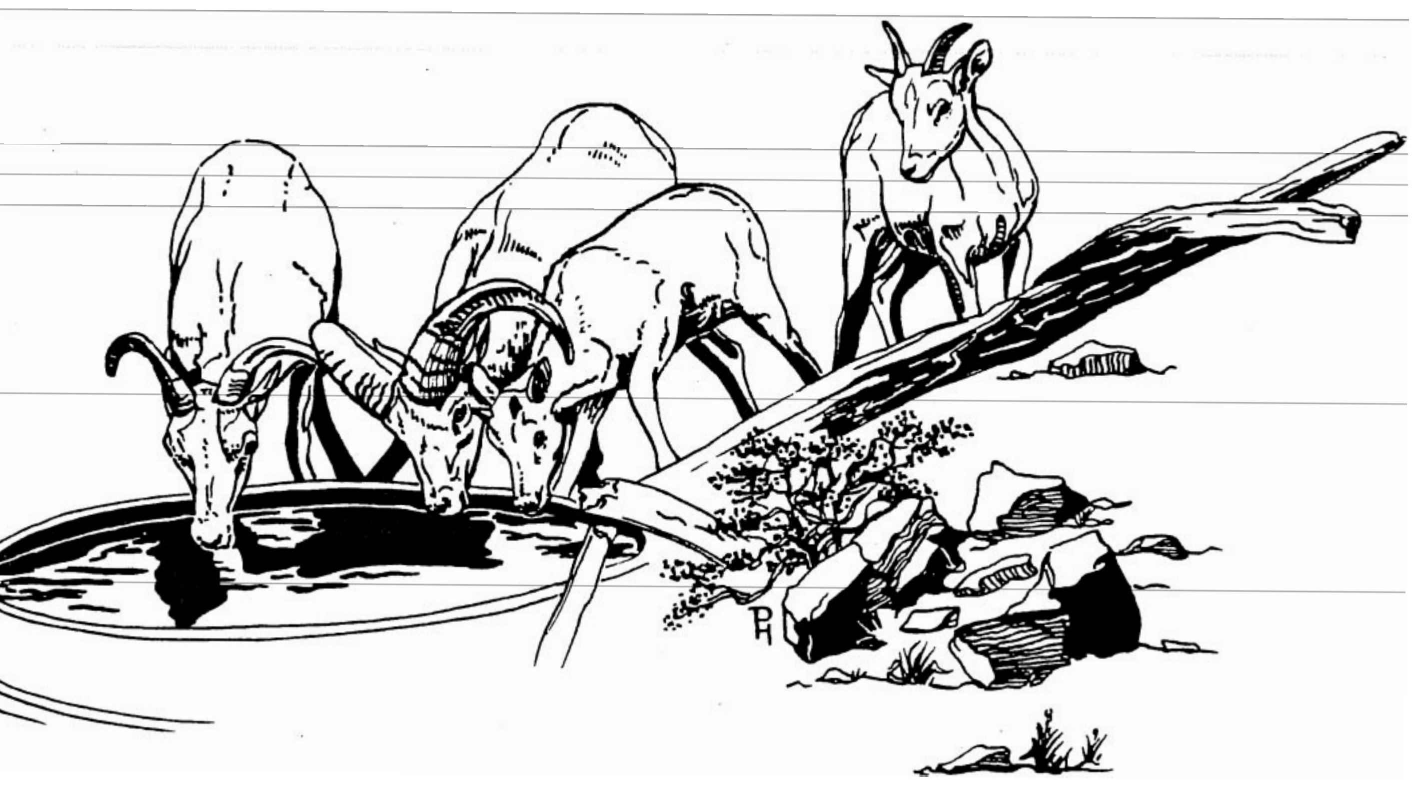


Figure 3. Frequencies of group sizes of all bighorn sheep observed during 7 aerial surveys in the Kofa Mountains, Arizona, 1994-1996.

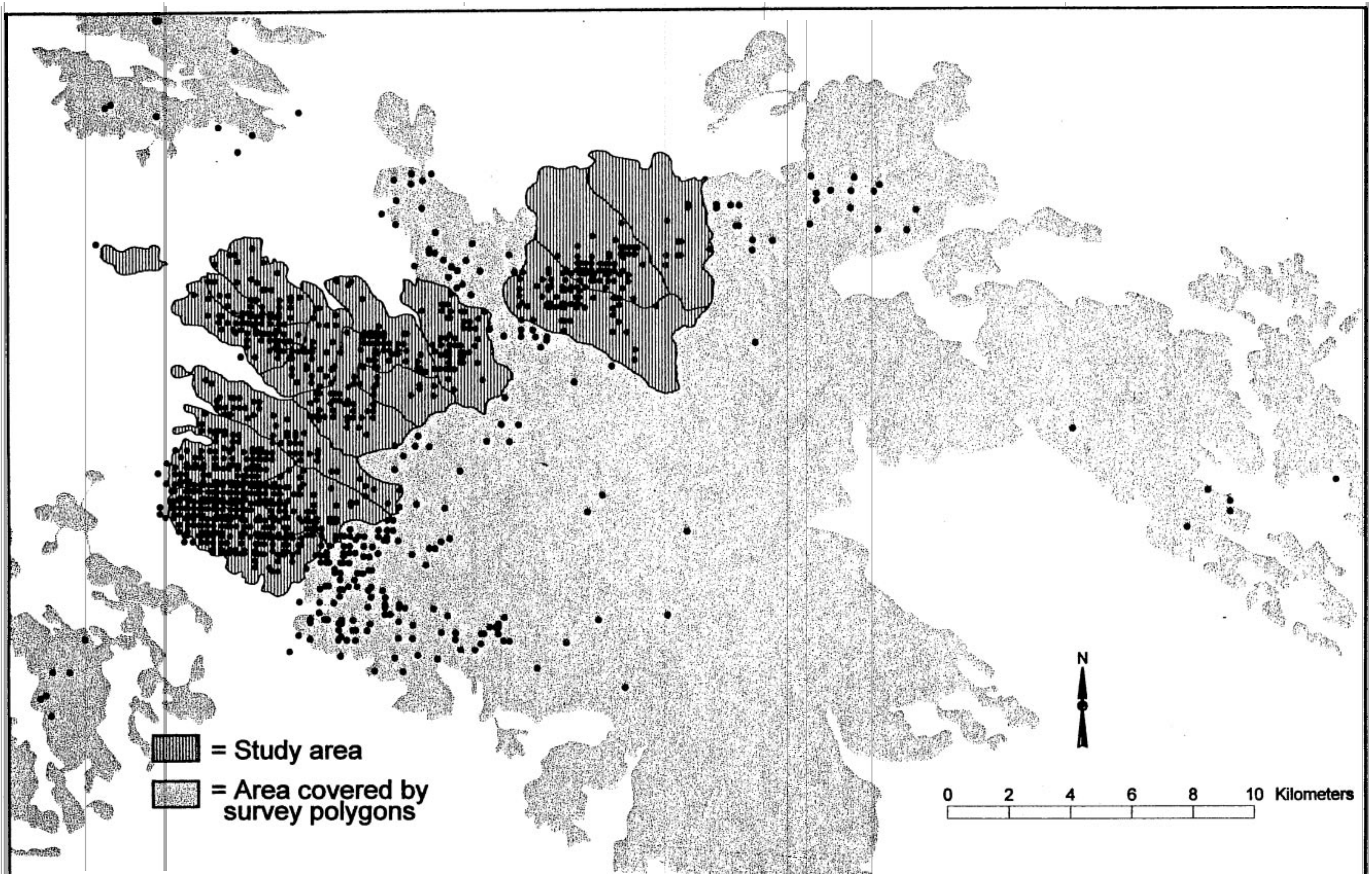


Figure 4. Fixed-wing telemetry locations of radiocollared bighorn sheep in the Kofa Mountains, Kofa National Wildlife Refuge.

STATUS AND FUTURE OF A NATIVE DESERT BIGHORN SHEEP POPULATION IN SOUTHEASTERN ARIZONA

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Abstract: We evaluated the long term viability of a population of desert bighorn sheep (*Ovis* canadensis *mexicana*) using information on demography, movements, habitat, and human impacts in the Silver Bell and West Silver Bell mountains, Anzona. The area is composed of ≥3 discrete habitat complexes, 1 of which has been increasingly impacted by open pit copper mining. Radio-instrumented rams traveled throughout the area, while ewes remained in discrete sub-populations. Aerial survey information over the past 12 years indicate a stable population, however numbers of sheep seen in the West Silver Bell Mountains have declined. Loss of this sub-population seems imminent unless natural immigration or artificial translocations occur. Recruitment and survival estimates suggest a stable total population, however local population reductions may reduce the overall population. Future recruitment and survival may decrease as a result of recent habitat losses and an attendant increase in human activity. Mountain lion *(Puma* concolor) predation was the most significant source of mortality for both rams and ewes. Predation, habitat loss, and human disturbance represent the greatest threats to this native population of desert bighorn sheep.

INTRODUCTION

Desert bighorn sheep numbers in Anzona declined during the early part of this century, reaching an estimated low of 2,500 in the 1950s (Russo 1956). Although numbers have increased due to intensive management, many populations are near what many researchers would consider minimum levels required to ensure long term viability (Krausman and Leopold 1986). Furthermore, highways, agriculture, mines, and other aspects of human encroachment have isolated these small populations (Gionfriddo and Krausman 1986, Cunningham and Hanna 1992). Isolation due to habitat fragmentation can adversely affect desert bighorn sheep populations by reducing resource availability and inhibiting genetic exchange (Duncan 1960, DeForge et al. 1979, Bleich et al. 1990). Bighorn sheep populations tend to be stable within large blocks of high quality habitat (Berger 1990). Wilson et al. (1980) stated that "... all areas utilized by desert bighorn sheep are essential to their continued survival."

The desert bighorn sheep population of the Silver Bell and West Silver Bell mountains is the last viable native desert bighorn sheep population in southeastern Anzona. Due to industrial, urban, and agricultural developments this population exists on a nearly isolated island of habitat. This area has been increasingly impacted by open pit copper mining. Renewed mining activities, which include the development of a new pit, coupled with an attendant increase in human activity, pose a serious threat to this native sheep population.

Human disturbance has been attributed as a factor in the decline of desert bighorn sheep populations, including those of the Santa Catalina Mountains, north of Tucson (Gionfriddo and Krausman 1986). If adequate precautions are not taken, the desert bighorn sheep population of the Silver Bell and West Silver Bell mountains may also be in jeopardy. We investigated demography, movements, and habitat use of desert bighorn sheep in the Silver Bell and West Silver Bell mountains. We used these data to evaluate the long term viability of the desert bighorn sheep population, determine the potential effects of human impacts, and design management options to promote the continued existence of this population.

This project benefitted from the assistance of several individuals and institutions, including the Arizona Desert Bighorn Sheep Society (ADBSS), the southwest mining &vision of ASARCO Incorporated, the Bureau of Land Management (BLM), the Foundation for North American Wild Sheep (FNAWS), and the Arizona Game and Fish Department (AGFD). Daniel Brooks, Bill Carrel, Rick Gerhart, and Dan Smith assisted with data collection. We would also like to acknowledge the support of Richard Ockenfels, Ray Schweinsburg, and Jennifer Wennerlund for their assistance with study design and data analysis.

STUDY AREA

The Silver Bell study area (SBSA) encompasses 227 km^2 and consists of an interconnected mountain complex comprised of the Silver Bell and West Silver Bell mountains (Fig. 1). The SBSA is composed of 50% BLM land, 22% State land, and 28% private land; 96% of the private land is owned by the ASARCO mining company. The SBSA encompasses an elevational range from approximately 500 m at the lowest elevations to 1,290 m at Silver Bell Peak. Average annual precipitation is 31.8 cm and the rainfall pattern is bimodal, with peaks in late summer (Jul-Sep) and winter (Dec-Feb). Mean summer temperatures are high with daytime highs commonly in excess of 38 C from June through September. Winter daytime high temperatures range from 15 to 20 C (Sellers and Hlll 1974).

Vegetation communities within the SBSA are typical of Sonoran desert scrub and dominated by creosote (Larrea tridentata) and bursage (Ambrosia deltoidea) at the lowest elevations, and foothill palo verde (C. microphyllum), saguaro (Carnegiea gigantea), and various prickly pear and cholla cacti (Opuntia spp.) at the upper elevations (Turner and Brown 1982). Jojoba (*Simmondsia chinensis*)-mixed scrub, a chaparral-like community dominated by jojoba, also occurs at some of the upper elevation sites, especially on north facing slopes (Turner and Brown 1982).

Livestock grazing and mining are the primary land uses within the SBSA. Most grazing occurred on BLM and State Land Department allotments. Livestock were concentrated around water sources located at lower elevations. Much of the SBSA has been impacted by prior mining activity. Shafts, adits, mine dumps, and pits are scattered throughout the SBSA, with the greatest concentration being at and near the ASARCO-owned Silver Bell Mine near Silver Bell Peak. The Silver Bell Mine is an open pit copper mine encompassing approximately 7,500 ha located on the southern and eastern edge of the Silver Bell Mountain areas. Impacts by the Silver Bell Mine cover approximately 1,600 ha, including pits, leach dumps, tailing piles, haul roads, and other developed areas. There was no active ore extraction at Silver Bell Mine during our study, however, there was some mineral leaching activity throughout the study.

METHODS

Twenty-two desert bighorn sheep (11m, 11f) were captured and fitted with motion sensing radiotransmitters. Each radiocollared (marked) desert bighorn sheep was located from the air and ground ≥50 times annually between September 1993 and February 1996. All locations were platted on U. S. Geological Survey (USGS) 7.5” topographical maps and Universal Transverse Mercator (UTM) coordmates for each location were recorded.

Each year was divided into a lambing and breedmg season, based upon the earliest known lambing date (Nov. 22) within the Silver Bell Mountains (AGFD unpubl. data). Ground locations were equally distributed between lambing (Nov 22 - May 17) and breedmg (May 18 - Nov 21) seasons. Three study area subunits were delineated based on distinct areas of desert bighorn sheep use determined from observations of marked ewes (Fig. 1). Open pit mining had occurred only within the Silver Bell Peak subunit (SBP). The SBP subunit encompassed all of the ASARCO land owned prior to March 1992 (the Silver Bell Mine property). This subunit received the highest level of human use and habitat alteration (Fig. 1). The Ragged Top Peak (RTP) and West Silver Bell (WSB) subunits were located to the north and west of this area (Fig. 1). No interchange of marked ewes was observed among the 3 subunits.

Each ground location was classified each desert bighorn sheep observed into age and sex categories following Geist (1971). Each group of desert bighorn sheep observed was classified as either rams (all male), mixed (males and females), or ewes (all females including those with lambs and yearlings). Lambs:100 ewes and yearlings:100 ewes were calculated to estimate productivity for each subunit. These estimates were based upon ground observations of marked and unmarked ewes. During each lambing season, the number of lambs:ewe for each group of desert bighorn sheep observed to estimate lambs:100 ewes was calculated for each subunit. As an index of recruitment, the same survey method was used to estimate yearlings:100 ewes for each subunit. Productivity estimates among ewe groups within different study area subunits was compared using Kruskal-Wallis ANOVA and Mann-Whitney Utests (Zar 1984).

During the breeding seasons of 1994 and 1995, helicopter surveys were conducted in which all desert bighorn sheep observed (marked and unmarked) within SBSA were recorded. A Lincoln-Peterson index of aerial survey data was used each year to estimate the total population (Seber 1982). We calculated 95% confidence intervals of population estimates for each year to describe the upper and lower limits of our estimates. We used results of annual helicopter surveys collected over the last 14 years to establish population trends within SBSA.

All radio transmitters were monitored for mortality pulse rates 3-5 times/week and mortality sites were investigated to determine the cause and date of death. Moralities were categorized as disease, predation, hunter harvest, or unknown. Predator identity was determined fiom kill remains using criteria fiom Woolsey (1985) and Shaw (1990). The software program MICROMORT (version 1.1; Heisey and Fuller 1985) was used to calculate gender-specific survival rates fiom radiotelemetry data. We compared survival rates between mined and unmined subunits, and between sexes using Z tests (Heisey and Fuller 1985).

Annual home-range characteristics for each were estimated marked desert bighorn sheep with the software program Home-range (Ackerman et al. 1990) using the minimum convex polygon (MCP) method (Hayne 1949). We calculated 100% (home-range) and 50% (core area) MCP for each marked desert bighorn sheep for which we had $\geq$50 locations (Bekoff and Mech 1984). Average distance moved was also calculated between consecutive locations ($\bar{x}$ movement) as a measure of movement within home-ranges. To identify potential effects of mining on desert bighorn sheep movements we compared home-range characteristics between sexes and among ewes of different subunits using Mann-Whitney U tests.

We identified 2 key habitat types that are important to desert bighorn sheep: lambing-nursery habitat, and pre and post-rut ram habitat. To identify lambing-nursery habitat, we observed each marked ewe once a week during the lambing season (Nov 22-May 17). To identify lambing sites, we plotted each location where a marked ewe was first observed with a newborn lamb; we used criteria fiom Hansen and Deming (1980) to identify newborn lambs. We also plotted all locations of ewes (marked and unmarked) observed with lambs during the lambing season and recorded these locations as nursery sites. To identify pre- and post-rut habitat used by rams, we recorded all locations of mature (class II-IV) rams not associated with ewes during the lambing season as bachelor ram locations. To quantitatively delineate high use areas within key habitats, we calculated 30% harmonic mean use areas (HMUA) for all bachelor ram and lambing-nursery locations. We overlaid a map of proposed mining on the lambing-nursery 30% HMUA and bachelor ram 30% HMUA to predict the potential impacts of the planned habitat alterations on the desert bighorn sheep population.

RESULTS

We collected 1,957 locations of the 22 marked animals; 649 from the air and 1,308 (85% visual) from the ground. Aerial and ground triangulation (non-visual) locations were used only for home-range and movement analyses. Temporal distribution of locations was as follows: 7% in 1993, 42% in 1994, 47% in 1995, and 4% in 1996. Marked rams comprised 46% of all locations and marked ewes comprised 54%.

We surveyed and classified ewe groups on 274 different occasions during the lambing seasons of 1993-94 (n = 90), 1994-95 (n = 112), and 1995-96 (n = 72); 48% were in SBP, 46% were in RTP, and 6% were in WSB subunits. For the lambing season of 1993-94, there were no significant differences in lambs:100 ewes or yearlings:100 ewes among ewe groups of different subunits (Table 1). We did not observe any ewe groups within the WSB subunit during the lambing seasons of 1994-95 and 1995-96. During the 1994-95 lambing season, lambs:100 ewes were higher and yearlings:100 ewes were lower for SBP than for the RTP subunit (Table 1). For the lambing season of 1995-96 there were no significant drfferences in lambs:100 ewes or yearlings:100 ewes between SBP and RTP-WSB subunits (Table 1). Desert bighorn sheep population estimates for SBSA were 100 (CI = 62 - 138) in 1994, and 67 (CI = 46 - 89) in 1995. Sex ratios determined from helicopter surveys were (50:100) in 1994, and (22:100) in 1995. Total number of sheep observed during annual helicopter surveys conducted over the last 14 years ranged from 35 to 74 (x = 43.4, s = 9.9, Table 2).

Nine of 22 (11 M, 11 F) marked desert bighorn sheep died during the study; 2 mortalities were attributed to drsease (1 M, 1 F), 2 rams were harvested by hunters, and 5 animals (2 M, 3 F) were lulled by mountain lions *(Puma concolor)*. Mountain lion predation was the largest source of mortality for both rams (0.12) and ewes (0.15). Survival rates for marked rams within SBSA were 0.82 (CI = 0.56 - 1.0) in 1994 and 0.65 (CI = 0.40 - 1.0) in 1995. Survival rates for marked ewes within SBSA were 0.75 (CI = 0.50 - 1.0) in 1994 and 0.78 (CI = 0.56 - 1.0) in 1995. There were no differences in survival rates between rams and ewes in 1994 (Z = 1.149, P = 0.125). In 1995, the ram survival rate was significantly lower than the ewe survival rate (Z = 3.354, P = 0.001). Survival rates for ewes within WSB (0.14, CI = 0.01 - 1.0) were lower than for RTP (1.0) and SBP (1.0, Z = -6.405, P < 0.001) in 1994. There were no marked ewes within WSB during 1995. Survival rates of marked ewes did not differ between RTP (0.78, CI = 0.48 - 1.0) and SBP (0.79, CI = 0.50 - 1.0, Z = 0.158, P = 0.444) in 1995.

We calculated annual home-ranges (100% MCP), core areas (50% MCP), and $\bar{x}$ &stance moved between consecutive locations for 18 of 22 marked desert bighorn sheep within SBSA (9 M, 9 F). Rams had significantly larger home-ranges (U = 9.0, P = 0.005), core areas (U = 0.0, P < 0.001), and $\bar{x}$ &stances between consecutive locations (U = 2.0, P < 0.001) than ewes (Table 3). Ewe home-ranges were restricted within subunit boundaries, while 5 of 9 ram home-ranges contained portions of all 3 subunits (Fig. 2). In 1995, a marked yearling ram (#71) moved between SBP and the Waterman Mountains (1.6 km to the south) on 4 occasions. This ram was also aerially located once in the Roskruge Mountains that are 3 km south of the Waterman Mountains. This ram was observed with ewes on 5 of 6 occasions when it was in the Waterman Mountains.

There was only 1 marked ewe within WSB for which we had enough locations to calculate home-range characteristics, therefore we only used data from RTP and SBP subunits for home-range comparisons between ewes from different subunits. Home-ranges were not significantly different between ewes of SBP and RTP subunits (U = 3.0, P = 0.149). However, core areas (U = 0.0, P = 0.021) and $\bar{x}$ distances between consecutive locations, (U = 0.0, P = 0.021) were greater for ewes of SBP than those of RTP (Table 3).

The total area proposed to be impacted within the newly acquired ASARCO property was 2.7 km^2. The percent overlap of key habitats with the proposed mine (main pits, haul roads, and leach dumps) is 10% bachelor ram HMUA and 0% lambing-nursery HMUA (Fig. 3). Bachelor ram groups made up 95% of the locations obtained within the proposed mine area throughout both years.

DISCUSSION

We found productivity estimates to be significantly different among subunits during 1 of 3 lambing seasons. The 1994-95 productivity estimates indicated that lambing rate was higher and yearling rate was lower within the SBP subunit. These data are inconclusive relative to the impacts of the closed mine on desert bighorn sheep herd productivity. Because the mine was inactive during the study period, we were unable to measure the effects of active mining on herd productivity. Spraker et al. (1984) found that increased atmospheric dust associated with dam construction predisposed lambs to pneumonia and, ultimately, increased neonate mortality.

Because we collected data for lambs:100 ewes estimates over a 6-month period each year there was a potential for bias due to differential neonate mortality. Neonate mortality occurred at an unknown rate during each lambing season and had an unknown effect upon lambs:100 ewes estimates. If neonate mortality was not consistent across the study area then estimates of lambs:100 ewes would be biased among subunits.

Given the wide confidence intervals, the population estimates for 1994 and 1995 are inconclusive relative to the stability of the desert bighorn sheep population within the SBSA. However, the total number of desert bighorn sheep observed for each flight was similar to surveys conducted over the past 14 years, suggesting a stable population. Lambing rates were consistent between years and the small difference in lambs:100 ewes for 1993-94 and yearlings:100 ewes for 1994-95 suggested higher recruitment rates than that reported elsewhere in Arizona by Remington (1989). Berger (1990) found that bighom sheep populations with <50 individuals were more susceptible to rapid extinctions than larger populations. The lower ranges of the population estimates for SBSA are close to this minimum size considered necessary for long term viability. Because of their relatively low numbers the desert bighorn sheep of WSB may be in danger of extirpation. The ewe population of WSB was low and we were unable to classify enough ewe groups to make productivity estimates. Quality of habitat within WSB was lower than other subunits in that the topography was less rugged, vegetation types were of lower quality, and permanent water sources were not as numerous. Counts obtained from helicopter surveys conducted over the last 14 years indicate that WSB once supported a larger population of ewes (AGFD unpublished data).

We found no significant Qfference in survival rates between RTP and SBP. This finding suggests that the presence of the closed mine in the SBP subunit did not alter survival rates for adult ewes. The steep, open terrain associated with the mine pits may provide security from predation, especially if predators are more sensitive to human presence. Survival rates within the WSB subunit were lower than both SBP and RTP. The WSB subunit had less escape terrain than both of the other subunits, which could make desert bighorn sheep within WSB more susceptible to lion predation.

Mountain lion predation was the largest source of mortality among all sexes and subunits. Mountain lions killed both rams and ewes of all age classes. Mortal@ from lion predation was nearly as great as the total mortality reported by Cunningham and deVos (1992), and Remington (1989). We observed 2 lions during normal ground telemetry efforts (1 female and 1 cub), and mine workers often report sightings. The only 2 marked ewes within WSB Qed within the first year of the study; both mortalities were attributed to lion predation. We also found 2 unmarked desert bighorn sheep carcasses in RTP that were piled in partially buried "caches" which was suggestive of lion predation. Removal of lions may temporarily reduce predation and increase survival of desert bighorn sheep within SBSA. While some researchers have maintained that heavy localized harvest of lions could reduce population densities, Cunningham et al. (1995) questioned the effectiveness of this approach in reducing predation on livestock. Clearly more information is necessary to evaluate the efficiency of this strategy to reduce desert bighorn sheep mortality.

Bighorn sheep move in response to seasonal changes in forage and water availability and to the reproductive cycle (Geist 1971, Simmons 1980, Festa-Bianchet 1986). During summer, rams move into more precipitous terrain to find ewes and initiate rut. Such seasonal movements usually result in large home-ranges. In Arizona, home-ranges of desert bighorn sheep rams may encompass up to 400 km^2 (Cochran et al. 1984). The difference in home-range sizes between rams and ewes in SBSA was similar to that reported in other desert bighorn sheep studies in Arizona (Simmons 1969, Witham and Smith 1979, Krausman et al. 1989, Cunningham and Hanna 1992). The relatively small ewe home-ranges may suggest that the areas contained high quality habitat; individuals had to travel less to meet their physiological needs for food, water, and cover. However, for rams, the larger home-ranges appear to reflect the isolated nature of ewe sub-populations with individual rams traveling relatively long distances to breed. Ewes of the SBP subunit had larger core areas and $\bar{x}$ distances between consecutive locations than those of WSB and RTP. This could indicate increased human disturbance or poorer quality habitat within SBP. Results of a habitat quality assessment by Bristow et al. (1996) does not support the latter.

Marked ewes did not move between subunits within SBSA during our study; therefore, these areas may represent isolated sub-populations of ewes. If so, intermountain movements by rams would be the only source of genetic exchange among these sub-populations. Long-range movements (up to 73 km) of rams during the rut have been well documented (Witham and Smith 1979, Ough and deVos 1984, Snuth et al. 1986). The isolated and fragmented nature of desert bighorn sheep habitat may predispose populations to problems associated with inbreeding (Hansen 1980, Bleich et al. 1990). These long range movements between mountain ranges may be necessary to maintain genetic diversity within populations (Schwartz et al. 1986).

Schwartz et al. (1986) argued that only a low level of exchange is necessary to maintain genetic diversity within small populations (<200 individuals); as few as 3 reproductively active migrants/generation. Using these criteria, the desert bighorn sheep of the Silver Bell and West Silver Bell mountains may not be susceptible to problems associated with genetic isolation if the current rate of interchange is not significantly reduced. The movement of ram # 71 between the Silver Bell, Waterman, and Roskruge mountains provides evidence of other potential sources of genetic exchange among these sub-populations that may further reduce the threats of genetic isolation. In addition, there exists the potential for interchange with remnant desert bighorn sheep populations on the Tohono O'odham reservation to the west of SBSA.

Bighorn sheep follow established traditions in their movement patterns, with young "learning" seasonal movements and travel routes from adults (Geist 1967, Festa-Bianchet 1986). Lambs stay with their maternal group for their first year, after which yearling males begin to associate more with mature rams, and yearling ewes adopt a ewe group. This behavior may allow them to best exploit seasonal ranges and locate conspecifics (Festa-Bianchet 1986). However, these tradrtional movement patterns make bighorn sheep quite conservative relative to drspersal and colonization. If traditional movement patterns are interrupted for a generation, they may be lost to the population (Geist 1967, Geist 1971).

Rams will probably continue to travel between the east and west portions of SBSA provided human activity in this area does not significantly increase (Bristow et al. 1996). That ram # 71 probably traveled directly across the portion of the mine with the highest traffic when crossing to the Waterman Mountains supports this contention. Although we have no direct observations of crossings by ram #71, if it had traveled in a straight line between consecutive locations, it would have moved directly across the Silver Bell Mine over an area of relatively high traffic and extensive habitat alteration. This travel route would have provided the shortest distance across relatively flat terrain with dense vegetation, and consequently low visibility. Most of the intermountain movements occurred during the breedmg season and mature rams were seldom observed at the Silver Bell Mine except during the breeding season. Thus, breedmg behavior may override a ram's sensitivity to human activities.

The area, where mining is proposed probably represents part of an important bachelor ram use area; rams comprised 95% of the desert bighorn sheep located where mining is proposed and where large bachelor ram groups were frequently observed. The largest rams (marked and unmarked) were observed in this area during the lambing season each year. Bighorn rams follow the largest-horned individual in a group (Geist 1971). Horn size is an indicator of body condition and nutrition, and is also related to reproductive success (Geist 1971). Smaller rams may have an advantage in following an individual that has proven his ability to effectively exploit seasonal ranges. Gwen the traditional nature of bighorn sheep movement patterns (Geist 1967), and the particular fidelity of rams for these pre-rut staging areas (Festa-Bianchet 1986), rams may be slow in re-establishing a stagmg area if they are forced to abandon another area. Loss of these pre-rut staging areas may have a greater impact than merely removing habitat. If social hierarchy is not well established before the rut, then rams may spend more time fighting while ewes are in estrus. This could delay breedmg such that more lambs are born outside the normal lambing period which could ultimately lower herd productivity. Slight changes in productivity could have serious implications for small bighom sheep populations such as those of the SBSA.

Perhaps the most obvious effect of open pit mining is the creation of the pits themselves (MacCallum and Geist 1992). The proposed mine will include the excavation of a main pit approximately 1.5 km^2 in area over a ≥12 year period. The proposed pit is in an area of gently rolling hills, and will increase the slope of large areas that will become the sides of the pit. Throughout the study we found ewe groups (including those with young lambs) using the walls of the inactive Oxide and El Tiro pits on the Silver Bell Mine property. The proposed mine will likely change the topography of the area near the pit such that it will be more attractive to ewe groups after mine development. This will .take several years, depending upon the amount of copper ore present and the market for copper. It seems unlikely that bighom sheep will use the area of the active mine until human activity is reduced.

Although the proposed mine will not directly impact any lambing-nursery habitat within SBSA it is likely that there will be an attendant increase in human activity in those areas; as well. Recreational use will likely increase as more people become familiar with the area, this recreational use could directly impact the lambing-nursery areas. Increases in human recreational use of bighom habitats has caused populations to abandon traditional ranges (Hicks and Elder 1979, DeForge et al. 1981). Increases in recreational use, especially in traditional lambing areas, could have serious impacts on this population.

Present productivity and mortality estimates indicate a stable population within SBSA. However, given the small population size and isolation of ewe sub-populations, genetic exchange provided through intermountain movements is essential to the long term viability of this population. The desert bighorn sheep within SBSA represent the last viable desert bighorn sheep population indigenous to the

Tucson basin. Historic populations of desert bighorn sheep in the Tucson, Sawtooth, Picacho, Rincon, and Santa Catalina mountains have declined or become extirpated due to industrial, urban, and agricultural developments (Krausman et al. 1979). The proposed mining within the Silver Bell Mountains will remove and alter a significant portion of important desert bighorn sheep habitat. The bachelor-ram habitat will be significantly impacted and the effects of this and a likely increase in recreational use is not clear. Past experience relative to impacts of human encroachment on desert bighorn sheep populations suggest a conservative approach is necessary to safeguard against extirpation. Future research into the impacts of industrial development, human activity, and predation on this population would provide information necessary to manage this and other populations of desert bighorn sheep. Intensive management in the form of habitat protection, and restricting recreational use during peak lambing and breedmg seasons may be necessary to ensure the long term viability of this important desert bighom sheep population.

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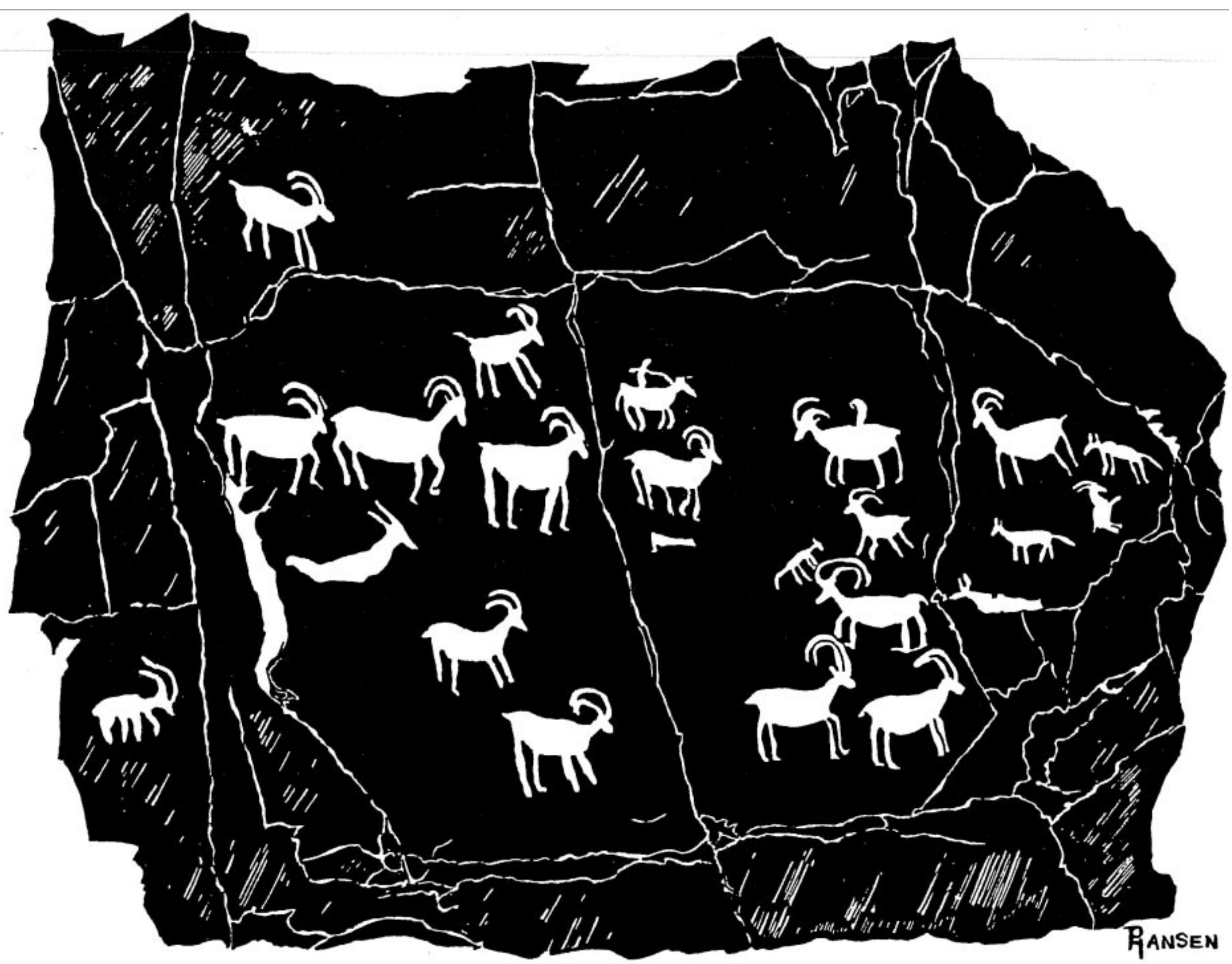


Table 1. Annual productivity estimates among ewes of the Silver Bell Peak (SBP), Ragged Top Peak (RTP), and West Silver Bell (WSB) subunits of the Silver Bell study area in southern Arizona.

Variable[a]	Year	Subunit	Mean	SD	Median	*n*		*P*
		SBP	0.37	0.41	0.33	25		
x lambs	1993-94	RTP	10.46	10.46	10.50	48	$X^2 = 3.42$	0.181
		WSB	0.22	0.35	0.0	17		
		SBP	0.10	0.22	0.0	25		
x yearlings	1993-94	RTP	0.09	0.17	0.0	48	$X^2 = 1.25$	0.570
		WSB	0.09	0.26	0.0	17		
x lambs	1994-95	SBP	0.55	0.43	0.67	64		
		RTP	0.29	0.33	0.29	48	$U = 1{,}009$	0.001
x yearlings	1994-95	SBP	0.27	0.37	0.0	64		
		RTP	0.51	0.47	0.40	48	$U = 1{,}024$	0.002
x lambs	1995-96	SBP	0.24	0.39	0.0	49		
		RTP	0.15	0.35	0.0	23	$U = 496$	0.288
x yearlings	1995-96	SBP	0.44	0.75	0.0	49		
		RTP	0.29	0.34	0.0	23	$U = 549$	0.842

[a] x lambs = number of lambs/adult ewe by group, x yearlings = number of yearlings/adult ewe by group.

[b] U = results of Mann-Whitney U test, X^2 = results of Kruskal-Wallis ANOVA test.

Table 2. Numbers of desert bighorn sheep seen during annual helicopter surveys within the Silver Bell and West Silver Bell mountains, southern Arizona, 1984-97.

Year	No. of groups seen	No. of Sheep seen	No. of lambs seen	sheep/hr flight time
1984	14	35	4	
1985	13	42	9	
1986	9	42	4	
1987	16	46	11	
1988	11	40	3	7.8
1989	10	31	4	
1990	12	42	7	6.3
1991	15	40	5	8.0
1992	21	74	13	13.4
1993	14	39	6	6.7
1994	12	46	3	9.4
1995	10	38	4	9.3
1996	13	42	6	8.4
1997	11	50	13	11.4

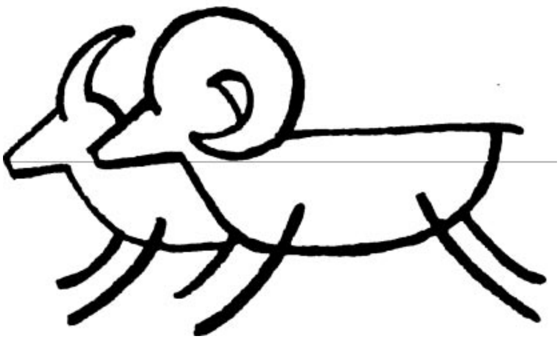


Table 3. Home-range sizes (100% MCP), core area sizes (50% MCP), and $\bar{x}$ distance moved between consecutive locations ($\bar{x}$ movements) for rams and for ewes of the Silver Bell Peak (SBP), Ragged Top Peak (RTP), and West Silver Bell (WSB) study area subunits within the Silver Bell study area, southern Arizona, 1993-96.

Sex[a]	100% MCP km^2	50% MCP km^2	X movements km	*n*	Subunit[b]
ewe	13.52	1.40	1.24	61	WSB
ewe	8.73	1.50	0.69	135	RTP
ewe	7.67	0.32	0.65	131	RTP
ewe	8.75	0.50	0.73	132	RTP
ewe	9.35	0.67	1.03	62	RTP
ewe	13.31	5.83	1.40	133	SBP
ewe	11.72	2.21	1.21	138	SBP
ewe	12.24	2.70	1.40	135	SBP
ewe	7.83	1.67	1.21	68	SBP
ram	83.36	18.47	3.23	132	
ram	91.29	29.49	1.49	137	
ram	76.85	6.47	2.29	139	
ram	73.79	24.97	2.89	69	
ram	24.77	1.35	1.24	114	
ram	59.52	9.48	2.09	57	
ram	34.49	4.87	2.95	62	
ram	29.52	3.98	3.07	58	
ram	41.80	5.37	2.01	101	

Mann-Whitney U test results for differences in home-range characteristics between sexes were: home-range ($U = 0.0$, $P < 0.001$), core area ($U = 9.0$, $P = 0.005$), and $\bar{x}$ movement ($U = 2.0$, $P < 0.001$).

[b] Mann-Whitney U test results for differences in home-range characteristics between mined (SBP) and unmined (RTP) subunits were: home-range ($U = 3.0$, $P = 0.149$), core area ($U = 0.0$, $P = 0.021$), and x movement ($U = 0.0$, $P = 0.021$).

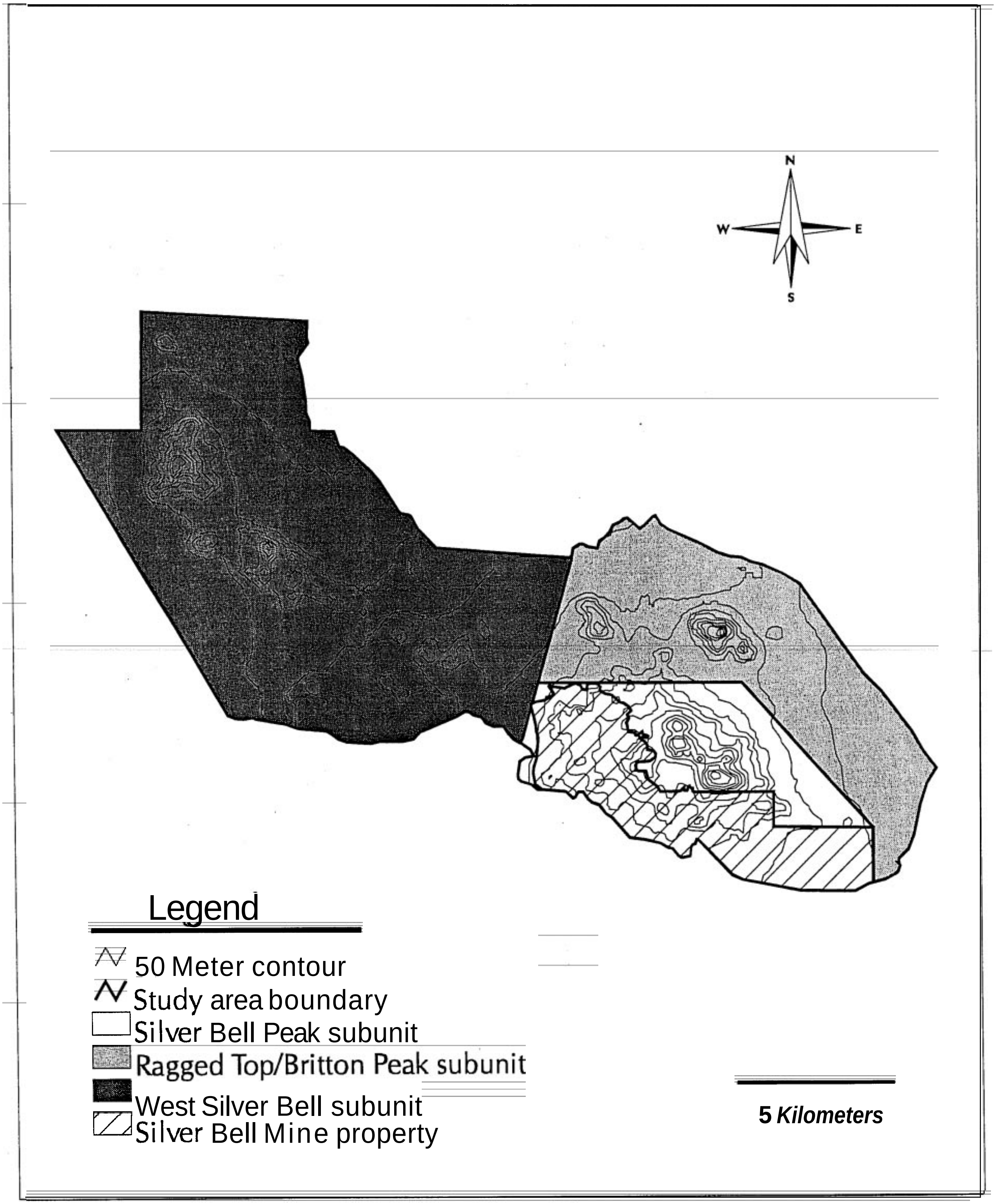


Figure 1. Silver Bell desert bighorn sheep study area and subunits in southern Arizona.

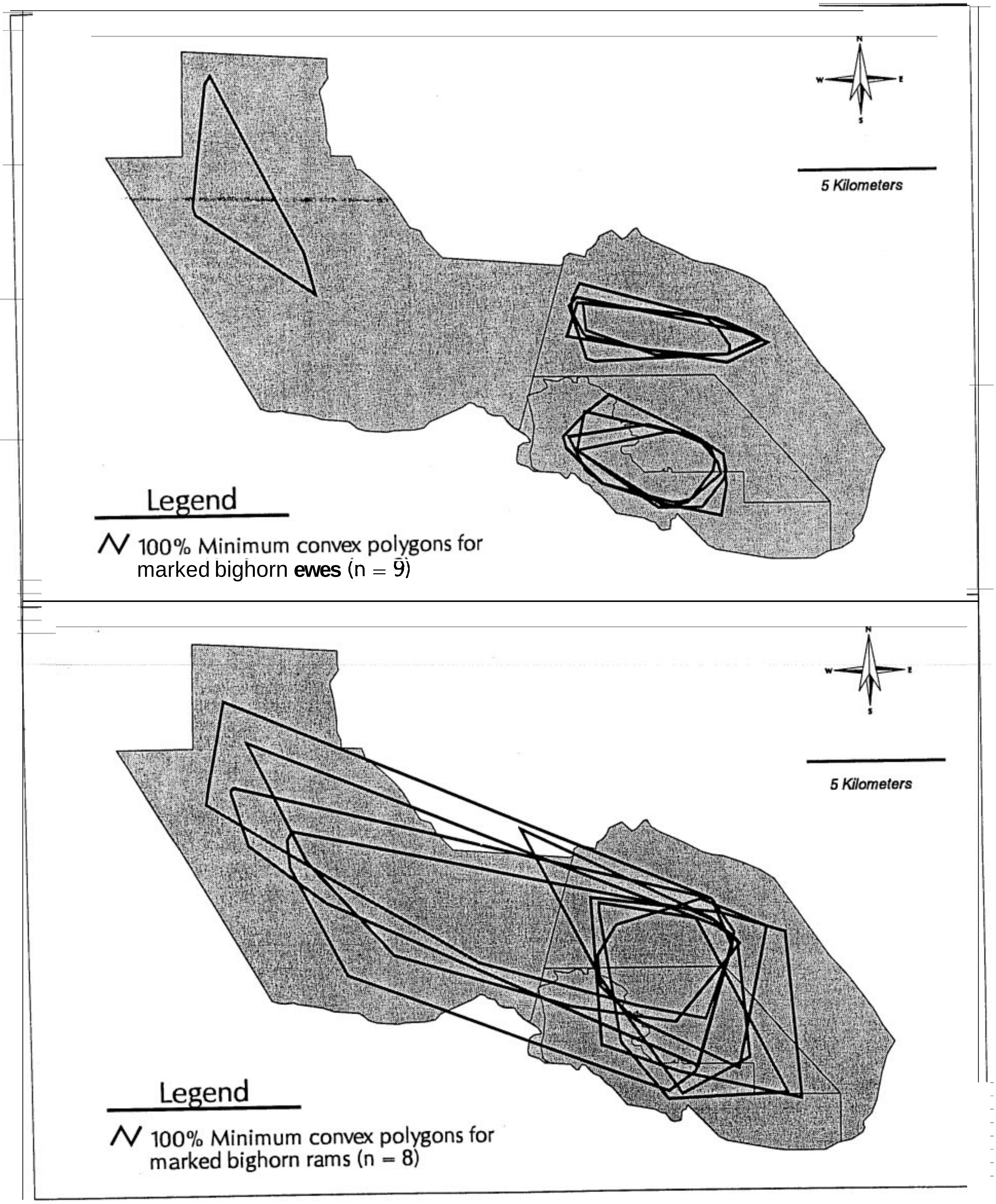


Figure 2. Home-ranges (100% MCP) of rams and ewes within the Silver Bell study area in southern Arizona.

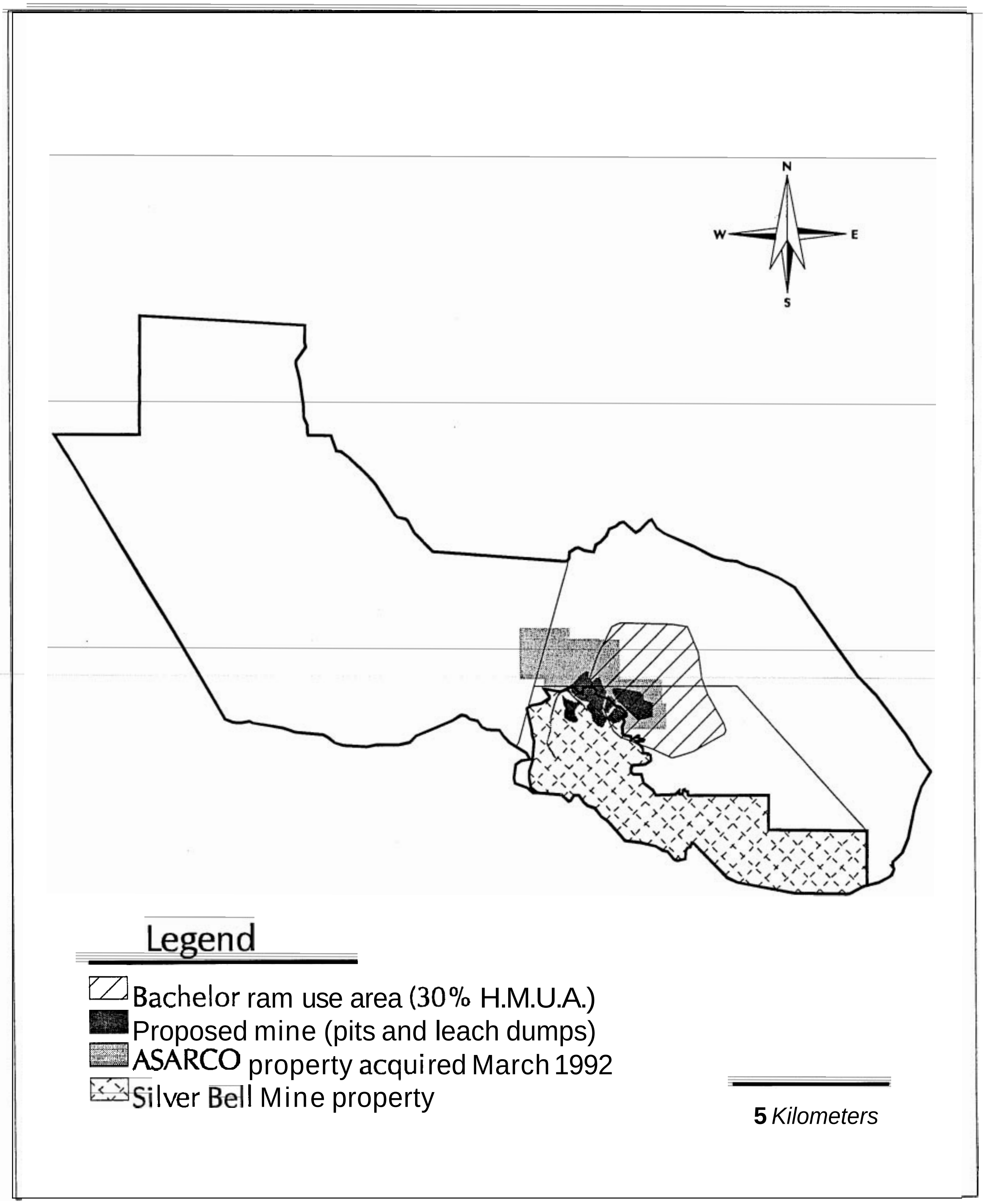
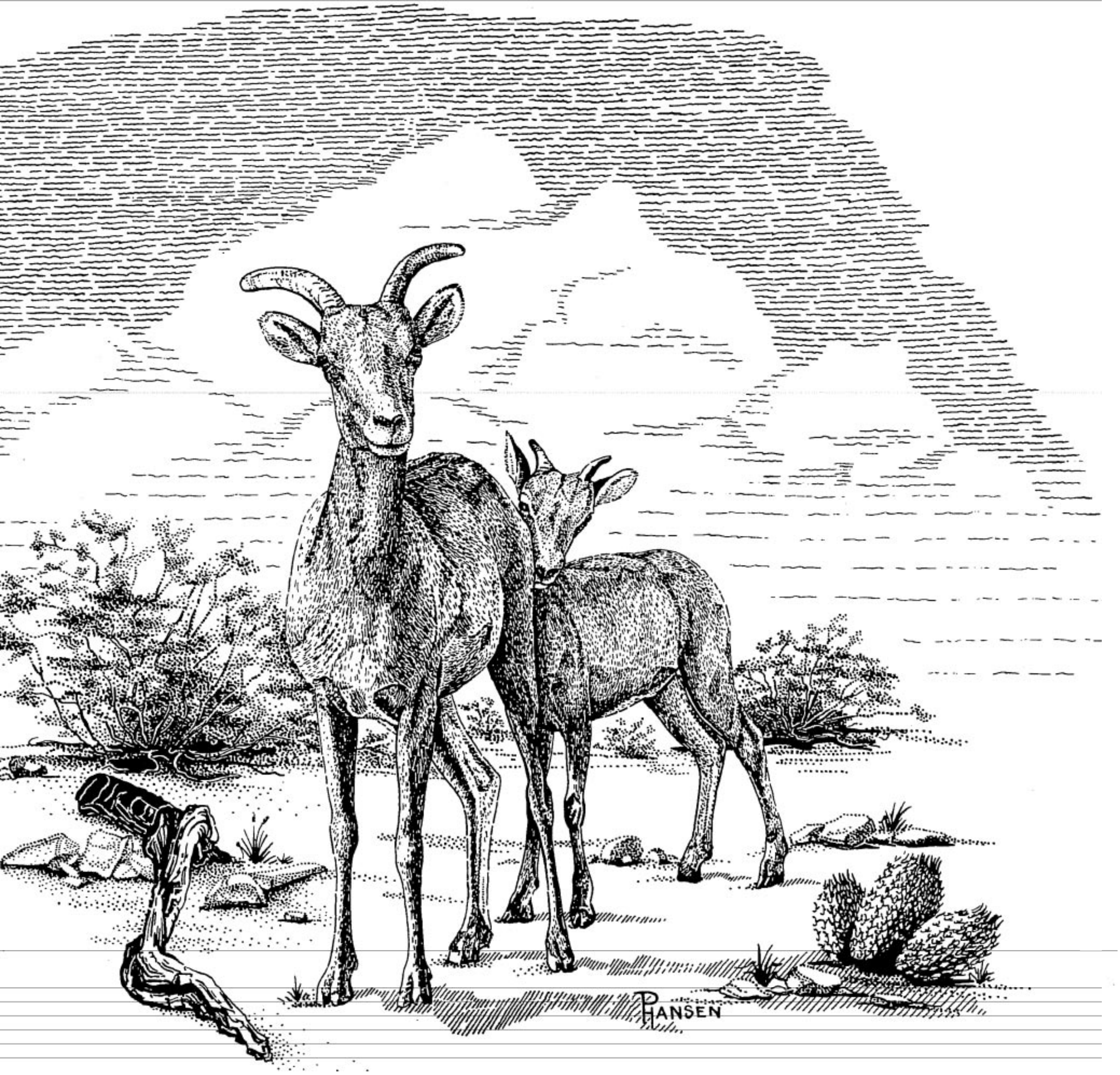


Figure 3. Proposed mine site (haul road, main pits, and leach dumps) and bachelor ram 30% harmonic mean core area within the Silver Bell study area in southern Arizona.

STATUS REPORTS



A 10-YEAR REVIEW OF BIGHORN SHEEP MANAGEMENT IN ARIZONA

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POPULATIONS

Estimates of Anzona's desert bighorn sheep (*Ovis canadensis mexicana* and *O. c. nelsoni*) indicate a relatively stable population of approximately 6,000 animals. The 1997 desert bighorn sheep helicopter surveys produced 2,576 classifications in 295.4 flight hours (8.7 sheep/hour). Survey results yield ratios of 55 rams: 100 ewes: 30 lambs: 10 yearlings.

When reviewing these values for the past 10 years, the estimated population increased from 4,500 in 1988, to a high of 6,500 in 1994 and 1995, before declining slightly to the 6,000 estimated desert bighorn sheep in Arizona today. Total observations peaked at 2,758 in 1994, but were only 1,578 in 1996. Total observations are directly related to survey effort. As the number of helicopter hours varies due to budgetary considerations, the total number of animals observed varies. The number of animals observed per hour has been relatively constant during the past 10 years, averaging 9.9 desert bighorn sheep observed per helicopter hour, ranging from 8.7 to 11.5.

RESEARCH

The Arizona Game and Fish Department (AGFD) is currently involved in several bighorn sheep research and management projects. These include an evaluation of survey methodology and observation rates and bighorn use of habitat near mining operations.

During the past 10 years, the AGFD has worked on projects regarding diseases, mortality rates, distribution and abundance in Mexico, water developments, and movements in an effort to develop a greater base of data to help manage desert bighorn sheep. Reports on 7 of these projects have been published in the Transactions during this period.

HABITAT IMPROVEMENTS

The AGFD, primarily in cooperation with the Bureau of Land Management and the Arizona Desert Bighorn Sheep Society (ADBSS), and more recently with Desert Wildlife Unlimited, continues to develop and maintain bighorn sheep waters. These water projects vary from simple tinaja modifications to extensive artificial water collection and storage systems.

In 1997, 5 water developments specifically for desert bighorn sheep were constructed. The AGFD began construction of water developments specifically for desert bighorn sheep in 1954. Since that time, some 150 waters have been developed specifically for bighorn sheep.

TRANSPLANTS

Since 1957, the AGFD has transplanted 1,210 desert bighorn sheep, with 99 going to Colorado, 46 to Utah, 29 to Texas, 23 to New Mexico, and 9 to various Zoos and Universities. Arizona is presently hunting transplanted bighorn sheep populations in 14 game management units, with 26 permits being offered in these areas.

Of these 1,210 animals, 535 (44%) were moved in the last 10 years. This is despite the recent drought conditions, and the corresponding impacts to the bighorn sheep population, that precluded bighorn sheep transplants in 1996 and 1997. Transplants are being considered for 1998.

This is the last year of a 3-year program to evaluate bighorn sheep habitat in Arizona for potential bighorn sheep release sites. Using a modified Cunningham/Hansen habitat suitability model, all potential habitat will be scored, with the higher scoring areas being prioritized for future transplants.

HARVEST

Bighorn sheep permits remain the most sought after hunting permits in Anzona. There was a record 7,077 applicants (5,173 resident and 1,904 nonresident) for the 97 regular season permits. This represents nearly 73 hunters applying for each permit, with individual unit odds varying from as low as 16:1 to 477:1, depending on the unit's accessibility and harvest history.

During the 1997 hunting season, 99 hunters participated, harvesting 92 rams, for a 93% success rate. The average age of the harvest was 7.2 years. During the past 10 years, the hunter success rate has averaged 92%. Since desert bighorn sheep hunting seasons were re-opened in Arizona in 1953, 2,978 permits have been authorized. Hunters have harvested 1,957 rams, for an average hunter success of 67%.

The 1997 season produced 10 animals which exceeded 168 Boone and Crockett points; of these 2 scored >180 points. During the past 10 years, 17.5% of the rams harvested scored above 168 Boone and Crockett points, and 2.6% scored >180 points. To date, 33 rams scoring over 180 points have been harvested in Anzona, including 3 over 190 points.

As a result of this year's surveys, desert bighorn sheep permits for the 1998 season will be increased from last year's 87 to 97. Two additional permits d l again be issued to raise funds for bighorn sheep management programs. For the past 13 years, the AGFD and the ADBSS have entered into an agreement whereby the ADBSS auctions 1 permit (at the Foundation for North American Wild Sheep convention) and raffles another to raise funds for bighorn sheep management projects. Since the program started in 1984, $2,525,860 has been raised from the 26 permits ($1,468,000 from the auction tags and $1,057,860 from the raffle tags).

In 1998, the auction permit was sold for $140,000. This makes a total of $1,204,000 from the last 5 bighorn sheep auction tags offered in Anzona. Arizona's bighorn sheep management program is dependent upon the funds derived from these permits.

STATUS OF BIGHORN SHEEP MANAGEMENT PROGRA0MS IN MEXICO - 1997

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Recent developments in the management of bighorn sheep in Mexico have been well reported at the past several Council Meetings, as well as in the Transactions. For example, the 1997 Transactions have 3 reports on Mexico. Rather than recover "old ground," I will simply discuss some of the events which have occurred regarding bighorn sheep management in Mexico since the 1998 Council Meeting.

Sonora

Additional helicopter surveys were conducted in Sonora in 1997. These included helicopter surveys conducted by ANGADI (an association of ranchers and landowners) on members' ranches and by CEMEX/UNAM (Cementos de Mexico/Autonomous University of Mexico) on Tiburon Island and in adjoining mainland sierras.

Helicopter surveys conducted in 1997 in various parts of Sonora produced 341 observations. In 1996, in these same areas, a similar survey effort produced 326 observations. This would indicate that the bighorn sheep population in Sonora is at least stable, if not increasing slightly as the relatively high lamb and yearling to ewe ratios would indicate.

ANGADI surveys have been "optimistic" in their results, producing in this year's issuance of 43 hunting permits (up from only 7 in 1995). Two additional permits for Tiburon Island were auctioned at the 1998 Foundation for North American Wild Sheep (FNAWS) convention (for $200,000 and $195,000) with the monies going to UNAM, to fund their Tiburon Island wildlife management program, and to the Seris, an indigenous people of the area, for social development programs. As part of Mexico's National Bighorn Sheep Conservation Program, bighorn sheep from Tiburon Island are to be used to repopulate historic habitat in the states of Coahuila and Chihuahua.

Tiburon Island, due to its high density of bighorn sheep, has been an area of intense management interest. Since 1995, 110 animals have been captured on the island and relocated to the mainland. Surveys conducted in 1993, 1996, and 1997 have noted the reduction of sheep on the island. The 1993 survey produced 62.3 bighorn sheep observations per hour. In 1996, the observation rate had declined to 59.5 per hour. In 1997, the rate had declined to 43.3. These results indicate both the sensitivity of the surveys and the level of the removals. Recommendations for appropriate removal rates have been made to the National Institute of Ecology (INE).

Baja California

The March 18, 1998, listing by the U. S. Fish and Wildlife Service of the Peninsular bighorn specifically excluded Baja California based upon the finding that the population there "is not likely to be in danger of extirpation within the foreseeable future because there are significantly more animals there than occur in the United States." Additional helicopter surveys are scheduled for Fall 1998 to better determine the current distribution and abundance of bighorn sheep in Baja California. In February, 3 hunting permits were issued for bighorn sheep in Baja California, with the first being auctioned at the 1998 Safari Club convention for $140,000. A subsequent court challenge caused FNAWS to withdraw the 2 permits that were to be auctioned at their 1998 convention. These permits were issued to the Association of Ejidos, who worked with the Mexican Foundation for the Conservation of Wild Sheep to promote this program. Hunting supported wildlife conservation is not as widely accepted in Mexico as it has been in the United States. The Mexican Foundation and INE have combined to promote the conservation of bighorn sheep throughout Mexico.

Baja California Sur

Following the 1996 survey of the Vizcaino Biosphere Reserve, 4 bighorn sheep hunting permits were raffled/auctioned through FNAWS, producing $287,000. The 4 hunters harvested 3 rams.

A second survey of the Reserve was flown in 1997. During this survey 103 bighorn sheep were observed, compared to 99 in 1996. However, due partly to the larger area surveyed in 1997, the population estimate for the Reserve was reduced fiom 293 animals to 254. As a result of this survey, only 3 permits were issued for a auction/raffle in 1998. These 3 permits produced over $200,000. The revenue from these permits was placed into a bank trust for which FNAWS is 1 of the required signatory parties. This is the first time that a non-Mexican organization has been placed on the board of this type of trust.

Biologists fiom the Reserve came to the United States for a field training course in bighorn sheep management - traveling through bighorn sheep habitat in Arizona, Nevada, and California, as well as meeting with bighorn sheep biologists in each of these states.

A survey was also conducted to the south of the Reserve in areas near Loreto and "El Mechudo." Results fiom this survey were 36 bighorn sheep observed near Loreto (12.7 sheep per hour) and 25 animals observed near El Mechudo (50 sheep per hour). These results are in comparison with DeForge et al. (1988) who saw only 7 animals in 6-7 hours of search/survey near Loreto and 31 in 2 hours near El Mechudo. Of particular significance, is that El Mechudo is the area where DeForge et al. (1998) had previously captured some 30 bighorn sheep for the Carmen Island project, which has been reported on at past Council Meetings.

In conclusion, as part of Mexico's National Program, local peoples are becoming involved in establishing conservation and management units which allow some use of bighorn sheep while promoting their conservation and recovery.

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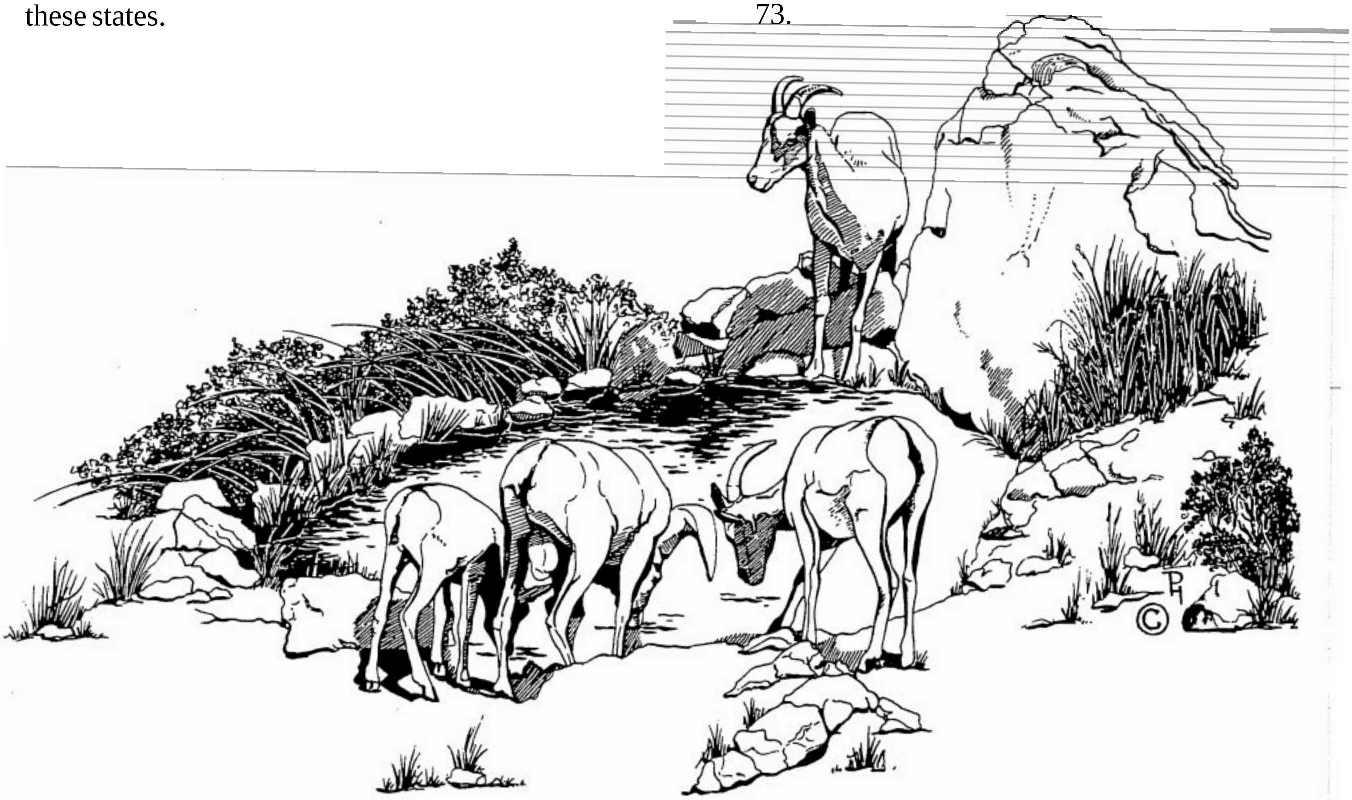

STATUS OF DESERT BIGHORN SHEEP IN NEVADA - 1997

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POPULATIONS

Three subspecies of bighorn sheep (*Ovis* canadensis) inhabit Nevada. California bighorn (*O.* c. *californiana*) occupy high desert plateaus and canyon rims in the northwest portion of the state. Rocky Mountain bighorn (*O.* c. canadensis) occur on mountain ranges in northeastern Nevada and desert bighorn (*O.* c. *nelsoni*), having the broadest Qstribution, inhabit mountain ranges in the southern two-thirds of the state. Inclusive of each subspecies, there are approximately 6,700 bighorn sheep in Nevada.

Extirpated from Nevada by the early 1930's (Tsukamoto 1993), today there are an estimated 1,200 California bighorn sheep as result of an aggressive re-establishment program which began in 1967. Since 1967, 587 California bighorn sheep have been released into 19 mountain ranges. Transplant stock has been furnished by British Columbia (n = 231), Idaho (n = 105), Oregon (n = 123), and in recent years Nevada (n = 128). California bighorn populations are stable in numbers and Qstribution.

The Califomia bighorn harvest program expanded substantially during the past decade. In the 1997 season, 32 tags were allotted for the resident hunt and 3 tags were apportioned to the non-resident hunt. A single tag was available in the Partnership in Wildlife (PIW) draw. Overall the hunter success rate was 86%.

Rochy Mountain bighorn were last observed on Wheeler Peak, White Pine County in 1929 (Hall 1946). Re-establishment of the subspecies to the northeast quarter of Nevada began with the release of 16 sheep in 1975. To date, 233 Rocky Mountain bighorn sheep furnished by the states of Colorado (n = 109), Wyoming (n = 48), and Alberta (n = 76) have been released into 6 mountain ranges. Last year, 2 additional translocations were achieved with releases of 13 and 19 sheep captured in Nevada. There are an estimated 250 Rocky Mountain bighorn sheep in Nevada.

The program to re-establish Rocky Mountain bighorn has met with tempered success. Though populations persist, either their anticipated expansions have not occurred, or as with the Ruby Mountain herd, a Qe-off resulted in the loss of 80% of the population. The die-off occurred during winter 1995 and 1996, and was coincident with the loss of 60% of the sympatric mountain goat population. Details associated with the die-off suggest a disease event occurred, and it is reasoned the temporal and spatial progression of the die-off was the likely result of a foreign, highly infectious and virulent pathogen (Foree 1997).

Desert bighorn populations continue to experience drought conditions. Though a few populations may have benefited from brief, localized precipitation, many have endured unusually arid conditions without meaningful reprieve since early 1995. Overall, water catchments have served to lessen the severity of drought years. Water catchment construction remains an integral element in the Nevada Division of Wildlife's (NDOW) program to re-establish mountain sheep in historic ranges.

During fall 1997, aerial surveys conducted on 36 mountain ranges enabled observations of 1,916 desert bighorn sheep. The statewide bighorn sample was comprised of 934 ewes, 587 rams, and 395 lambs (63 rams: 100 ewes: 42 lambs). Based primarily on data collected during aerial surveys, there are an estimated 5,300 desert bighorn sheep in Nevada. The statewide population estimate approximates 5-year and 10-year statewide averages as well as the estimate derived last year.

Desert bighorn capture operations during fall 1997 and winter 1998 involved 65 animals and 3 translocations. A private contractor was employed to conduct the captures using the aerial net-gun technique. In Nevada, release of 2 bighorn contingents effectively fulfilled 2 re-introductions. Texas was furnished 20 desert bighorn sheep.

In November 1997, of 22 desert bighorn sheep trapped in the River Mountains, Clark County, 2 were released, 19 were translocated to the Delamar Mountains, Lincoln County, and 1 died as result of injuries sustained during capture. In January 1998, 23 desert bighom were captured in the Pancake Range, Nye County, of which 21 were released in the Gillis Range, Mineral County, and 2 died due to capture related injuries. Further north, capture efforts resumed in the Gabbs Valley Range, Mineral County, and resulted in a release cohort of 20 bighorn sheep which were furnished to Texas.

Analyses of biologic samples collected fiom desert bighorn sheep in the Pancake Range and Gabbs Valley Range indicated no evidence of diseases that may affect individual or population survivorship. Sampling and testing protocols differed between populations, however. Comprehensive health assessments were conducted for Gabbs Valley Range sheep whereas only Pasteurellaceae isolates were cultured for the Pancake Range contingent. Biologic samples collected from the former cohort were sent to the Department of Veterinary Pathology Microbiology and Immunology, University of California, Davis, and pharyngeal and reproductive swab samples collected fiom the later contingent were sent to the Caine Veterinary Teaching Center, Animal and Veterinary Science Department, University of Idaho.

Since 1968, 1,268 desert bighorn sheep have been translocated to 34 mountain ranges in Nevada. In addition, to assist efforts to re-establish populations in other states, 280 desert bighorns have been furnished to Colorado (*n*=114), Texas (*n*=107), Utah (*n*=52), and Wyoming (n = 7). In Nevada, bighorn capture and re-establishment operations are scheduled to occur in fall 1998.

HABITAT IMPROVEMENTS

In 1997 and early 1998, water catchments were constructed in the Desert Range, Clark County (n = 1), Gillis Range, Mineral County (n = 2), Delamar Mountains, Lincoln County (n = 2), and Arrow Canyon Range, Clark County (n = 3). An existing catchment in the Arrow Canyon Range was modified which entailed installation of 2 2,300 gallon water storage tanks. Collectively, water project construction and unit upgrades equated to 54,800 gallons of additional water storage capacity.

Statewide, the combined storage capacity of 121 water catchments is 594,100 gallons. These projects are funded entirely, or in part, by Nevada Bighorns Unlimited (Reno and Fallon chapters), Fraternity of the Desert Bighorn (Las Vegas), Foundation for North American Wild Sheep, and Safari Club International (Desert Chapter). Water catchment construction and maintenance is accomplished largely by volunteers from these organizations. Projects were constructed by U. S. Fish and Wildlife Service, Bureau of Land Management and NDOW.

HARVEST

The desire to hunt desert bighorn rams in Nevada remains great. There were 3,185 applicants for 98 resident tags and 1,581 applicants for 11 non-residents tags; alternatively, there were 33 applicant. for each resident tag and 144 applicants for each non-resident tag. Relative to last year, the resident and non-resident quotas represented reductions of 11% (12 tags) and 8% (1 tag), respectively: Two special auction tags and 2 PIW tags were also allotted. Participation in the PIW draw involved 8% (251) of the resident applicants, which reflected a slight decrease from the participation rate last year. Forty-three (39%) tags of the available 109 resident and non-resident tags in 1997 corresponded to hunt units with bighorn populations established through translocations.

In 1997, 85 rams were harvested for a hunter success rate of 75%. Overall, hunter success was 3% below the 10-year average. The average age of rams harvested was 6.1 years, slightly more than half a year older than the average age last year. Unofficially, 2 rams exceeded the Boone and Crockett minimum score of 168 points, and a ram harvested in the Black Mountains, Clark County, attained the highest Boone and Crockett score, 170 6/8.

In May 1998, the Nevada State Board of Wildlife Commissioners will authorize desert bighorn harvest quotas. Hunt areas and quotas are expected to remain largely unchanged relative to last year. In 1998, the first of 2 auction tags generated $52,000 at the Reno Chapter of Nevada Bighorns Unlimited banquet; the second tag was hosted by the Fallon Chapter of Nevada Bighorns Unlimited and was purchased for $48,000. Revenues collected through sale of special auction tags are deposited in the Wildlife Heritage Trust Account.

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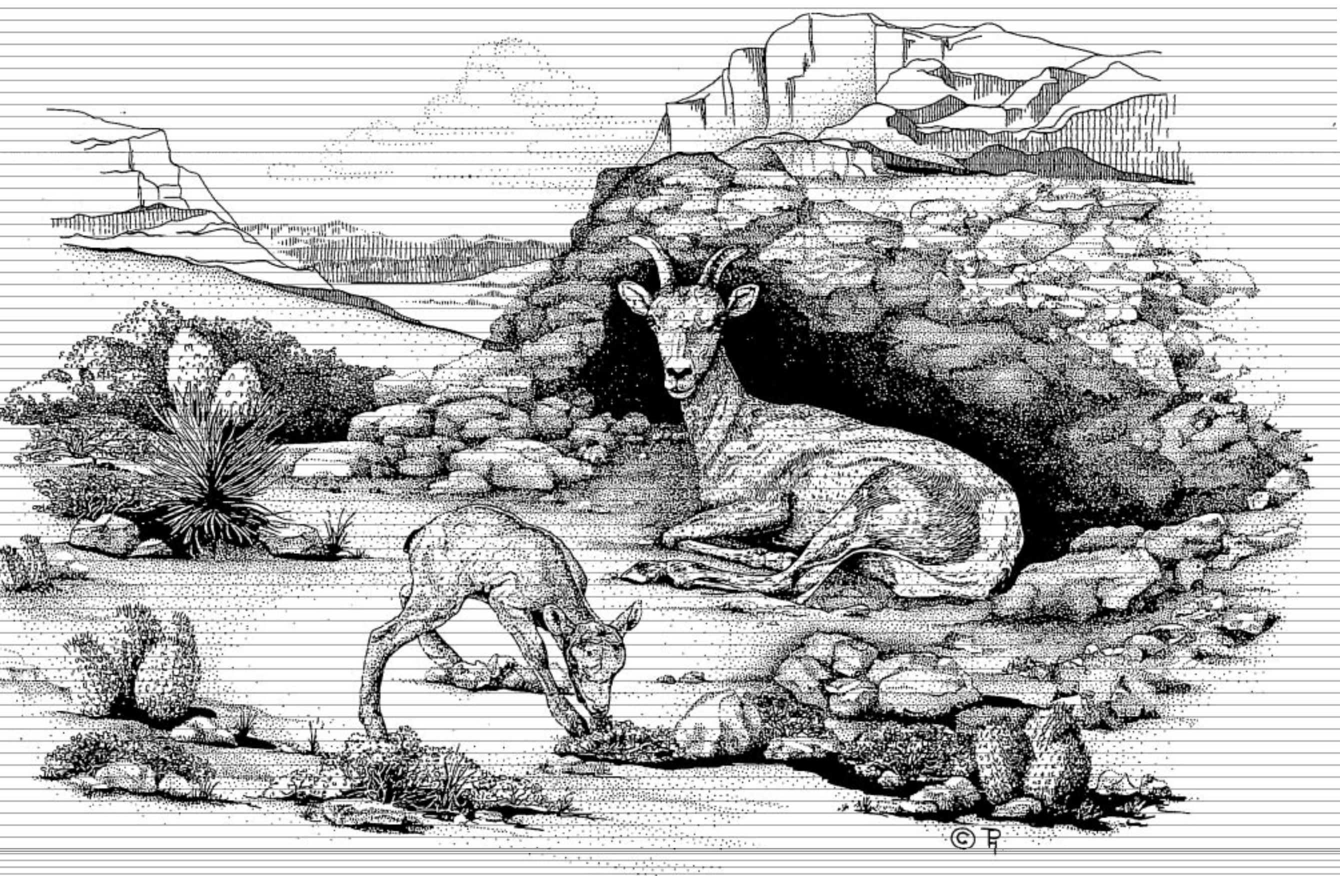

STATUS OF DESERT BIGHORN SHEEP IN NEW MEXICO - 1997

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POPULATION

Desert bighorn sheep (*Ovis canadensis* ***mexicana***) continue to be listed as a state-endangered species in New Mexico (NMDGF 1995). In 1997, there were 7 free-ranging desert bighorn sheep populations in New Mexico. In addition, a captive population is maintained at the Red Rock Wildlife Area (RRWA).

During the fall helicopter surveys 160 desert bighorn were observed. The population estimate of wild bighorn in New Mexico is 238 (includmg the 45 bighorn released in November 1997 and 7 known mortalities between time of transplant and end of year). Sixty-seven desert bighorn sheep have active radiocollars (28% of the estimated state-wide population). The post-transplant population at RRWA is 75. Wild populations generally had poor lamb:ewe ratios, with the exception of the Fra Cristobal herd. Here 16 lambs were known to be born and all survived the year (76:100). For the other populations the mean lamb:ewe ratio was 30:100 (range =0-39). The mean ram:ewe ratio was 66:100 (range=52-74).

Total helicopter count-time, excludmg the San Andres Mountain survey, was 23 hours. The mean observation rate was 7.9 bighorn/hour (range=2.3-19.8). An additional 5 hours of helicopter count-time was spent in the San Andres Mountains and 1 bighom sheep was observed (0.2 bighorn/hour). On average, 87% of each estimated population was observed during the helicopter census (range 68-100%). An estimated 80% of individual bighorn sheep were observed.

Transplants

On November 18-19, 1997, 45 desert bighorn sheep were captured using helicopters and net guns and removed from the RRWA. Twenty-four bighorn (12 ewes, 12 rams) were released into the southern end of bighorn sheep habitat in the Peloncillo Mountains. In addition, 6 rams were released in the Big Hatchet Mountains, 8 rams in the Ladron Mountains, and 7 rams in the Fra Cristobal Mountains. The 33 rams were removed to balance the sex ratio in RRWA which had become skewed (65 rams: 35 ewes) due to previous transplants. No mortalities occurred during the capture or transport. The transplant removed 12 adult ewes and 33 adult rams (1 CI, 15 CII, 11 CIII, and 6 CIV rams).

BOOTHEEL METAPOPULATION

The Bootheel metapopulation in southwest New Mexico and southeast Arizona consists of populations in the Peloncillo Mountains of Arizona and New Mexico, the Animas Mountains, the Hatchet Mountains, and the Alamo Hueco Mountains. The estimated size of this metapopulation is 200. The helicopter surveys were flown between October 18-21, 1997.

Peloncillo Mountains

A total of 33 bighorn sheep was observed in the New Mexico portion of the Peloncillo Mountains. In addition, 32 bighorn sheep were observed in the Arizona portion of the Peloncillo Mountains (D. Skinner, pers. commun.). The lamb:ewe:ram ratios in New Mexico were 33:100:87. An augmentation of 24 bighorn (12 ewes, 12 rams) was made into the southern portion of the bighorn habitat in November, after the helicopter survey.

Including the additional transplanted bighorn, the population estimate in the Peloncillo Mountains is 64. Since 1995, 2 desert bighom rams have been harvested annually from this population.

Animas Mountains

A total of 13 bighorn sheep was observed in the Animas Mountains, the same number as in 1996 (Rominger and Fisher 1996). This group of bighorn apparently represents a rare self starting herd in an unoccupied habitat. Founders are apparently fiom the Peloncillo herd. The lamb:ewe:ram ratios were 29:100:57. The presence of 2 lambs suggests that ewes did lamb in this mountain range. The population estimate for the h a s Mountains is 15 bighorn sheep.

Hatchet Mountains

A total of 41 bighorn was observed in the Little Hatchet and Big Hatchet mountains. The lamb:ewe:ram ratios were 39:100:89. This is the only population where the number of observed bighorn was <70% of the estimated population. Including the 6 released rams, the population estimate for the Hatchet Mountains is 66 bighom sheep. The observation of a radio-collared ram during the 1997 census indicates that movement fiom the Peloncillo Mountains to the Big Hatchets has occurred.

Alamo Hueco Mountains

A total of 5 bighorn sheep was observed in the Alamo Hueco Mountains. The lamb:ewe:ram ratios were 0:100:67. We estimate the Alamo Hueco population to be the 5 individuals observed. A radio-collared ram fiom the original release in 1986 was identified from both the ground and the air.

NON-BOOTHEEL POPULATIONS

Ladron Mountains

During the October 2, 1997 helicopter census, a total of 26 bighom sheep was observed in the area of the Ladron Mountains. The Ladron Mountain population had separated into at least 3 distinct subpopulations during 1996. However, during the 1997 census all bighom were seen in the region south of the Ladron complex, primarily along the Rio Salado. The lamb:ewe:ram ratios were 21:100:64. Mortality of radio-collared bighorn sheep, due primarily to predation, continued in 1997. A lion was harvested in an attempt to reduce the mortality rate on desert bighorn and no moralities of radio-collared bighom sheep occurred in 1997 after this removal. In November, 1997, 8 rams were added to this population. The population estimate is 38.

Fra Cristobal Mountains

Daily monitoring of the Fra Cristobal population and the fact that all ewes remain radio-collared, resulted in a known population of 49 bighorn sheep. A total of 16 lambs was observed in 1997 and all survived the year. Six radio-collared rams were killed by mountain lions during 1997. The lamb:ewe:ram ratios were 76:100:33. A ram in poor physical condition was collected and was determined to be infected with ***Elaeophora schneideri.*** Several other bighorn sheep appear to be infected with this parasite, which had not previously been reported in bighorn sheep (Boyce et al. in prep.).

San Andres Mountains

In April 1997, the 2 remaining bighorn sheep (1 ram/1 ewe) known to be in the San Andres Mountains, were captured and fitted with new radio-collars. Subsequently the ram was killed by a mountain lion. A helicopter census of the San Andres National Wildlife Refuge, conducted in December 1997, located no bighorn sheep, except for the radio-collared ewe. Several ground observations of this ewe have not detected other bighorn sheep. In addition, 3 remote cameras at watering sites did not photograph any bighorn during 1997.

Red Rock Wildlife Area Captive Population

The population estimate in the RRWA was 120 desert bighorn sheep prior to the removal of 45 during a transplant operation. The removal of 33 rams during this transplant has resulted in a sex ratio nearer parity. If the population increases as projected, a transplant will occur in 1999. To aid the monthly counts by the caretaker, an annual census of the RRWA with 15+ biologists was initiated in 1997.

RESEARCH

A research project was initiated to use DNA fingerprinting techniques to identify individual mountain lions that prey upon desert bighorn sheep. In addition, this technique will be used as a population estimation technique in isolated mountain ranges. In the Fra Cristobal Mountains a research project on habitat use and causes of mortality has been supported by the Turner Endangered Species Fund.

HARVEST

During 1997, 2 rams were harvested in the Peloncillo Mountains in the third annual hunt. To date, the auction of 3 New Mexico desert bighorn sheep tags at the Foundation for North American Wild Sheep conventions has produced $293,000.

LITERATURE CITED

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Rominger, E. M. and A. E. Fisher. 1997. Status of desert bighorn sheep in New Mexico, 1996. Desert Bighorn Council Trans. 84-86.

Table 1. Synopsis of 1997 desert bighom helicopter surveys in New Mexico. Figures do not include the 45 bighorn sheep released in November 1997.

Herd	Observed Total (lambs)	Estimate	Lamb:Ewe:Ram	Bighorn/hour	Count Time (hours)
Peloncillo	33 (5)	45	33:100:87	5.3	6.3
Animas	13 (2)	15	29:100:57	7.6	1.8
Hatchet	41 (7)	60	39:100:89	6.3	6.5
Alamo Hueco	5 (0)	5	00:100:67	2.3	2.2
Fra Cristobal	44 (16)[1]	44	76:100:33	19.8	2.1
Ladron	26 (3)	30	21:100:64	6.2	4.2
San Andres	1(0)		00:100:00	0.2	5.0
Total/Mean	163 (33)	200[2]	33:100:66[3]	7.9[3]	28.1

[1]Based on known value fi-om ground surveys---only 41(12) counted fi-om helicopter.

[2]Seven bighorn mortalities occurred between October census and end of year; with the release of 45 bighorn from RRWA in November, the statewide estimate is 238.

[3] This mean constructed by using value for each mountain range. Does not include San Andres census data.

STATUS OF DESERT BIGHORN SHEEP IN TEXAS - 1997

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POPULATIONS

The Trans Pecos region of Texas currently supports 7 free ranging populations of desert bighorn sheep. These occur within the Sierra Diablo, Baylor, Beach, Van Horn, and Sierra Vieja mountains, and the Texas Parks and Wildlife Department's (TPWD) Black Gap and Elephant Mountain Wildlife Management Areas (WMA). Helicopter surveys conducted in September 1997 indicated a relatively stable sheep population. A total of 257 sheep was observed during 19.7 hours of flight time (Table 1.). These survey results yielded ratios of 58 rams:100 ewes:37 lambs.

As a result of persistent disease problems the Sierra Diablo WMA brood pen facility was vacated in May 1997. Forty-five sheep consisting of 21 ewes, 12 rams, and 12 lambs, were released at Black John Canyon in the Sierra Diablo Mountains.

Presently, the population located on the Chilicote Ranch in the Sierra Vieja Mountains, is the only captive population within Texas. At last count, the Chilicote Ranch contained 8 rams, 17 ewes, and 5 lambs.

The population at Black Gap WMA was augmented in January 1998 with the net-gun capture of 20 sheep from the Gabbs Range in Nevada. The release consisted of 3 ram lambs, 15 adult ewes, and 2 ewe lambs.

RESEARCH

Geographic Information System technology is currently being used in evaluating and monitoring desert bighorn sheep habitat and populations. Initial efforts have focused on the development of complete base layers for Black Gap, Elephant Mountain, and Sierra Diablo WMAs. This technology will play a vital role in future management decisions.

The TPWD has initiated a study of the Qets and seasonal forage utilization of desert bighorn sheep at Elephant Mountain WMA. The 2 year study is scheduled to begin in September 1998 and will be conducted by the staff of Elephant Mountain WMA. The objectives of the study are to determine the seasonal Qets and foraging habits of free-ranging sheep and to determine the difference in diets between sexes. The findings will be used to assist biologists in monitoring the bighorn sheep population and habitat, and in formulating scientific based management decisions.

HABITAT IMPROVEMENTS

In March 1997, 4 water developments were completed at Elephant Mountain WMA through the cooperative efforts of the Texas Bighorn Society (TBS) and TPWD. These included: construction of 1 slick-rock guzzler at the north end of Elephant Mountain; construction of 2 apron-type guzzlers within the Del Norte Mountains; and rehabilitation of the Molcajete Spring water catchment at the south end of Elephant Mountain. Three water developments are proposed for Black Gap WMA in 1998. These include construction of 2 slick-rock guzzlers and 1 conventional type guzzler.

Aggressive habitat enhancement practices continue to be planned and implemented at Black Gap and Elephant Mountain WMAs. In order to restore and maintain suitable sheep habitat, practices such as brush clearing and prescription burning will continue. These efforts will be expanded on the above areas as well as other state owned properties which support sheep populations.

Complete floral and faunal baseline inventories of state owned properties are currently in progress. Baseline inventories are critical for monitoring trend and evaluating management. These efforts will continue.

HARVEST

The 1997 hunting season proved to be a record year for the number and quality of desert bighorn sheep harvested in Texas. During the season, 4 hunters harvested 4 desert bighom sheep with 3 qualifying for the Boone and Crockett record book. The success of the 1997 bighom hunting season demonstrates the commitment and effectiveness of the cooperative efforts by private landowners, conservation organizations such as the Texas Bighorn Society, and the TPWD.

A new state record was established by Daniel Boone of Lubbock, Texas with the harvest of a 10-year-old ram from the Baylor Mountains that scored 176 1/8. The permit had been auctioned at the 1997 FNAWS Convention for $52,000.

The 1996 FNAWS permit, which auctioned for an all time high of $77,000 to Robert Johnson of Van Horn, Texas, was deferred to the 1997 hunting season. Although numerous sheep were observed in 1996, no ram was harvested. A 158 Boone and Crockett point 7-year-old ram was harvested in the Beach Mountains under this permit in 1997.

A second record book 9-year-old ram, which scored 174 7/8, was harvested by Larry Green of La Ward, Texas. The ram was harvested in the Baylor Mountains through a private landowner permit.

The 1997 Texas Grand Slam hunt also proved successful with the harvest of a third Boone and Crockett record book ram. The 8-year-old ram, which scored 174 3/8 points, was harvested at Elephant Mountain WMA by William Brittain of Amarillo, Texas. The Texas Grand Slam is a hunt package which consists of 4 big game species including 1 desert bighom sheep. Unlimited $10 applications were sold to both resident and non-resident hunters. Approximately $50,000 was generated for the bighorn sheep program in 1997.

PROBLEMS / OPPORTUNITIES

Restocking of suitable habitat continues to be a slow process as a result of low numbers of brood stock. Transplanting from stable populations within the state of Texas as well as from other states must be continued. Based on availability, Elephant Mountain WMA will continue to serve as the primary source of brood stock from within the state. Continued cooperation between conservation agencies is critical to the desert bighorn restoration program in Texas.

Exotic wildlife such as aoudad sheep continue to be observed within existing populations as well and within proposed release sites. Efforts to control or eliminate these problem animals will continue to be accomplished by lethal means through the cooperative efforts of the TPWD and private landowners.

Predator problems persist within some bighorn sheep populations and in some proposed release sites. Target predator control will continue to be practiced as required.

Present knowledge of certain aspects of bighom populations and habitat is limited. Research efforts must be expanded in order to manage more effectively.

Table 1. Desert bighorn sheep observed during the 1997 helicopter survey

Mountain Range	Sheep Observed	Ratio per 100 ewes Rams/Lambs	Trend
Metapopulation*	132	44/42	Stable
Van Horn Mountains	4	00/100	Stable
Black Gap WMA	25	100/50	Increasing
Elephant Mountain WMA	66	84/22	Stable
Chilicote Ranch	30	47/29	Stable
Total	257	58/37	Stable

* Sierra Diablo, Baylor, and Beach Mountains

Table 2. Summary of desert bighorn sheep numbers and locations in Texas (free ranging and captive populations).

Area	Rams	Ewes	Lambs	Total
Metapopulation	-	-	-	-
Baylor Mountains	3	10	3	16
Beach Mountains	8	28	10	46
Sierra Diablo Mountains	20	33	17	70
Van Horn Mountains	0	2	2	4
Black Gap WMA*	10	10	5	25
Elephant Mountain WMA	27	32	7	66
Sierra Diablo WMA**	-	-	-	-
Chilicote Ranch	8	17	5	30
Total	76	132	49	257

* The herd of Black Gap WMA was augmented in January 1998 with the transplant of 20 sheep (15 adult ewes, 3 ram lambs, and 2 ewe lambs) from Nevada (not included in the above table).

** The Sierra Diablo brood pen facility was vacated in May 1997. The sheep were released at Black John Canyon, located in the Sierra Diablo Mountains.

STATUS OF DESERT BIGHORN SHEEP IN UTAH - 1997

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POPULATIONS

Desert bighorn sheep (*Ovis canadensis* nelsoni) are native to southern and southeastern Utah's canyon country. As the partial result of an aggressive transplant program for the past 25 years, bighorns continue to increase and expand their range. The current estimate of desert bighorn sheep in Utah is approximately 2,600 animals. Gaps between herds continue to fill, progressing toward the eventual establishment of metapopulations.

Managers are currently surveying hunted units every other year due to personnel and budget constraints. Eight of the current 20 management units were surveyed in 1997. Fall helicopter surveys of these 8 management units resulted in 745 desert sheep observations (Table 1). Trend data show all of these units, with the exception of the Island-in-the-Sky, having increased numbers since they were last surveyed. The average number of desert sheep observed per hour of helicopter flight time was 13.2 for the North and South San Rafael units where 416 desert sheep were observed.

Since 1973, a total of 546 desert sheep have been translocated into historic habitat in Utah. Eighteen desert sheep were captured by Utah Division of Wildlife Resources (UDWR) personnel in January 1998 on the Escalante Unit. Six of these sheep were radio-collared and moved within the Escalante Unit to assist in range expansion. Six more went to the South San Rafael unit; while the last 6 went to the North San Juan unit to assist in the re-establishment of a population that crashed some 10 years ago. No transplants from out of state were conducted in Utah during 1997.

RESEARCH

Several studies continue, while others were initiated in 1997. Radio telemetry monitoring of transplanted animals to gather information regarding habitat utilization, production, and survivability, continue in North Wash, Coyote Canyon, Paria Canyon, South San Rafael, and Capitol Reef National Park. New studies were initiated during 1997 in North San Juan and Cow Canyon. In addition to the transplant project mentioned earlier, a cooperative project with the National Park Service: Bureau of Land Management (BLM), and UDWR resulted in the capture and radio collaring of 20 desert sheep in January 1998, 12 in Canyonlands National Park, 3 in the Lockhart Unit, and 5 in the Potash Unit. Managers are interested in gathering life history information such as habitat use, movement patterns, production, and survivability.

HABITAT IMPROVEMENTS

Several new guzzlers were installed or repaired last year to improve habitat quality and encourage herd expansion. The BLM has been successful in obtaining funding for this endeavor. The Utah Chapter of the Foundation for North American Wild Sheep continues to pursue resolutions of conflicts with domestic sheep.

HARVEST

Twenty-eight hunters harvested 26 desert rams in 1997. This harvest was slightly lower than 1995's record harvest of **33** rams. Many nice rams were taken, including 5 in the 160 range. Twenty-nine permits have been recommended for 1998, including 1 in Lockhart Canyon, a unit opened to hunting for the first time.

PROBLEMS / OPPORTUNITIES

As populations expand, managers continue to be concerned about disease problems. It is realized that linkage of populations could also result in widespread die-offs if epidemics occur. For this reason and others, continued monitoring of the health of herds and potential disease problems is imperative. Several desert sheep populations are relatively close to domestic sheep grazing allotments. Attempts to reactivate several domestic sheep allotments are also of concern. Predation by mountain lions is still a concern since they now inhabit many areas containing desert sheep herds. Mountain lion predation could prove to be a problem in the establishment of new bighorn populations.

Tremendous increases in recreation, tourism, and film production in desert sheep habitat is now our greatest concern. Because of the increase in biking, hiking, rafting, and 4-wheeling activities; in certain areas we may have already seen our highest desert sheep population levels. Statistics from the Moab area show a 10-fold increase in the past 10 years in the number of bikers. Up to 100,000 people ride the slick-rock bike trail annually, with 500,000 rides taken annually on various other trails in the Moab area. 4-wheel drive vehicle rentals are also up. Jeep Safari, a week long event centered around Easter weekend, involves 3,000 to 4,000 vehicles that drive some 29 trails. Rock climbers have developed and published routes in and around prime desert sheep habitat. Lack of recent desert sheep use near guzzlers has been attributed to this human disturbance, as it has been discovered that there are newly established climbing routes adjacent to these water developments. Film production is increasingly popular in Utah's canyon country. Two-hundred eleven film permits were issued by the BLM statewide in Utah over the last 3 years, with 122 of these being issued by the Moab District office alone. Joe Cresto, wildlife biologist for the BLM, Moab office, estimates that 22% of these permits were issued in desert sheep habitat. Much of this filming involves low level helicopter flying. Mr. Cresto adds that peregrine falcon eyries have been adversely affected, with 2 failing in the last 5 years in areas where filming occured. Besides lands administered by the BLM, other filming occurs on private as well as state land.

Wildlife biologists are cautiously optimistic about the future of desert bighorn sheep in Utah. The cumulative impacts, largely unknown, are forecast to only increase with the coming of the 2002 Olympics as more of the world discovers Utah's recreation opportunities.

Table 1. Helicopter surveys and population estimates of Utah desert bighorn sheep, 1997.

AREA	Last Yr. Surveyed	Rams	Ewes	Lambs	Total	Lambs: 100 Ewes	Rams: 100 Ewes	Est. Pop.	Trend
North San Rafael	1997	83	90	41	214	44	92	350	Up
South San Rafael	1997	69	91	42	202	46	76	350	Up
Potash	1996	47	48	21	116	44	98	200	Stable
South San Juan	1996	31	60	13	104	22	52	160	Stable
North San Juan	1996	2	4	0	6	0	50	20	Stable
Lockhart	1996	18	28	7	53	25	64	100	Up
Little Rockies/ North Wash	1996							100	Up
Dirty Devil	1996	14	10	7	31	70	140	50	Up
Westwater								20	Down
Escalante	1997	40	46	22	108	48	87	300	Up
Kaiparowits	1997	20	30	14	64	47	67	150	Up
Paria /Coyote Canyon	1997	5	17	4	26	24	29	60	Up
Arches/Professor Valley	1994	15	35	12	62	34	45	120	Up
Island-in-the-Sky	1997	31	31	14	77	45	100	200	Down
Maze	1994	7	10	5	22	50	70	80	Up
Needles	1992	4	4	2	10	50	100	30	Stable
Capitol Reef National Park	1997	10	12	8	37	67	83	100	Up
Zion National Park						48	37	80	Stable
Navajo Tribe	1996	9	14	5	30	43	36	70	Up
Beaver Dam	1997	11	4	2	17	50	275	60	Up
TOTAL								**2600**	**Up**

PROGRAM FOR THE 42ND ANNUAL MEETING OF THE DESERT BIGHORN COUNCIL

LAS CRUCES, NEW MEXICO
APRIL 7-10,1998

Tuesday April 7,1998

6:00 – 8:00 PM **Registration and Visitor's Information Table**

Wednesday April 8,1998

6:00 – 7:00 AM **Registration and Visitor's Information Table**

7:00AM – 10:00PM Field Trip/Social to White Sands Missile Range (BBQ at Hardin Ranch starting @ 5:00 PM) Trip Leader: Dave Holdermann, *White Sands Missile Range*

6:00 – 8:00 PM **Registration and Visitor's Information Table**

Thursday April 9,1998

7:00 - 10:00AM **Registration and Visitor's Information Table**

8:30 – 9:30 AM **Welcoming Address and Introductions**

Jerry Maracchini, *Director, New Mexico Department of Game & Fish*

T. A. Ladd, *Director, National Range, Environment & Safety Directorate, White Sands Missile Range*

Renne Loboefener, *Geographic Assistant Regional Director, Arizona/New Mexico, U.S. Fish and Wildlife Service*

Linda Rundell, *District Manager, Bureau of Land Management*

Morning Session

SESSION I: STATE STATUS REPORTS
Chair – Amy Fisher

10:00 – 12:00 PM

Arizona – Raymond Lee
California – Richard Weaver
Nevada – Pat Cummings
New Mexico – Eric Rominger
Texas – Michael Pittman
Utah – Steve Flinders
Mexico – Raymond Lee

SESSION II
Chair – Bill Merhege

1:30 – 1:50 PM

Tracking Mountain Lion Predation of Desert Bighorn Sheep With Fecal DNA
Holly Ernest, Esther Rubin, Chuck Hayes, Mark Jorgensen, Steve Torres, and Walter Boyce

1:50 – 2:10PM

Microsatellite Variation In Desert Bighorn Sheep (*Ovis canadensis* spp.): Conservation Implications
Gustavo A. Gutierrez-Espeleta, Steve Kalinowski, and Phil Hedrick

2:10 – 2:30PM

Elaeophora Infection in Bighorn Sheep in New Mexico
Walter Boyce, Amy Fisher, Henry Provencio, Eric Rominger, and John Thilsted

SESSION III: Panel Discussion
The Role of Sympatic Deer in Desert Bighorn Ranges
Chair – Walter Boyce

Panel:

Warren Ballard – *Associate Professor, Texas Tech University*
Walter Boyce – *Professor, Universiiy of California, Davis*
Paul Krausman – *Professor, University of Arizona*
Raymond Lee – *Big Game Management Supervisor, Arizona Game and Fish Department*

Questions to panel and discussion

Friday April 10,1998

SESSION IV
Chair – Raul Valdez

8:00 –8:20AM	Survival and Recruitment of Wild and Captive-Reared Peninsular Bighorn Sheep in the Santa Rosa Mountains, California Stacey Ostermann, Jim DeForge, and W. Daniel Edge
8:20 – 8:40AM	Seasonality of Breeding in Bighorn Sheep in a Low Latitude Desert Environment Esther Rubin and Walter Boyce
8:40 – 9:00AM	Maternal Behavior and Productivity of an Indigenous Desert Bighorn Sheep Population on The Navajo Reservation Nike Goodson, David Stevens, Kathleen McCoy, and Jeff Cole
9:00 – 9:20AM	Status and Future of a Native Desert Bighorn Sheep Population in Southeastern Arizona Kirby Bristow and Ronald Olding
9:20 – 9:40AM	Sighting Rates of Bighorn Sheep During Helicopter Surveys on the Kofa National Wildlife Refuge, Arizona John Hervert, Robert Henry, Mark Brown, and Ronald Kearns
9:40 – 10:00AM	An Examination of Desert Bighorn ***(Ovis canadensis** nelsoni*) Habitat Using 30 m and 100 m Resolution Elevation Data Darren Divine, Donald Ebert, and Charles Douglas
10:30 – 12:00PM	Business Meeting

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DESERT BIGHORN COUNCIL MEETINGS 1957 - 1998

Year	Location	Chairperson	Secretary	Treasurer	Transactions Editor
1957	Las Vegas, NV	M. Clair Albous			
1958	Yuma, AZ	Gale Monson & Warren Kelly			
1959	Death Valley, CA	M. Clair Albous	Fred Jones	Fred Jones	
1960	Las Cruces, NM	Warren Kelly	Fred Jones	Fred Jones	
1961	Hermosillo, MX	Jon Akker	Ralph Welles	Ralph Welles	
1962	Grand Canyon, AZ	James Blaisdell	Charles Hansen	Charles Hansen	Charles Hansen & L. Fountein
1963	Las Vegas, NV	Al Jonez	Charles Hansen	Charles Hansen	Jim Yoakum
1964	Mexicali, MX	Rudulfo Corzo	Charles Hansen	Charles Hansen	Charles Hansen & D. Smith
1965	Redlands. CA	John Goodman	John Russo	John Russo	Jim Yoakum
1966	Silver City, NM	Cecil Kennedy	John Russo	John Russo	Jim Yoakum
1967	Kingman, AZ	Claude Lard	John Russo	John Russo	Jim Yoakum
1968	Las Vegas. NV	Ray Brechbill	John Russo	John Russo	Jim Yoakum
1969	Monticello, UT	R. & B. Welles	W. G. Bradley	W. G. Bradley	Jim Yoakum
1970	Bighop, CA	William Graf	W. G. Bradley	W. G. Bradley	Jim Yoakum
1971	Santa Fe, NM	Richard Weaver	Tillie Barling	Tillie Barling	Jim Yoakum
1972	Tucson, AZ	George Welsh	Doris Weaver	Doris Weaver	Charles Hansen
1973	Hawthorne, NV	Warren Kelly	Doris Weaver	Doris Weaver	Juan Spillet
1974	Moab. UT	Carl Mahon	Lanny Wilson	Lanny Wilson	Juan Spillet
1975	Indio, CA	Bonnar Blong	Lanny Wilson	Lanny Wilson	Charles Hansen
1976	Bahia Kino, MX	Mario Luis Cossio	Peter Sanchez	Peter Sanchez	Charles Hansen
1977	Las Cruces, NM	Jerry Gates	Peter Sanchez	Peter Sanchez	Charles Hansen
1978	Kingman, AZ	Kelly Neal	Peter Sanchez	Peter Sanchez	Charles Hansen
1979	Boulder City, NV	Bob McQuivey	Peter Sanchez	Peter Sanchez	Charles Hansen
1980	St. George. UT	Carl Mahon	Peter Sanchez	Peter Sanchez	Charles Hansen
1981	Kerrville, TX	Jack Kilpatric	Peter Sanchez	Peter Sanchez	Charles Hansen
1982	Borrego Sprs., CA	Mark Jorgensen	Rick Brigham	Rick Brigham	Charles Hansen
1983	Silver City, NM	Andrew Sandoval	Rick Brigham	Rick Brigham	Charles Hansen
1984	Bullhead City, AZ	Jim deVos, Jr.	Rick Brigham	Rick Brigham	Charles Hansen
1985	Las Vegas, NV	David Pullman, Jr.	Rick Brigham	Rick Brigham	Charles Hansen
1986	Page, AZ	Jim Guymon	Bill Dunn	Bill Dunn	Paul Krausman
1987	Van Horn, TX	Jack Kilpatric	Bill Dunn	Bill Dunn	Paul Krausman
1988	Needles, CA	Vernon Bleich	Don Armentrout	Don Armentrout	Paul Krausman
1989	Grand Junction, CO	Jerry Wolfe	Don Armentrout	Don Armentrout	Paul Krausman
1990	Hermosillo, MX	Raul Valdez	Don Armentrout	Don Armentrout	Paul Krausman
1991	Las Cruces. NM	Bill Montoya	Don Armentrout	Don Armentrout	Paul Krausman
1992	Bullhead City, AZ	Jim deVos, Jr.	Stan Cunningham	Stan Cunningham	Paul Krausman
1993	Mesquite, NV	Kathy Longshore	Charles Douglas	Charles Douglas	Walter Boyce
1994	Moab, UT	Jim Guymon	Charles Douglas	Charles Douglas	Walter Boyce
1995	Alpine, TX	Doug Humphries	Charles Douglas	Charles Douglas	Ray Boyd
1996	Holtville, CA	Andy Pauli	Charles Douglas	Charles Douglas	Ray Boyd
1997	Grand Junction, CO	Dale Reed & Van Graham	Steve Torres	Charles Douglas	Raymond Lee
1998	Las Cruces, NM	Eric Rominger & Dave Holdermann	Darren Divine	Charles Douglas	Raymond Lee