ARIZONA GAME AND FISH DEPARTMENT

RESEARCH BRANCH
TECHNICAL REPORT #25

HABITAT USE AND MOVEMENTS OF DESERT BIGHORN SHEEP NEAR THE SILVER BELL MINE, ARIZONA

A Final Report

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November 1996

Arizona Desert Bighorn Sheep Society
Arizona Game and Fish Department
ASARCO, Incorporated
Bureau of Land Management
and
Foundation for
North American Wild Sheep

Arizona Game and Fish Department Mission
To conserve, enhance, and restore Arizona's diverse wildlife resources and habitats through aggressive protection and management programs, and to provide wildlife resources and safe watercraft and off-highway vehicle recreation for the enjoyment, appreciation, and use by present and future generations.

Arizona Game and Fish Department
Research Branch

Technical Report Number 25

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Suggested Citation:

Bristow, K. D., J. A. Wennerlund, R. E. Schweinsburg, R. J. Olding, and R. E. Lee. Habitat use and movements of desert bighorn sheep near the Silver Bell Mine, Arizona. Ariz. Game and Fish Dep. Tech. Rep. 25, Phoenix. 57pp.

ISSN 1052-7621
ISBN 0-917563-32-8

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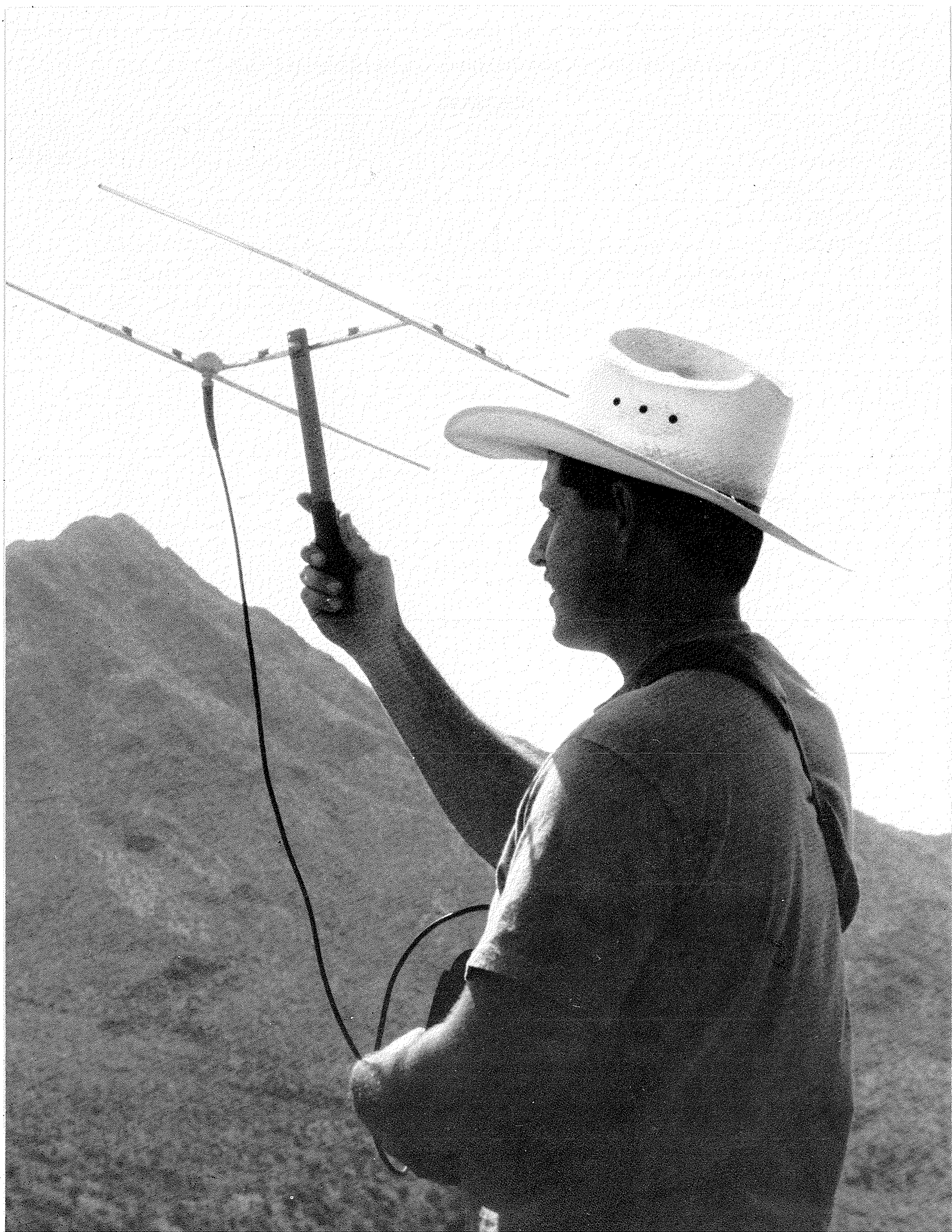
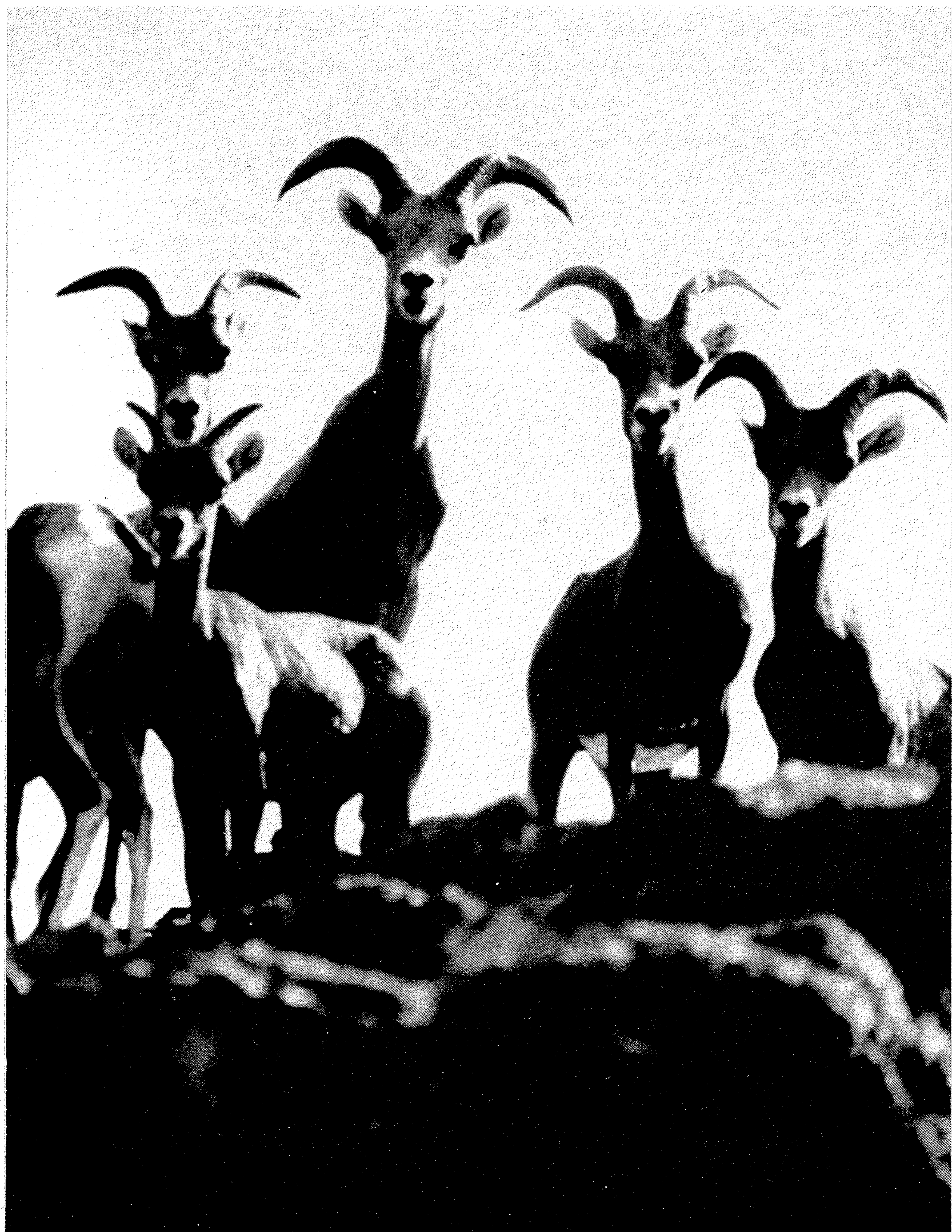


ACKNOWLEDGMENTS

This project benefitted from the assistance of several individuals. Jim deVos provided project administration and supervision. Stan Cunningham, Jim deVos, Carl Gustavson, Richard Ockenfels and Brian Wakeling provided assistance with study design. Daniel P. Brooks, Anna Cahill, Jim Heffelfinger, Bob Henry, John Hervert, Bob Miles, Ted Noon, Mike Pruss, and Dan Smith assisted on capture operations. Rick Gerhart and Dan Smith conducted annual helicopter surveys. Bill Carrel collected all the aerial telemetry data. Scott Woods and Sue Boe helped with digitizing and analyzing GIS information. Amber Alexander assisted with figure preparation. Daniel P. Brooks and Tim Rogers assisted with ground telemetry and habitat data collection. Warren Ballard, Vernon Bleich, Jim deVos, Steve Germaine, Jim Heffelfinger, Paul Krausman, Mike Pruss, Joan Scott, and Brian Wakeling all reviewed the manuscript providing invaluable comments and critiques. Vicki Webb produced the final layout, design, and table formatting.

Ted Noon (University of Arizona, Veterinary Diagnostics Laboratory) performed necropsies of marked animals found dead in the field. Derek Cooke and David Duncan (ASARCO Silver Bell Mine unit) provided considerable logistic support and information about historic, present, and proposed mining activities within the study area. Art Coats and Ken Wood (ASARCO Silver Bell Mine unit) provided logistic support to data collection on the Silver Bell Mine property.

This project was cooperatively funded by the Arizona Desert Bighorn Sheep Society (ADBSS), the Southwest Mining Division of ASARCO Incorporated, the U.S. Bureau of Land Management (BLM), the Foundation for North American Wild Sheep (FNAWS), and the Arizona Game and Fish Department (AGFD). We are grateful for their support and are especially indebted to the following individuals from those agencies: Pete Cimellaro, Matt Dominy, and Gar Thomas (ADBSS), Becky Layne and Pete Cimellaro (FNAWS), Derek Cooke, David Duncan, and David Skidmore (ASARCO Inc.), and Karen Simms and Mark Fredlake (BLM). Special thanks go to Pete Cimellaro for help in seeking funding at the inception and throughout the life of the study.



HABITAT USE AND MOVEMENTS OF DESERT BIGHORN SHEEP NEAR THE SILVER BELL MINE, ARIZONA

Kirby D. Bristow, Jennifer A. Wennerlund,
Raymond E. Schweinsburg, Ronald J. Olding, and Raymond E. Lee

Abstract: We investigated habitat use, behavior, movements, and demography of desert bighorn sheep (*Ovis canadensis mexicana*) near the ASARCO Silver Bell Mine in the Silver Bell and West Silver Bell mountains, Arizona prior to mine expansion. The Silver Bell Mine closed in 1984, but mining within a new area has been proposed. The area where mining is proposed comprised 1.2% of the entire study area. We radiocollared 22 desert bighorn sheep (11 M, 11 F) and obtained 1,957 locations from the air and ground. We compared habitat use, behavior, movements, and demography of desert bighorn sheep, between mined and unmined areas during the lambing and breeding seasons. Throughout the study area, desert bighorn sheep selected habitats rated as good and excellent. During the lambing season, ewes showed a stronger selection for habitats rated as excellent than did rams. In the area where mining was proposed, rams comprised 95% of the locations. Sixty-two percent of the area within the proposed mine site was rated as fair quality desert bighorn sheep habitat with the remainder rated as good. Desert bighorn sheep of both sexes used habitats altered by earlier mining activity in proportion to availability throughout the year; however, mature rams avoided altered habitats during the lambing season. All intermountain movements of marked animals (n = 37) were made by rams. We detected 21% of the intermountain movements between east and west portions of the study area using remote telemetry units; 71% of these movements between east and west portions of the study area probably occurred north of the proposed mine site. Home range size estimates were greater for rams ($\bar{x}$ = 57.2 km^2) than ewes ($\bar{x}$ = 10.3 km^2). We detected no differences in home range size between ewes on mined and unmined areas; however, core areas were larger for ewes on mined areas. Productivity estimates were not different between mined and unmined areas. Ewe groups in mined areas showed no indication of habituation or increased sensitivity to human presence. Desert bighorn sheep regularly used habitats within the closed mine; we were unable to investigate how they will react to increased traffic, noise, and habitat alterations associated with mine expansion. Management options and mitigation recommendations to reduce negative impacts and promote continued existence of the desert bighorn sheep herd are discussed.

Key Words: Arizona, behavior, demography, desert bighorn sheep, effects of disturbance, habitat rating, habitat use, home range, mining, movements.

INTRODUCTION

When Europeans first arrived in western North America, bighorn sheep (*Ovis canadensis*) were more widely distributed and existed in greater numbers than today (Buechner 1960). Furthermore, bighorn sheep occupied a wider range of habitats, including areas of low rocky hills now more commonly associated with mule deer (*Odocoileus hemionus*) (Grinnell 1928). With the westward expansion of civilization, bighorn sheep numbers declined and distribution was reduced (Manville 1980). The decline in numbers has been attributed to introduced diseases, competition with domestic and feral livestock, unregulated hunting, habitat alteration, and mining (Cowan 1940, Buechner 1960, Weaver 1975, DeForge et al. 1981). Of these, habitat alteration due to advancement of human settlement has had the greatest impact (Duncan 1960).

Desert bighorn sheep numbers in Arizona declined during the early part of this century, reaching an estimated low of 2,500 in the 1950s (Russo 1956). Although populations have increased due to intensive management, many herds are now isolated by highways, agriculture, mines, and other aspects of human encroachment (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*a*).

East (1983) considered habitat fragmentation to be the primary cause of the current extinction crises facing many species including desert bighorn sheep (Duncan 1960). Due to their high resource needs, resulting in large home ranges and low population densities, large mammals are especially susceptible to problems associated with habitat fragmentation (Wilcox and Murphy 1985). Shaffer (1981) suggested that genetic stochasticity, demographic uncertainty, environmental variation, and catastrophes all affect population persistence. Habitat fragmentation can exacerbate the effects of all these processes (Wilcox and Murphy 1985).

Bighorn sheep are adapted to steep, mountainous, open terrain (Geist 1971, Hansen 1980*a*). Steep, rugged topography is the most important and obvious terrain feature of bighorn sheep habitat (Holl 1982). These topographic features and, consequently, bighorn sheep populations, occur in a naturally fragmented distribution often separated by large areas of unsuitable habitat (Hansen 1980*a*). These habitats are relatively rare and the geologic conditions that created them occur at such a low rate that, effectively, no new habitats are being created (Geist 1967).

Bighorn sheep depend upon their keen eyesight and great agility on rocks to avoid predators (Geist 1971). These adaptations are reflected by the habitats they use. In general, bighorn sheep habitat must include adequate food and water resources, and rugged terrain suitable for predator avoidance (Hansen 1980*a*). These habitat components are often spread over large areas requiring seasonal movements by bighorn sheep (Welles and Welles 1961, Monson 1964, Geist 1971, Witham and Smith 1979, Cochran and Smith 1983, and Ough and deVos 1984).

Bighorn sheep population numbers tend to be stable within large blocks of high quality habitat (Berger 1990). Wilson et al. (1980:3) stated that "... all areas utilized by desert bighorn sheep are essential to their continued survival." Movement corridors between isolated blocks of habitat increase the probability that desert bighorn sheep can access key habitat components as well as provide a means for genetic exchange between sub-populations (Bleich et al. 1990*a*).

Mining and road building may negatively impact wildlife including bighorn sheep. Potential negative impacts to wildlife populations associated with industrial development include increased exposure to toxic chemicals, abandonment of impacted areas, and increased susceptibility to poaching and disease (Morgantini and Bruns 1988). Kuck (1986) concluded that, while big game populations could adapt to disturbance associated with phosphate mining in Idaho, they would be unable to compensate for lost habitat within critical seasonal ranges. Ungulates generally reduce their use of habitats near industrial activities (Perry and Overly 1976, Morgantini and Worbets 1988), and bighorn sheep may abandon an area associated with high human use (Jorgenson 1988).

Not all industrial impacts to bighorn sheep habitats are negative. Increased water availability, creation of steep talus slopes, removal of dense vegetative cover, and exposure of mineral seeps can all benefit bighorn sheep. MacCallum and Geist (1992) found that bighorn sheep were attracted to mineral licks and altered habitat associated with an abandoned open pit coal mine in Alberta. Elliot (1984) found that the use of active coal mines by Dall's sheep (*Ovis dalli*) reduced predation by wolves (*Canis lupus*) that avoided these areas.

In March 1992, as part of a land exchange, the Bureau of Land Management (BLM) provided the Southwestern Mining Department of ASARCO Inc. with 1,558 ha of land in the Silver Bell Mountains, near the Silver Bell Mine (Fig. 1). A large portion of the exchanged land (17%) lies between the Silver Bell and West Silver Bell mountain ranges. Desert bighorn sheep may use this area to move between the 2 mountain ranges (R. J. Olding, Ariz. Game and Fish Dep., pers. commun.). During the land exchange the Arizona Game and Fish Department (AGFD) recommended a conservation easement on the northern portion of the exchanged land to maintain a movement corridor for desert bighorn sheep (Fig. 1).

The desert bighorn sheep population of the Silver Bell and West Silver Bell mountains represents 1 of the last remaining desert bighorn sheep populations in the Tucson basin. Due to industrial, urban, and agricultural developments this population exists on an isolated island of habitat in southcentral Arizona. The future of this native sheep population is of particular concern due to this isolation. Isolation due to human encroachment is considered 1 of the most important factors limiting bighorn sheep populations (Gionfriddo and Krausman 1986). 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 are in jeopardy.

Published literature is equivocal relative to the impact of mining on bighorn sheep, and results

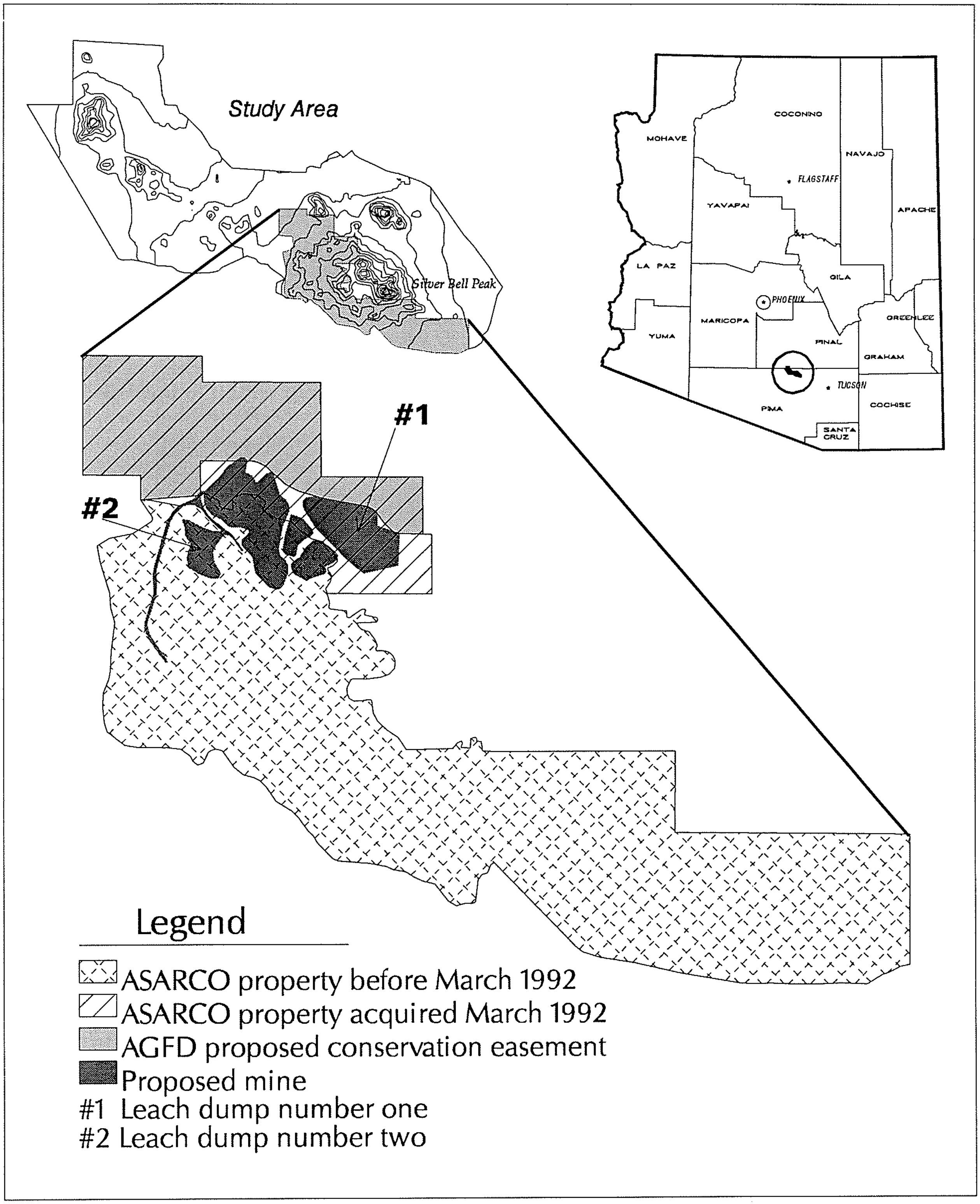


Figure 1. ASARCO property, proposed mine, and conservation easements within the Silver Bell Mountains, southern Arizona, 1993-96.

appear to be site-specific. Some bighorn sheep populations habituate to mining and other human activities (MacCallum and Geist 1992), while other populations avoid areas of activity (MacArthur et al. 1979). We investigated habitat use, behavior, movements, and demography of desert bighorn sheep in the Silver Bell and West Silver Bell mountains. We used these data to predict the potential impacts of mine expansion within the exchanged land relative to the proposed conservation easement. Specifically, our objectives were to:

- Evaluate desert bighorn sheep habitat quality in the Silver Bell and West Silver Bell mountains;

- Identify key habitats, (lambing-nursery, post-rut ram range, and escape terrain) in the Silver Bell and West Silver Bell mountains;

- Determine movement rates and identify movement corridors between the Silver Bell and the West Silver Bell mountains;

- Compare behavior, habitat use, home range size, and demography between areas of different levels of human use and habitat alteration within the study area; and

- Predict potential impacts of proposed mining within the newly acquired ASARCO property on the desert bighorn sheep population.

STUDY AREA

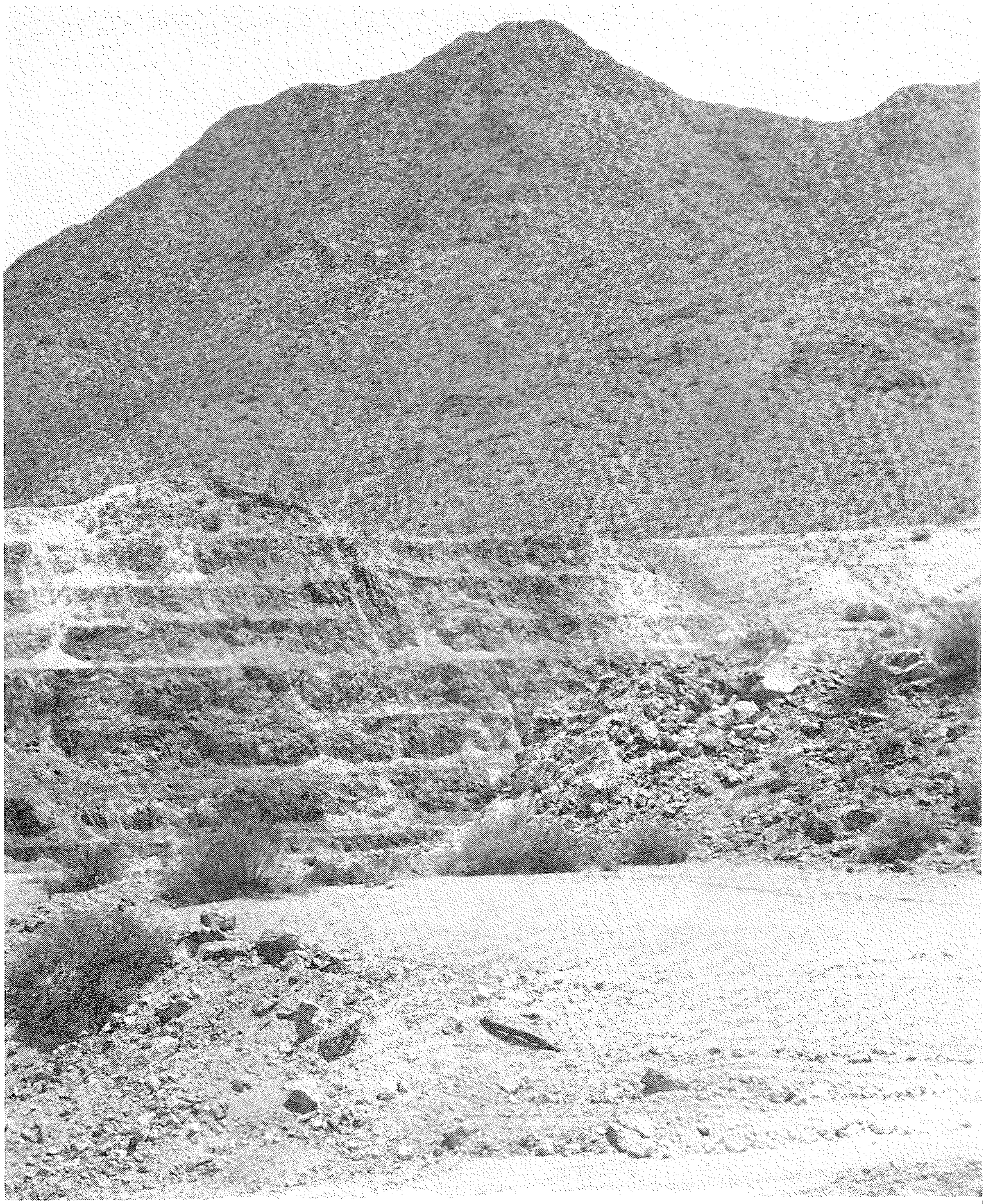
The Silver Bell study area (SBSA) consisted of an interconnected mountain complex comprised of the Silver Bell and West Silver Bell mountains (Fig. 1). The Silver Bell and West Silver Bell mountains are part of a series of low desert mountain ranges in southcentral Arizona. The SBSA encompassed 227 km^2 and included all areas of broken terrain and surrounding hills that are contiguous to this mountain complex. The mountain complex is oriented northwest-southeast and is approximately 9 by 25 km. The SBSA was 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 encompassed an elevational range from approximately 500 m at the lowest elevations to 1,290 m at Silver Bell Peak. The geology of the SBSA was complex with a variety of exposed rock. Parent rock material was composed primarily of basalt and granite with some limestone and shale present. Soils generally were coarse, rocky or cobbly with sandy soils occurring in the washes and low lying areas (Duncan et al. 1990). Annual precipitation at the ASARCO Silver Bell Mine averaged 31.8 cm since 1956. Rainfall pattern was bimodal with peaks in late summer (Jul-Sep) and winter (Dec-Feb). Mean summer temperatures were high with daytime highs commonly in excess of 38 C from June through September. Winter daytime high temperatures ranged from 15 to 20 C (Sellers and Hill 1974).

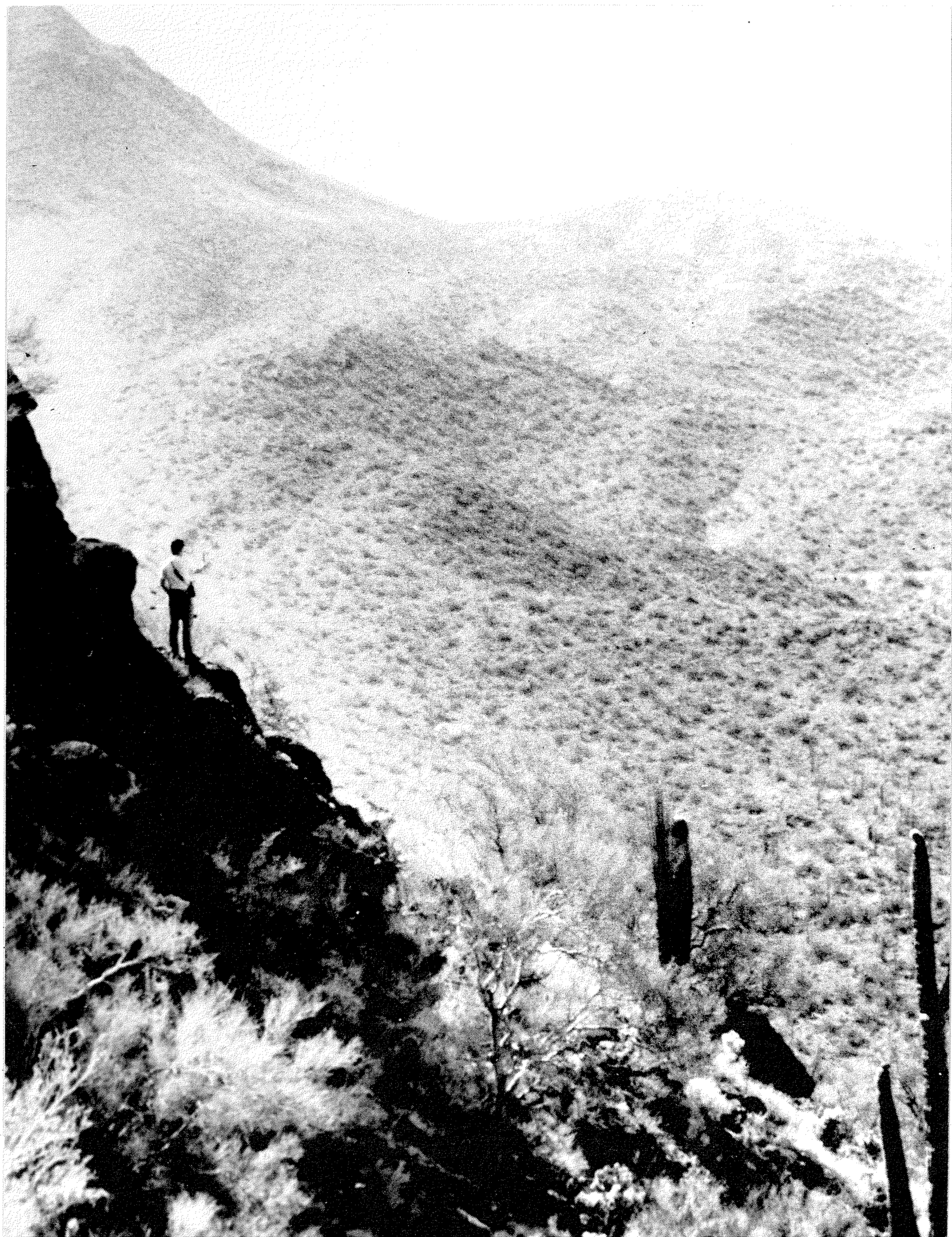
Four vegetation communities occurred within SBSA. A creosote (*Larrea tridentata*)-bursage (*Ambrosia deltoidea*) community dominated the lowest elevations. The hillsides were composed primarily of a palo verde (*Cercidium* spp.)-mixed cacti community. This community was dominated by foothill palo verde (*C. microphyllum*), saguaro (*Carnegiea gigantea*), and various prickly pear and cholla cacti (*Opuntia* spp.) (Turner and Brown 1982). A desert riparian community occurred along major washes and drainages. This community was dominated by palo verde, ironwood (*Olneya tesota*), mesquite (*Prosopis velutina*), and acacia (*Acacia* spp.) (Turner and Brown 1982). Jojoba (*Simmondsia chinensis*)-mixed scrub, a chaparral-like community dominated by jojoba, occurred at some of the upper elevation sites (Turner and Brown 1982).

Livestock grazing and mining were the primary land uses within 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 had been impacted by prior mining activity. Shafts, adits, mine dumps, and pits are scattered throughout SBSA, with the greatest concentration being at and near the ASARCO-owned Silver Bell Mine near Silver Bell Peak.

The existing Silver Bell Mine is an open pit copper mine encompassing approximately 6,000 ha located on the southeastern edge of the Silver Bell Mountains. There are 2 primary pits on the Silver Bell Mine covering approximately 1,600 ha, including leach dumps, tailings piles, haul roads, and other developed areas. During full operation the Silver Bell Mine employed over 300 workers and supported a community of 500 located on the southern edge of the mine property. Since the mine closed in 1984 ASARCO has maintained a crew of around 20 workers at the Silver Bell Mine and the community has been abandoned. Active ore extraction at Silver Bell Mine has not taken place since 1984, although there was some mineral leaching throughout the study.



The Silver Bell Mine is an open pit copper mine encompassing 6,000 ha on the southeastern edge of the Silver Bell Mountains.



METHODS

Capture and Telemetry

We captured desert bighorn sheep using a hand-held net gun fired from a helicopter (deVos et al. 1984). We fitted each desert bighorn sheep with a motion-sensing radio transmitter collar (Telonics Inc., Mesa, Ariz.). We aged captured rams by counting horn annuli and ewes by tooth eruption and replacement (Hansen and Deming 1980). We captured desert bighorn sheep across the study area as they were encountered to approximate the natural distribution of the population.

Between September 1993 and September 1995, we aerially located each radiocollared (marked) desert bighorn sheep ≥2 times/month using methods described by LeCount and Carrel (1979). Between September 1993 and February 1996, we visually located each marked desert bighorn sheep from the ground ≥30 times annually. We separated locations of individual marked animals by ≥24 hours to avoid autocorrelation of consecutive locations (Swihart and Slade 1985). When time constraints prohibited visual observation, we recorded ground triangulation locations. We plotted all locations on U.S. Geological Survey (USGS) 7.5′ topographical maps, and recorded Universal Transverse Mercator (UTM) coordinates for each.

We divided each year into a lambing and breeding season. The beginning of the lambing season was based upon the earliest known lambing date (Nov. 22) within the Silver Bell Mountains (AGFD unpubl. data). The beginning of the breeding season (May 18) was determined by subtracting the gestation period for desert bighorn sheep from the beginning of the lambing season (Turner and Hansen 1980). Ground locations were equally distributed between lambing (Nov 22 - May 17) and breeding (May 18 - Nov 21) seasons.

For each ground location we recorded: sex and age class, vegetation type, percent of vegetative cover, slope, elevation, aspect, and distance to escape terrain and permanent water. We classified each desert bighorn sheep observed into age and sex categories following Geist (1971). We classified each group of desert bighorn sheep that we observed as rams (all male), mixed (males and females), or ewes (all females including those with lambs and yearlings). At each ground location we recorded vegetation type as none (bare rock), creosote-bursage, palo verde-mixed cacti, desert riparian, or jojoba-mixed scrub (Turner and Brown 1982). We estimated the percent of vegetative cover for each ground location as the percent of a 1 ha^2 area centered on the location site that was covered by vegetation large enough to hide a standing adult desert bighorn sheep. We subjectively classified vegetative cover as: open = <10% cover, moderately open = 10-25% cover, moderately dense = 25-50% cover, and dense = >50% cover. We measured percent slope, elevation, and aspect, and we estimated distances to escape terrain and permanent water using USGS 7.5′ topographical maps for each ground location. We defined escape terrain as rugged, rocky areas with >60% slope (Holl 1982).

We delineated 3 study area subunits based on distinct areas of desert bighorn sheep use determined from observations of marked ewes (Fig. 2). 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. 2). The Ragged Top/Britton Peak (RTP) and West Silver Bell (WSB) subunits were located to the north and west of this area (Fig. 2). We compared behavior, habitat use, home range characteristics, and demography among ewe groups, which included groups of ewes and mixed groups, within the 3 subunits. We observed no interchange of marked ewes among the 3 subunits.

Habitat Quality

To evaluate desert bighorn sheep habitat at the finest scale possible, we gridded the entire study area into 28,025 cells each representing an area of 0.81 ha (90 m x 90 m). We chose a cell size representing the finest scale at which we could evaluate topography. We evaluated habitat within each cell according to Cunningham (1989) as modified by Ebert and Douglas (1994). We rated 5 habitat components; vegetation type, precipitation, water availability, human use, and natural topography (slope class). We collected most of the habitat data through field surveys and entered them into a geographic information system (GIS) for analysis.

We created a map of the SBSA showing the vegetation type of each cell, based upon the vegetative communities described earlier. We assigned the following scores to vegetation types to reflect increasing value to desert bighorn sheep with increasing score, after Cunningham (1989); bare rock or areas where vegetation had been removed = 0 points, creosote-bursage = 8 points, desert riparian = 12 points, palo verde-mixed cacti = 16 points, and jojoba-mixed scrub = 20 points. Each cell within SBSA received a vegetation type

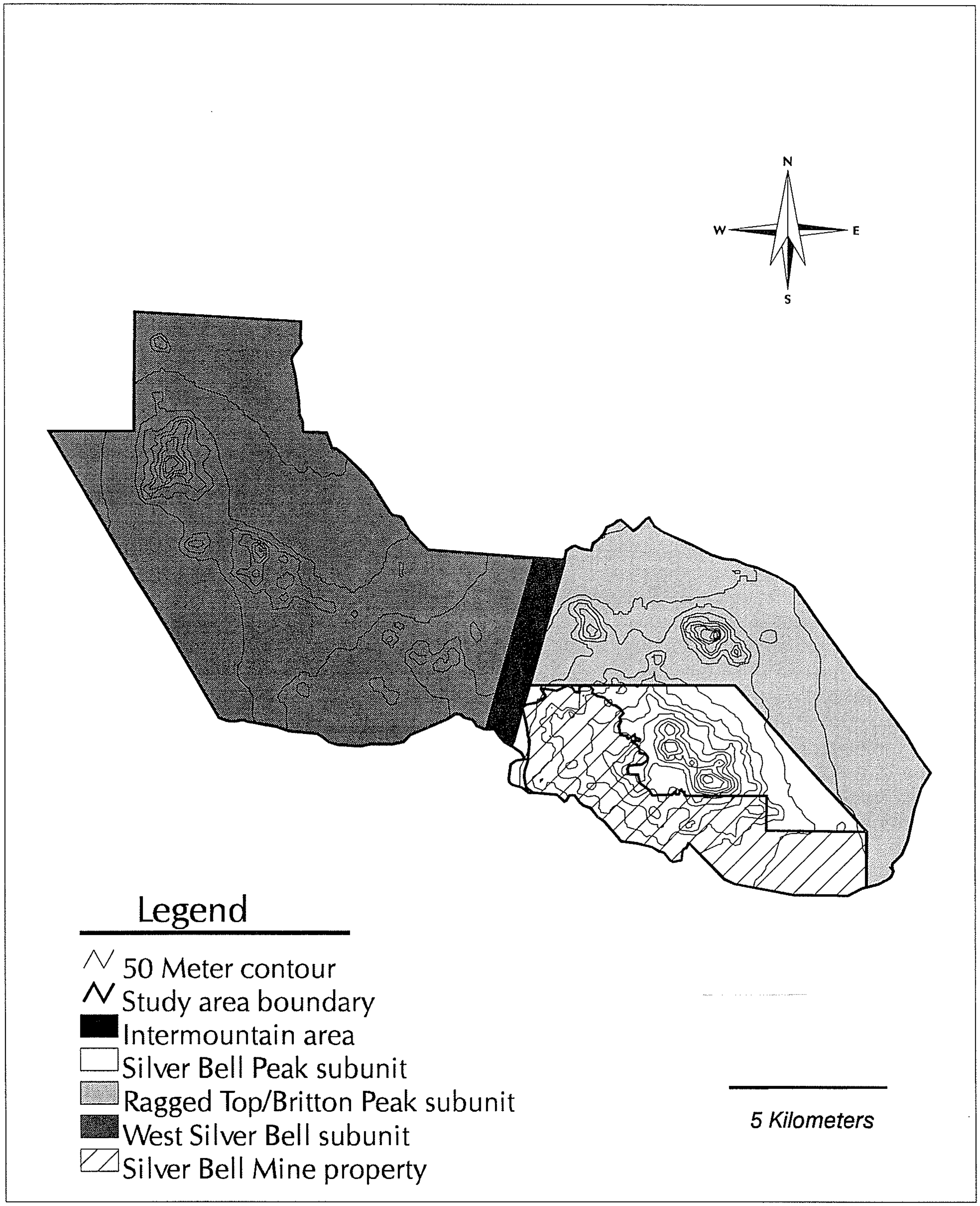


Figure 2. Silver Bell desert bighorn sheep study area and subunits, southern Arizona, 1993-96.

score based upon its dominant vegetation type.

We used historical rainfall records collected at the Silver Bell Mine to rate precipitation, and assumed precipitation to be uniform throughout the study area. We scored precipitation after Cunningham (1989), with a maximum possible score of 5 points. We located potential water sources within SBSA using USGS 7.5′ topographical maps, through ground surveys, and interviews with area ranchers, miners, and land managers. Each cell received a score between -10 and +5, based on its distance to the closest water source; cells <3.2 km received 5 points (Ebert and Douglas 1994). We rated each water source within the SBSA that we determined may have been visited by desert bighorn sheep. Water source scores were based on 3 criteria (Cunningham 1989); amount and permanence (≤5 points), type of terrain and obstruction (fences, corrals, thick vegetation, ≤5 points), and amount of use by native and introduced ungulates (≤5 points). Scores for each criterion were summed for a maximum score of 15 points for each water source. Permanent water sources located in or near rugged terrain with little or no ungulate use rated the highest. We assigned scores for water availability to each cell by adding the score of the closest water source to the score for distance to that water source (Ebert and Douglas 1994).

We evaluated each human activity within SBSA and subjectively categorized it as high, medium, or low density human use and/or economic potential after Cunningham (1989). We then subjectively assigned scores (0-10 points) to cells within these human activity areas based upon whether the activity precluded desert bighorn sheep use of the area (Ebert and Douglas 1994). We assigned increasing scores (11-20 points) to cells surrounding these areas of human activity to reflect the diminishing influence of human disturbance with increased distance from it (Ebert and Douglas 1994). Maximum possible score for the human use component (20 points) was assigned to areas that had low human use and were >300 m from any human activity area (Ebert and Douglas 1994).

We derived slope from the 1-degree Digital Evaluation Model (DEM) distributed by the Department of Defense. The 1-degree blocks are referred to as Digital Terrain Elevation Data Level 1 (DTED-1), and each cell represents an area 90 m x 90 m. Using the Arc/Info® Grid® module (Ver. 7.0) we developed a percent slope cover by identifying the maximum rate of change in elevation from each cell to neighboring cells. As an index of land surface ruggedness (LSRI), we calculated the mean slope total for each cell by adding the slope values within each 3 x 3 cell matrix and assigning the sum to the central cell. We assigned natural topography scores to each cell based upon the LSRI values. Cells with higher LSRI values (percent slope classes) received higher scores, with a maximum score of 20 for any cell (Ebert and Douglas 1994).

For each cell within SBSA we summed the scores of the 5 habitat components, with a maximum possible score of 85 for any cell. We then assigned each cell to a habitat quality class, after Ebert and Douglas (1994). Quality class ratings were: ≤45 points = poor; 46-60 points = fair; 61-74 points = good; and ≥ 75 points = excellent quality habitat. To test the influence of the human use component on the habitat quality rating system, we subtracted the human use component score from the habitat quality rating for each cell within SBSA. To ensure that the 2 habitat quality rating systems classified habitat in a comparable fashion, we assigned value ranges to habitat quality classes in the same percentages as Ebert and Douglas (1994). Quality class ratings for the habitat quality rating system without the human use component were: ≤33 points = poor; 34-45 points = fair; 46-56 points = good; and ≥ 57 points = excellent quality habitat.

We created a map of SBSA that showed the habitat quality class of each 0.81 ha cell for both habitat quality rating systems. To test the usefulness of each habitat quality rating system, we overlaid all desert bighorn sheep locations on each of these habitat quality rating maps and made comparisons to determine which was the better predictor of desert bighorn sheep use.

Key Habitats

We identified 3 key habitat types that are important to desert bighorn sheep: lambing-nursery habitat, pre- and post-rut ram habitat, and escape terrain. 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 recorded and plotted each location where a marked ewe was first observed with a newborn lamb; we used criteria from 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) (Jennrich and Turner 1969) for all bachelor ram and lambing-nursery locations. We used GIS to identify escape terrain (areas of steep, rugged terrain in excess of 60% slope). We mapped all 3 key habitat areas (lambing-nursery 30% HMUA, bachelor ram 30% HMUA, and escape terrain) and entered them into a GIS cover to predict potential impact of proposed mining.

Movement Corridors

To determine when a crossing of the intermountain area between the east and west portions of the study area occurred (Fig. 2), we recorded the study area subunit in which each marked animal could be found for each day of radiotracking (3-5 days/week). When we discovered that a marked animal had moved between east and west portions of the study area we recorded animal identification number, date, and time.

We estimated the total number of crossings of the intermountain area for 1994 and 1995. We conducted annual fall helicopter surveys in which all desert bighorn sheep observed within SBSA were recorded. We used a Lincoln-Peterson index of aerial survey data each year to estimate population size (Seber 1982). We multiplied the proportion of the marked population that made crossings by the estimated total population to estimate the number of desert bighorn sheep that made crossings. Then we multiplied the crossings/year/marked desert bighorn sheep by the number of desert bighorn sheep that made crossings. We charted the number of crossings/month to identify the season when the majority of crossings occurred.

To identify movement corridors, we used 2 remote receiving-recording telemetry units (Telonics, Mesa, Ariz.) that recorded the radiofrequency and time that a marked desert bighorn sheep came near the units. These units were placed in the intermountain area and oriented such that 1 unit scanned north and the other south; each receiver had a range of approximately 2 km. We monitored the units weekly during the spring and summer of 1994 and 1995, when most of the crossings occurred.

In all cases where desert bighorn sheep were observed within the intermountain area, we monitored them for a minimum of 1 hr to document movement route and behavior patterns. We recorded the exact route traveled, the amount of time observed, and the behavior of the marked animal.

Behavior

For all visual ground locations we classified the behavior of the marked animal as feeding, bedded, fleeing, sentry, traveling, nursing, mating, or watering. We also collected information on behavioral response of desert bighorn sheep to the presence of the observer. We recorded distance to observer (response distance), reaction to observer (flight or non-flight), distance desert bighorn sheep moved, and whether the observer was above or below the desert bighorn sheep. We assumed response distance represented a measure of desert bighorn sheep sensitivity to the observer and distance moved represented a measure of reaction strength. We compared behavior information between sexes and among ewes from different study area subunits.

Habitat Use

To determine if permanent water sources influenced desert bighorn sheep habitat use, we mapped all permanent water sources within SBSA and digitized them into a GIS database. We then generated contour buffers in 1 km intervals around all permanent water sources and calculated the proportion of SBSA within each buffer. We calculated the proportion of desert bighorn sheep locations within each distance buffer and determined selection or avoidance of each isometric buffer area by sex and among study area subunits.

To examine the effects of mining-related habitat alterations on desert bighorn sheep we mapped all areas on the Silver Bell Mine property where earth was disturbed including roads, pits, leach dumps, and tailings piles. We obtained this information from USGS 7.5′ topographical maps and updated it through ground surveys and interviews with ASARCO personnel. We then digitized all habitat alterations into a GIS database. We generated contour buffers of 200 m intervals around all disturbed areas and calculated the proportion of SBSA within each buffer. For all desert bighorn sheep locations that were ≤ 1 km of disturbed habitats, we calculated the proportion within each 200 m buffer and determined selection or avoidance of each isometric buffer area by sex and season.

We overlaid a map of the proposed mine (pits, roads, and leach dumps) on maps of each of the 3 key habitat areas (lambing-nursery 30% HMUA, bachelor ram 30% HMUA, and escape terrain) to estimate the total area of each that would be affected. We also rated the quality of desert bighorn sheep habitat within the proposed mine. Incorporating results from our estimates of habitat use, effects of habitat alterations, and desert bighorn sheep behavior, we made predictions on how the desert bighorn sheep would react to the new mine.

Home Ranges

We estimated annual home range characteristics for each 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 ≥50 locations (Bekoff and Mech 1984). We also calculated average distance moved 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.

Demography

We calculated lambs:100 ewes, and yearlings:100 ewes to estimate productivity for each subunit. These estimates were based upon ground observations of marked and unmarked ewes obtained during radiotracking. During each lambing season, we calculated the number of lambs:ewe for each group of desert bighorn sheep observed to estimate lambs:100 ewes for each subunit. As an index of recruitment, we used the same survey method to estimate yearlings:100 ewes for each subunit.

During breeding seasons of 1994 and 1995 we conducted helicopter surveys and recorded all desert bighorn sheep observed within SBSA. We aerially located each marked animal immediately before and after each helicopter survey to establish the number of marked animals available to be observed during the survey. Personnel surveying desert bighorn sheep from the helicopter were not advised of the location or number of marked animals available until after the survey. We used a Lincoln-Peterson index of aerial survey data 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 monitored all radio transmitters for mortality pulse rates 3-5 times/week during normal ground and aerial telemetry. When a mortality signal was detected we investigated the site within 2 days to determine the cause and date of death. We categorized mortalities as disease, predation, hunter harvest, or unknown. We used criteria from Honess and Winter (1956) to identify common lesions associated with diseased desert bighorn sheep carcasses. Whenever possible we collected samples from desert bighorn sheep carcasses for analysis at the University of Arizona Veterinary Diagnostic Laboratory. We determined predator identity from kill remains using criteria from Woolsey (1985) and Shaw (1990). All bighorn sheep hunters are required to check their rams through an AGFD office and provide information on date, time, and location of harvest. We used the software program MICROMORT (version 1.1; Heisey and Fuller 1985) to calculate gender-specific survival rates from radiotelemetry data.

Statistical Analyses

We used a Kolmogorov-Smirnov 1-sample test to determine if frequency distributions of each data set differed from a normal distribution (Zar 1984). We used nonparametric tests for all data sets that were not normally distributed. All statistical tests were considered significant when $\alpha \leq 0.05$. For chi-square goodness-of-fit tests, we used data from the habitat quality evaluation to establish availability of each habitat parameter throughout SBSA and by subunit.

Habitat Quality. We tested the 2 habitat quality rating systems throughout SBSA (with and without human use) by comparing desert bighorn sheep use with availability within habitat quality classes. We used chi-square goodness-of-fit to determine if desert bighorn sheep used habitat quality classes in proportion to their availability. If use differed from availability, we calculated Bonferroni confidence intervals (Neu et al. 1974). If the percent area available within a particular habitat quality class was outside the Bonferroni confidence interval, then we calculated Jacobs' D (Jacobs 1974) to determine magnitude of selection.

We compared the distribution of the area within habitat quality classes between the 2 habitat quality rating systems using a chi-square contingency test. We also used a chi-square contingency test to determine if differences existed between the 2 habitat quality rating systems within the Silver Bell Mine property where human use was greatest and where human use scores were lowest. To determine if desert bighorn sheep used habitat quality classes regardless of human use score, we contrasted the chi-square goodness-of-fit, Bonferroni confidence intervals, and Jacobs' D values between each habitat quality rating system within the Silver Bell Mine property.

Key Habitats. We used 2-sample t-tests to compare elevations and average group size between key habitat locations, (bachelor ram and lambing-nursery) and locations of rams and ewes obtained during the rest of the year. We compared aspect and distance to escape terrain between key habitat locations and locations of rams and ewes obtained during the rest of the year using non-parametric Mann-Whitney *U* tests (Zar 1984). For bachelor ram and lambing-nursery locations, we used chi-square goodness-of-fit, Bonferrroni confidence intervals, and Jacobs' *D* to test for selection-avoidance of vegetation type, slope class, and habitat quality classes.

Movement Corridors. To determine if the crossing rate differed between years we compared the number of known crossings of marked desert bighorn sheep of the intermountain area between 1994 and 1995 using a Mann-Whitney *U* test.

Behavior. To determine if desert bighorn sheep behavior was different near the mine we compared seasonal distribution of behavior classes of ewe groups within different study area subunits using chi-square contingency tests. We compared the distance that the observer could approach before a flight response was elicited (response distance) and the distance fled by herd composition class and among ewes of the 3 different study area subunits using Kruskal-Wallis ANOVA. We compared behavioral response variables within sexes between seasons using Mann-Whitney *U* tests.

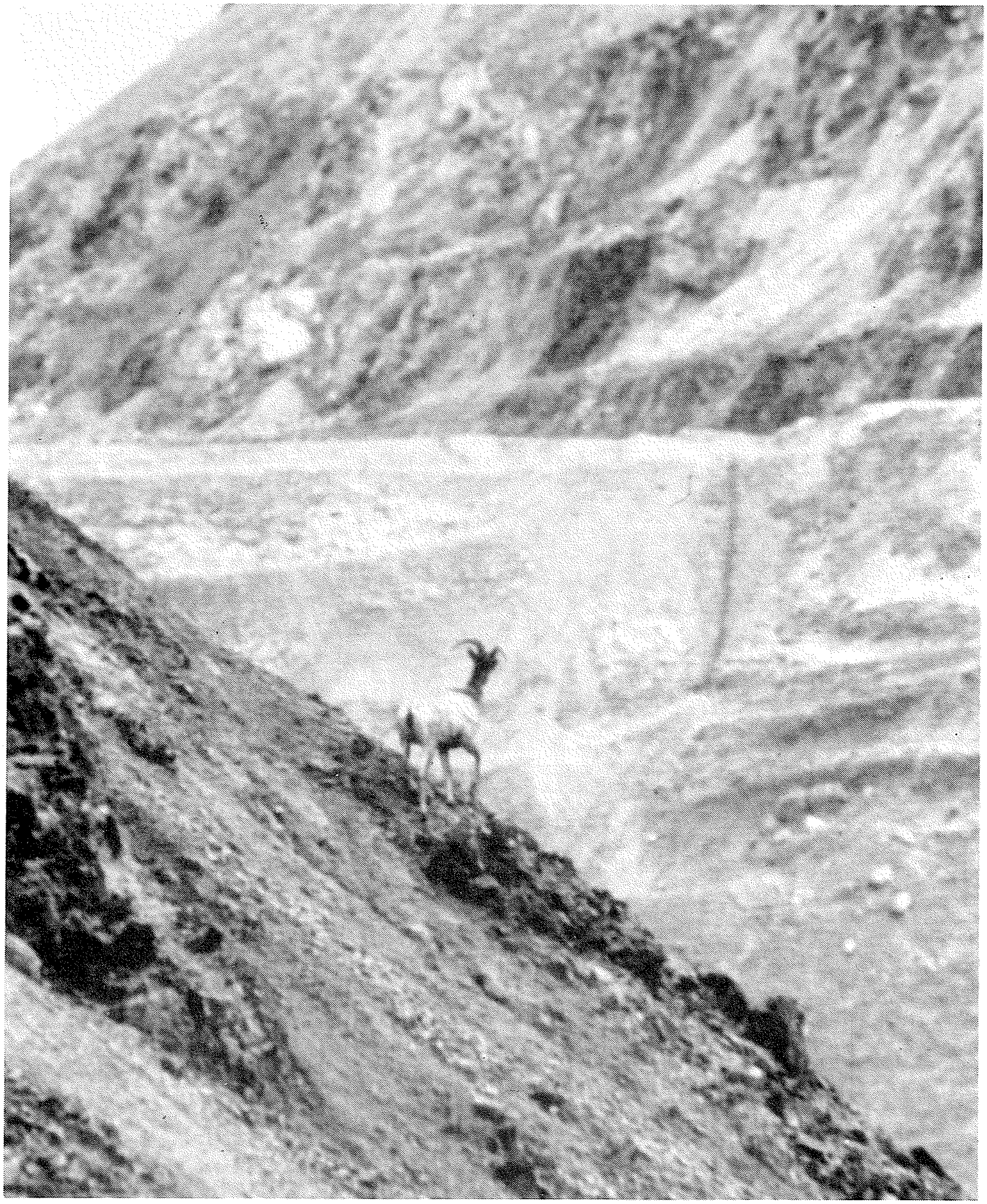
Habitat Use. We used chi-square goodness-of-fit, Bonferroni confidence intervals, and Jacobs' *D* to test for seasonal selection by rams and ewes within slope classes, distance to water categories, and vegetation types. We compared seasonal use of vegetative cover classes between sexes by using a chi-square contingency test.

We used chi-square goodness-of-fit, Bonferroni confidence intervals, and Jacobs' *D* to test for selection within slope classes, distance to permanent water categories, and vegetation types by ewe groups within different study area subunits. We compared seasonal use of vegetative cover classes by ewe groups of different study area subunits by using chi-square contingency tests. We compared seasonal use of slope, aspect, and distance to escape terrain among ewe groups of different study area subunits using Kruskal-Wallis ANOVA.

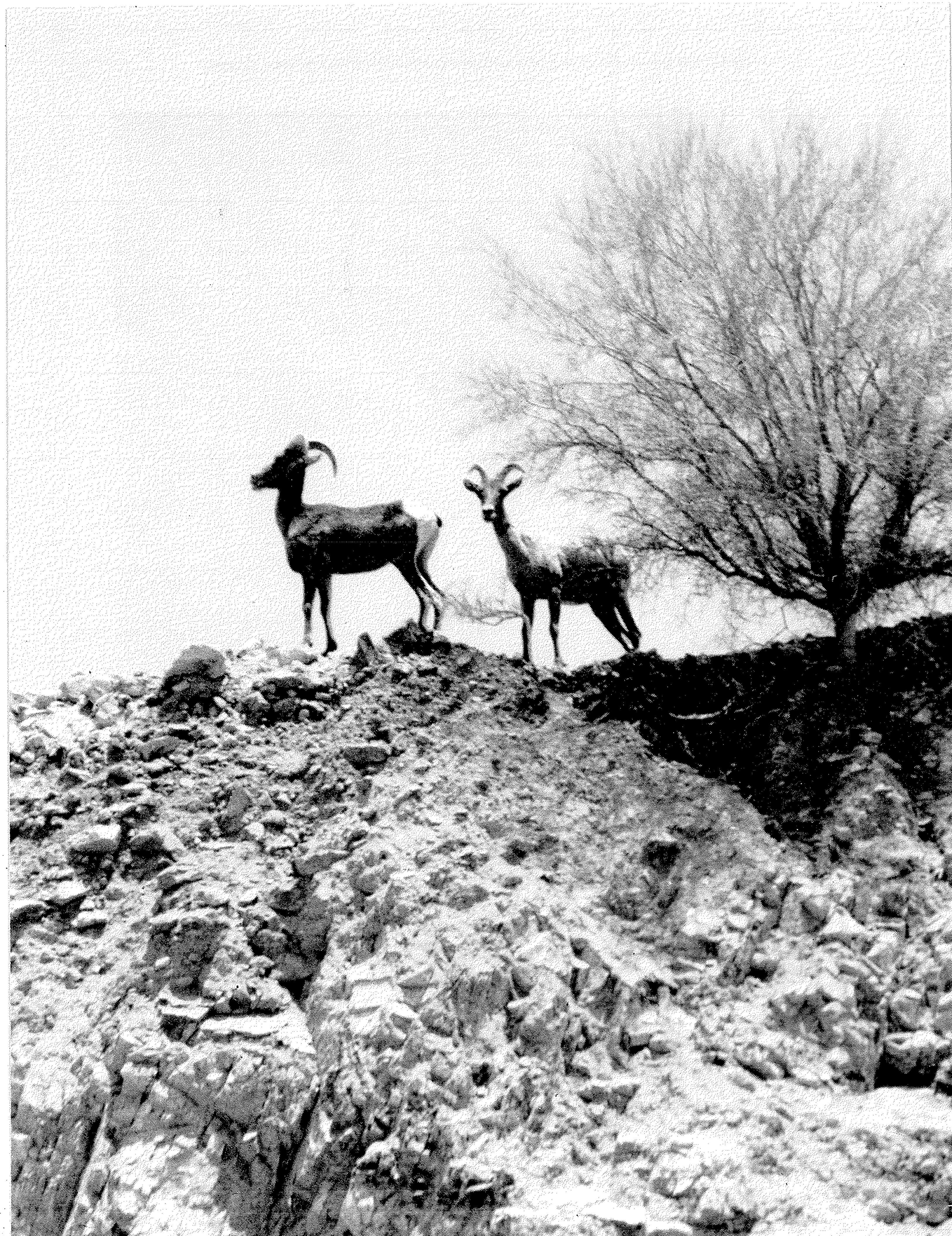
Within the SBP subunit we tested sheep locations $\leq$1 km of disturbed areas for selection-avoidance of 200 m isometric buffer areas using chi-square goodness-of-fit, Bonferroni confidence intervals, and Jacobs' *D*. We also calculated chi-square goodness-of-fit, Bonferroni confidence intervals, and Jacobs' *D* values within sexes and seasons, to determine differences in use of disturbed areas.

Home Ranges. We calculated average home range, core area, and $\bar{x}$ distance between consecutive locations for males and females and tested for differences in home range characteristics between sexes using Mann-Whitney *U* tests. We also compared home range characteristics of ewes within different study area subunits using Mann-Whitney *U* tests.

Demography. We compared productivity estimates among ewe groups within different study area subunits using Kruskal-Wallis ANOVA and Mann-Whitney *U* tests. We compared survival rates between mined and unmined subunits, and between sexes using Z tests (Heisey and Fuller 1985).



Radiocollared ewe located in the oxide pit area of the Silver Bell Mine.



RESULTS

Capture and Telemetry

We radiocollared 22 desert bighorn sheep (11 M, 11 F) in the SBSA during 3 capture operations conducted between September 1993 and December 1994 (Table 1). Between September 1993 and February 1996, we recorded 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%.

Habitat Quality

The SBSA was composed of 3% excellent, 13% good, 61% fair, and 23% poor quality desert bighorn sheep habitat (Fig. 3). Habitat quality ratings ranged from 19 to 84 ($\bar{x}$ = 51.4, *SE* = 10.26). Most of the excellent quality habitat occurred in the vicinity of Silver Bell and Ragged Top peaks. These areas contained a combination of steep slopes and jojoba-mixed scrub vegetation. There was <0.001% excellent quality habitat in the WSB subunit and only 10.6% was rated as good quality habitat. The WSB contained no jojoba-mixed scrub vegetation, had reduced water availability, and topography was generally less steep.

Throughout SBSA, desert bighorn sheep selected habitat that rated good and excellent and avoided habitat that was rated as fair or poor (Table 2). Within the RTP and WSB subunits, ewe groups consistently selected the highest scoring habitats available (Table 2). However, within SBP, where human use was greatest, ewe groups selected areas rated as fair, and avoided areas rated as good (Table 2). This pattern of habitat use was similar to that found on the Silver Bell Mine property (within the SBP subunit).

When we excluded the human use component from analyses, the SBSA was composed of 1% excellent, 14% good, 66% fair, and 19% poor quality desert bighorn sheep habitat (Fig. 4). For the entire study area, the distribution of area within each habitat quality rating class was not significantly different between the 2 habitat quality rating systems (X^2 = 3.4, 3 df, P = 0.331). Excluding the human use component had little effect on the habitat quality scores within WSB because human use was very low within this subunit (Table 3). However, within the Silver Bell Mine property the distribution of habitat quality classes was significantly different between the 2 habitat quality rating systems (X^2 = 9.05, 2 df, P = 0.010). Many areas on the Silver Bell Mine that were rated as fair quality when human use scores were included, were rated as good quality when they were excluded (Fig. 4). The habitat quality rating system excluding the human use component more closely reflected desert bighorn sheep use patterns. Within the mine, when human use scores were excluded, desert bighorn sheep selected good quality habitat, and avoided fair and poor quality habitat (Table 4). When human use scores were included, desert bighorn sheep selected fair quality habitat and used good quality habitat according to availability (Table 4).

Key Habitats

We documented 19 lambing site and 206 nursery site locations during 3 lambing seasons (Fig. 5). Most (83%) of the marked ewes were first observed with young lambs between December and March (Fig. 6). Given a gestation of 180 days (Turner and Hansen 1980), the peak of the breeding season would be June to August. Most lambing-nursery locations were in the RTP and SBP subunits. Some ewes were observed with young lambs in and near the mine pits and leach dumps of SBP. Average group sizes were larger for ewes during the lambing season ($\bar{x}$ = 4.0, SE = 0.15) than during the breeding season ($\bar{x}$ = 2.7, SE = 0.14, t = 5.94, P < 0.001). The $\bar{x}$ elevation for lambing-nursery locations was 1,016 m (SE = 8.5), the median aspect was 180° (P_{25} = 70°, P_{75} = 230°), and the median distance to escape terrain was 0 m (P_{25} = 0.0 m, P_{75} = 0.0 m). Lambing-nursery site elevations were higher (t = 5.27, P < 0.001) and distances to escape terrain shorter (U = 12,116, P = 0.001) than for locations of ewes obtained during the rest of the year. Among ewes, aspect use during the lambing season differed from those of the breeding season (U = 12,078, P = 0.015). The median aspect for ewe locations was 200° (P_{25} = 143°, P_{75} = 273°) for the breeding season. Because marked ewes did not move between subunits we calculated 30% harmonic mean use areas (HMUA) for SBP and RTP subunits. We were unable to collect enough lambing-nursery locations within WSB to calculate a 30% HMUA. The 30% HMUA for lambing-nursery locations encompassed 11.4 km² in SBP and 0.2 km² in RTP (Fig. 5). During the lambing season, ewes with lambs selected the jojoba-mixed scrub and bare rock vegetation types (Table 5). Ewes with lambs also selected slope classes >20% (Table 6).

Table 1. Desert bighorn sheep captured and fitted with radio collars within the Silver Bell study area, southern Arizona, 1993-94.

Date	Sex	Age at capture[a]	Subunit
Sept. 8, 1993	ram	7 - 8 years	Silver Bell Peak
Sept. 8, 1993	ram	8 - 9 years	Ragged Top
Sept. 8, 1993	ram	4 - 5 years	Ragged Top
Sept. 8, 1993	ram	5 years	Ragged Top
Sept. 9, 1993	ram	≤1 year	West Silver Bell Mts.
Sept. 9, 1993	ram	9 years	West Silver Bell Mts.
Sept. 9, 1993	ram	5 years	West Silver Bell Mts.
Nov. 15, 1993	ewe	3 - 4 years	Silver Bell Peak
Nov. 15, 1993	ewe	7 years	Silver Bell Peak
Nov. 15, 1993	ewe	2 - 3 years	Silver Bell Peak
Nov. 15, 1993	ram	6 - 7 years	Ragged Top
Nov. 15, 1993	ewe	7 - 8 years	Ragged Top
Nov. 16, 1993	ewe	4 - 5 years	Ragged Top
Nov. 16, 1993	ewe	6 years	West Silver Bell Mts.
Nov. 16, 1993	ewe	7 - 8 years	West Silver Bell Mts.
Nov. 16, 1993	ewe	6 years	Ragged Top
Dec. 22, 1994	ewe	4 years	Ragged Top
Dec. 22, 1994	ram	≤1 year	Silver Bell Peak
Dec. 22, 1994	ewe	8 - 9 years	Silver Bell Peak
Dec. 22, 1994	ewe	6 years	Silver Bell Peak
Dec. 22, 1994	ram	4 years	Silver Bell Peak
Dec. 22, 1994	ram	5 years	Ragged Top

[a] Age determined by tooth replacement and horn annuli (Hansen and Deming 1980).

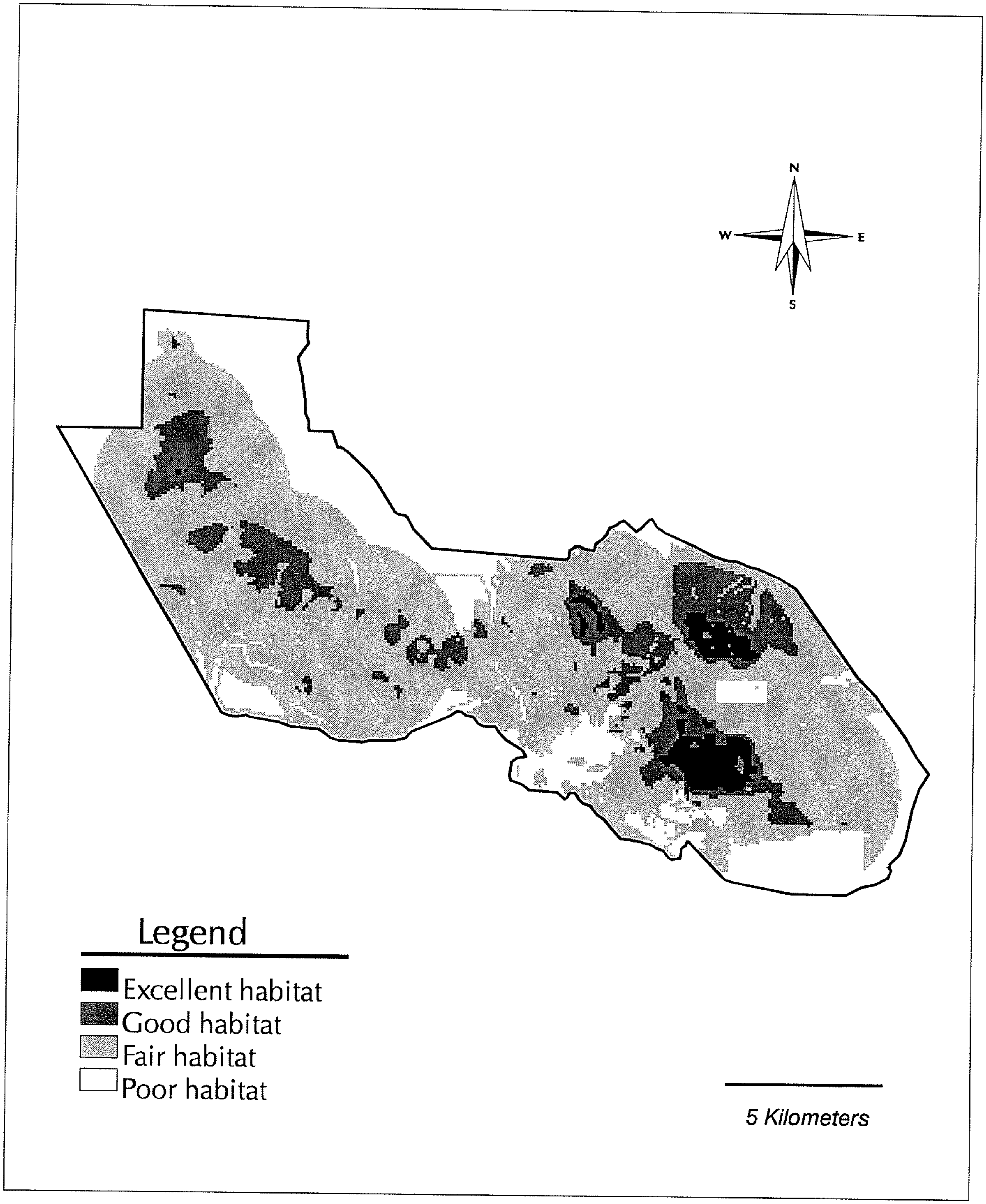


Figure 3. Desert bighorn sheep habitat quality zones within the Silver Bell study area, southern Arizona, 1993-96.

Table 2. Desert bighorn sheep use of areas with different habitat quality ratings compared with availability within the Silver Bell study area (SBSA), Ragged Top Peak (RTP) subunit, Silver Bell Peak (SBP) subunit, and West Silver Bell (WSB) subunit, southern Arizona, 1993-96.

Area	Habitat quality rating	No. of locations	% of locations	% of area	No. of locations expected	Bonferroni 90% CI	Jacobs' D[a]
	Poor	29	3.7	23.2	250.6	2.6 - 5.3	-0.75
SBSA	Fair	219	28.3	60.0	653.0	24.9 - 31.1	-0.60
	Good	208	26.9	13.3	143.5	24.0 - 30.0	+0.41
	Exc.	318	41.1	3.1	33.0	37.7 - 44.4	+0.92
	Poor	0	0.0	11.3	42.6	0 - 0	-1.00
RTP	Fair	13	3.4	63.8	241.2	28.5 - 39.5	-0.55
	Good	81	21.4	20.7	78.3	16.7 - 26.1	
	Exc.	284	75.2	4.2	15.8	70.2 - 80.2	+0.97
	Poor	36	10.6	32.3	110.2	6.9 - 14.3	-0.60
SBP	Fair	194	56.9	46.9	159.9	50.9 - 62.9	+0.20
	Good	24	7.0	12.3	41.9	- 0.3 - 1.7	-0.90
	Exc.	87	25.5	8.5	29.0	20.2 - 30.8	+0.57
	Poor	0	0.0	24.3	13.4	0 - 0	-1.00
WSB	Fair	4	7.3	65.0	35.8	- 0.1 - 14.8	-0.92
	Good	51	92.7	10.6	5.8	85.2 - 100	+0.98

[a] Use differed from availability for: SBSA (X^2 = 5,590.0, 3 df, $P < 0.001$, n = 1,080), RTP (X^2 = 4,809.9, 3 df, $P < 0.001$, n = 378), SBP (X^2 = 180.9, 3 df, $P < 0.001$, n = 341), and WSB (X^2 = 393.9, 2 df, $P <$ 0.001, n = 55). Jacobs' D indicates direction and magnitude of avoidance or selection.

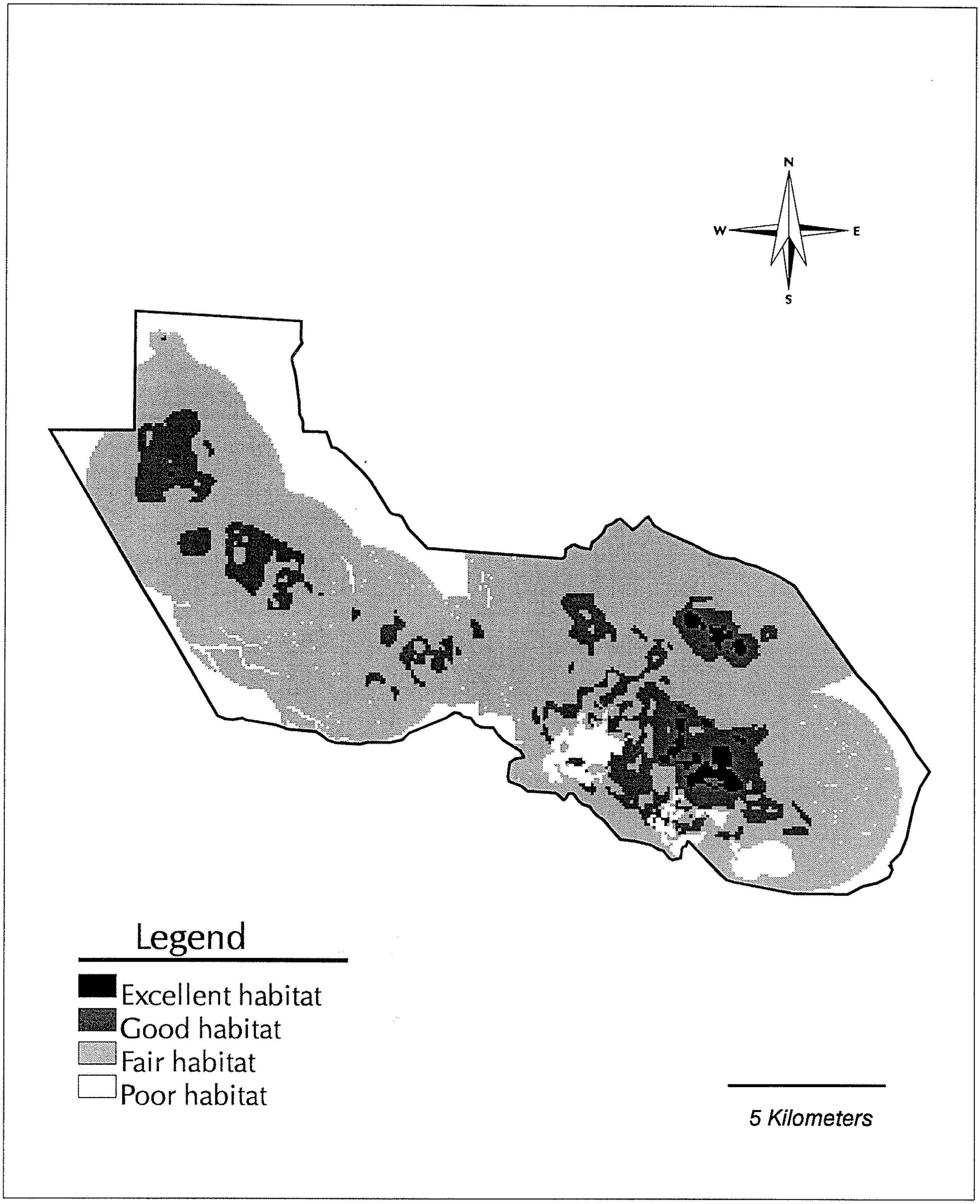


Figure 4. Desert bighorn sheep habitat quality zones, excluding the human use factor, within the Silver Bell study area, southern Arizona, 1993-96.

Table 3. The quantity and percent of area within each habitat quality rating class for each habitat quality rating system among the Ragged Top Peak (RTP), Silver Bell Peak (SBP), and West Silver Bell (WSB) subunits, southern Arizona, 1993-96.

Subunit	Habitat quality rating[a]	km²	% of area	Habitat quality rating[a]	km²	% of area
RTP	Poor I	6.16	11.1	Poor II	5.19	9.4
	Fair I	35.02	63.4	Fair II	43.24	78.2
	Good I	11.38	20.7	Good II	5.88	10.6
	Exc. I	2.66	4.8	Exc. II	0.96	1.7
SBP	Poor I	16.29	32.3	Poor II	7.40	14.7
	Fair I	23.67	46.9	Fair II	26.88	53.3
	Good I	6.16	12.2	Good II	13.62	27.0
	Exc. I	4.25	8.4	Exc. II	2.52	5.0
WSB	Poor I	29.51	24.2	Poor II	30.01	24.6
	Fair I	78.94	64.8	Fair II	79.23	65.1
	Good I	12.77	10.5	Good II	12.46	10.2
	Exc. I	0.05	<0.001	Exc. II	0.05	<0.001

[a] I Habitat rating including human use scores. II Habitat rating excluding human use scores.

Table 4. Desert bighorn sheep use compared with availability of areas of different habitat quality ratings, using 2 habitat rating methods within the Silver Bell Mine property, southern Arizona, 1993-96.

Habitat quality rating[a]	No. of locations	% of locations	% of area	No. of locations expected	Bonferroni 90% CI	Jacobs' D[a]
Poor I	39	16.0	53.1	129.6	10.7 - 21.2	-0.71
Fair I	202	82.8	45.9	111.9	77.6 - 88.4	+0.70
Good I	3	1.2	1.0	2.9	0.4 - 2.4	
Exc. I	0	0.0	0.0	0.0	0 - 0	
Poor II	24	9.8	25.6	62.5	5.6 - 14.1	-0.52
Fair II	66	27.0	54.7	133.4	20.6 - 33.4	-0.53
Good II	154	63.1	19.6	47.9	56.2 - 70.0	+0.75
Exc. II	0	0.0	0.1	0.2	0 - 0	

[a] I Habitat rating including human use scores. II Habitat rating excluding human use scores.

[b] Use differed from availability for I (X^2 = 136.0, 2 df, $P < 0.001$, n = 244), and II (X^2 = 57.8, 2 df, $P <$ 0.001, n = 244). Jacobs' D indicates direction and magnitude of avoidance or selection.

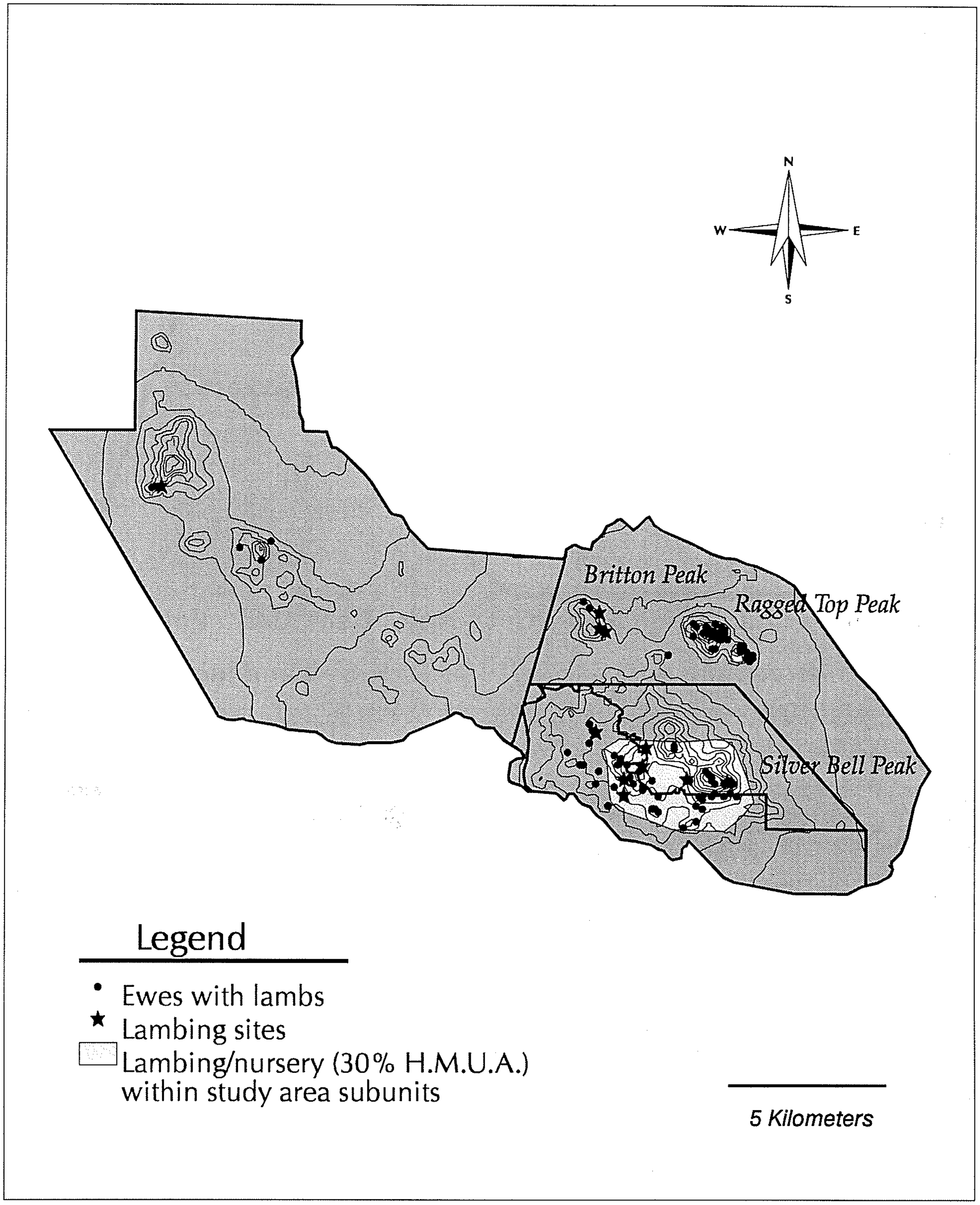


Figure 5. Lambing-nursery locations and 30% harmonic mean use area (30% HMUA) within the Silver Bell study area, southern Arizona, 1993-96.

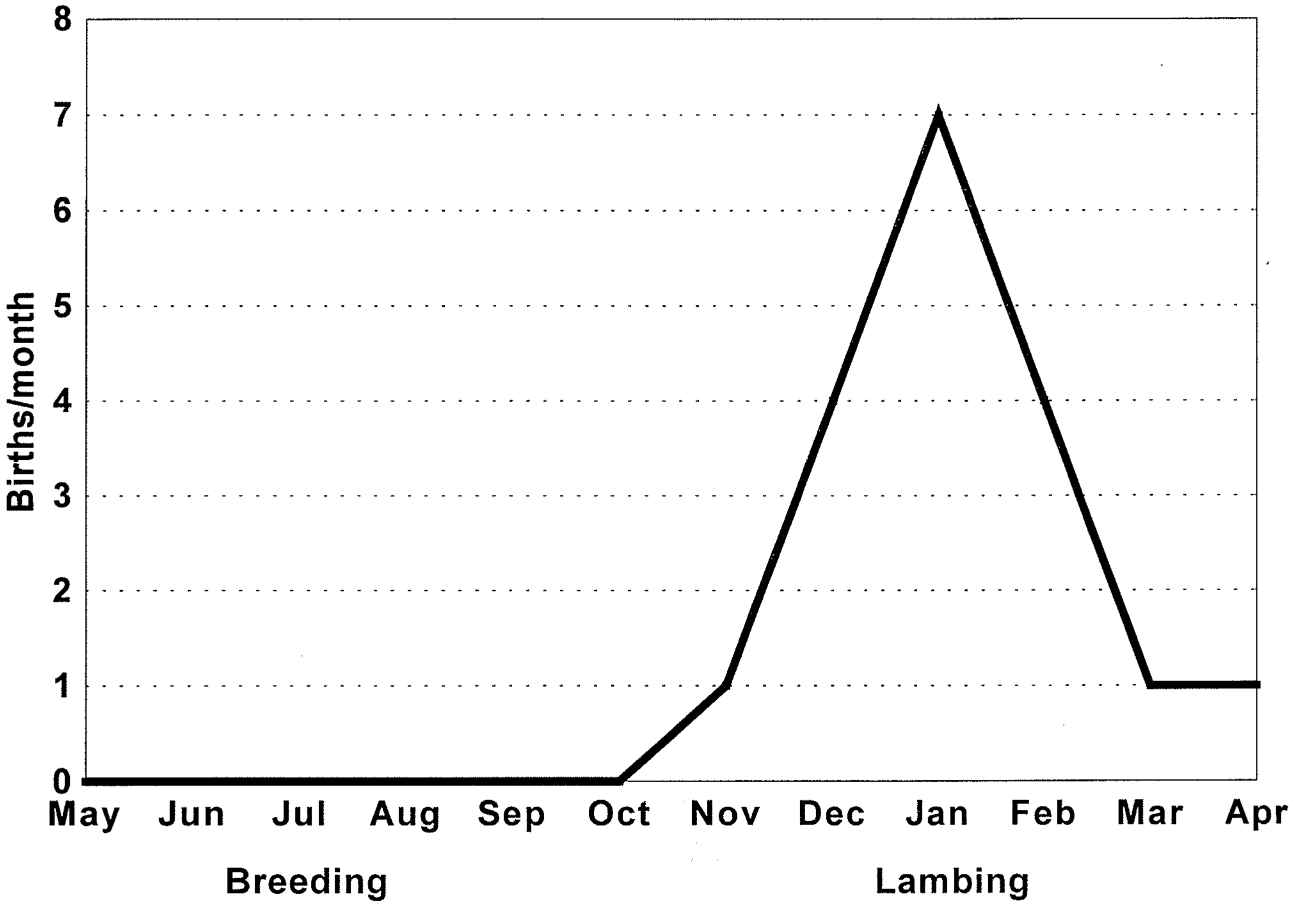
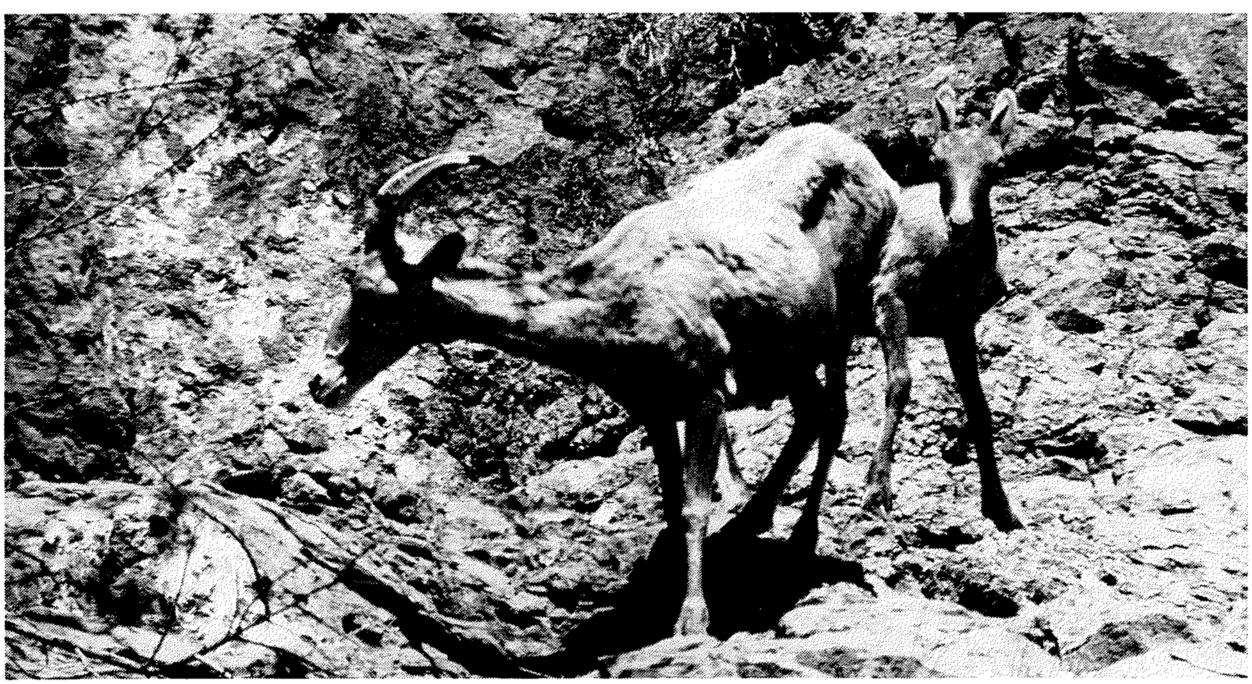


Figure 6. Number of lambs born to marked ewes by month within the Silver Bell study area, southern Arizona, 1993-96.



Some ewes were observed with lambs in and near the mine pits on the Silver Bell Mine.

Table 5. Seasonal use of vegetation classes by rams and ewes compared with vegetation class availability, Silver Bell study area, southern Arizona, 1993-96.

Sex-Season	Vegetation Type	No. of locations	% of locations	% of area	No. of locations expected	Bonferroni 90% CI	Jacobs' D[a]
	bare rock	0	0.0	3.2	3.4	0 - 0	-1.0
Rams-	creosote	0	0.0	4.6	4.8	0 - 0	-1.0
Breeding	riparian	3	2.9	3.2	3.4	-0.9 - 6.7	
	palo verde	74	70.4	84.7	88.9	60.0 - 80.8	-0.40
	jojoba	28	26.7	4.2	4.5	16.6 - 36.8	+0.79
	bare rock	2	1.7	3.2	3.7	-1.0 - 4.4	
Ewes-	creosote	0	0.0	4.6	5.4	0 - 0	-1.0
Breeding	riparian	1	0.9	3.2	3.7	-1.1 - 2.9	-0.57
	palo verde	63	53.8	84.7	99.1	43.1 - 64.5	-0.65
	jojoba	51	43.6	4.2	4.9	32.9 - 54.3	+0.89
	bare rock	1	0.8	3.2	3.8	-1.1 - 2.7	-0.61
Rams-	creosote	0	0.0	4.6	5.5	0 - 0	-1.0
Lambing	riparian	2	1.7	3.2	3.8	-1.1 - 4.4	
	palo verde	86	71.7	84.7	101.6	62.1 - 81.2	-0.37
	jojoba	31	25.8	4.2	5.0	16.5 - 35.1	+0.78
	bare rock	12	8.3	3.2	4.6	3.0 - 13.6	+0.47
Ewes and	creosote	1	0.7	4.6	6.7	0.1 - 2.3	-0.74
Lambs-	riparian	0	0.0	3.2	4.6	0 - 0	-1.0
Lambing	palo verde	69	47.6	84.7	122.9	37.9 - 57.3	-0.72
	jojoba	63	43.4	4.2	6.2	33.8 - 53.0	+0.89

[a] Use differed from availability for Rams-Breeding (X^2 = 133.5, 4 df, $P < 0.001$, n = 105), Ewes-Breeding (X^2 = 454.2, 4 df, $P < 0.001$, n = 117), Rams-Lambing (X^2 = 144.5, 4 df, $P < 0.001$, n =120), and Ewes and Lambs-Lambing (X^2 = 565.4, 4 df, $P < 0.001$, n = 145). Jacobs' D indicates direction and magnitude of avoidance or selection.

Table 6. Use of slope classes by bachelor rams (rams) and ewes with lambs (ewes) compared with slope class availability, Silver Bell study area, southern Arizona, Nov. 22 - May 18, 1993-96.

Sex	Slope Class	No. of locations	% of locations	% of area	No. of locations expected	Bonferroni 90% CI	Jacobs' D[a]
	0-20%	87	46.8	87.1	162.0	38.3 - 55.3	-0.77
	21-40%	68	36.6	0.0	18.6	28.4 - 44.8	+0.68
Rams	41-60%	25	13.4	2.4	4.5	7.6 - 19.2	+0.73
	61-80%	6	3.2	0.4	0.7	0.2 - 6.2	
	>80%	0	0.0	0.1	0.2	0 - 0	- 1.0
	0-20%	52	25.6	87.1	176.9	18.5 - 32.7	-0.90
	21-40%	67	33.0	10.0	20.3	25.3 - 40.7	+0.63
Ewes	41-60%	57	28.1	2.4	4.9	20.7 - 35.5	+0.88
	61-80%	12	5.9	0.4	0.8	2.0 - 9.8	+0.88
	>80%	15	7.4	0.1	0.1	3.1 - 11.7	+0.98

[a] Use differed from availability for rams (X^2 = 299.6, 4 df, $P < 0.001$, n = 186) and ewes (X^2 = 3,126.5, 4 df, $P < 0.001$, n = 203). Jacobs' D indicates direction and magnitude of avoidance or selection.

We recorded 186 bachelor ram locations (Fig. 7). We seldom located ram-only groups on the Silver Bell Mine property, especially during the lambing season. During the lambing season, 7.2% of ram-only group locations were on the mine property compared to 17.6% for the remainder of the year. Average group sizes were larger for rams during the lambing season ($\bar{x}$ = 2.0, SE = 0.10) than during the breeding season ($\bar{x}$ = 1.3, SE = 0.06, t = 5.37, $P < 0.001$). Mean elevation was 861 m (SE = 9.3) and the median distance to escape terrain was 50 m (P_{25} = 0.0 m, P_{75} = 150 m) for bachelor ram locations. Among rams elevations (t = 1.74, P = 0.082) and distance to escape terrain (U = 10,751, P = 0.087) were not significantly different between seasons. Aspect values for ram locations were different between seasons (U = 9,217, $P < 0.001$). The median aspect for ram locations was 150° (P_{25} = 50°, P_{75} = 250°) during the lambing season and 255° (P_{25} = 60°, P_{75} = 320°) during the breeding season. The 30% harmonic mean use area for bachelor ram locations encompassed 13.7 km² (Fig. 7). During the lambing season bachelor rams selected jojoba-mixed scrub and avoided bare rock (Table 5). Bachelor rams also selected slope classes ≥20% and ≤60% during the lambing season (Table 6).

During the lambing season ewes with lambs and bachelor rams selected areas that were rated as good or excellent (Table 7). Jacobs' D selection values for ewes with lambs exhibited a wider range than those for bachelor ram locations (Table 7). During the lambing season bachelor rams were less selective relative to habitat ratings than ewes with lambs (Table 7).

Escape terrain accounted for only 0.7% of SBSA. The WSB subunit had less escape terrain (0.2%) than other subunits. Escape terrain availability was similar between the SBP (0.8%) and RTP subunits (0.8%) (Fig. 8).

Movement Corridors

Rams moved between all 3 study area subunits, however, there was no interchange of marked ewes between subunits. We recorded 33 intermountain crossings by marked rams between the Silver Bell and West Silver Bell mountains; these movements occurred between May 20 and February 28 each year. Crossings were usually made during the breeding season (Jun - Dec; n = 27; Fig. 9). Individual marked rams crossed once at the beginning of the breeding season and then back at

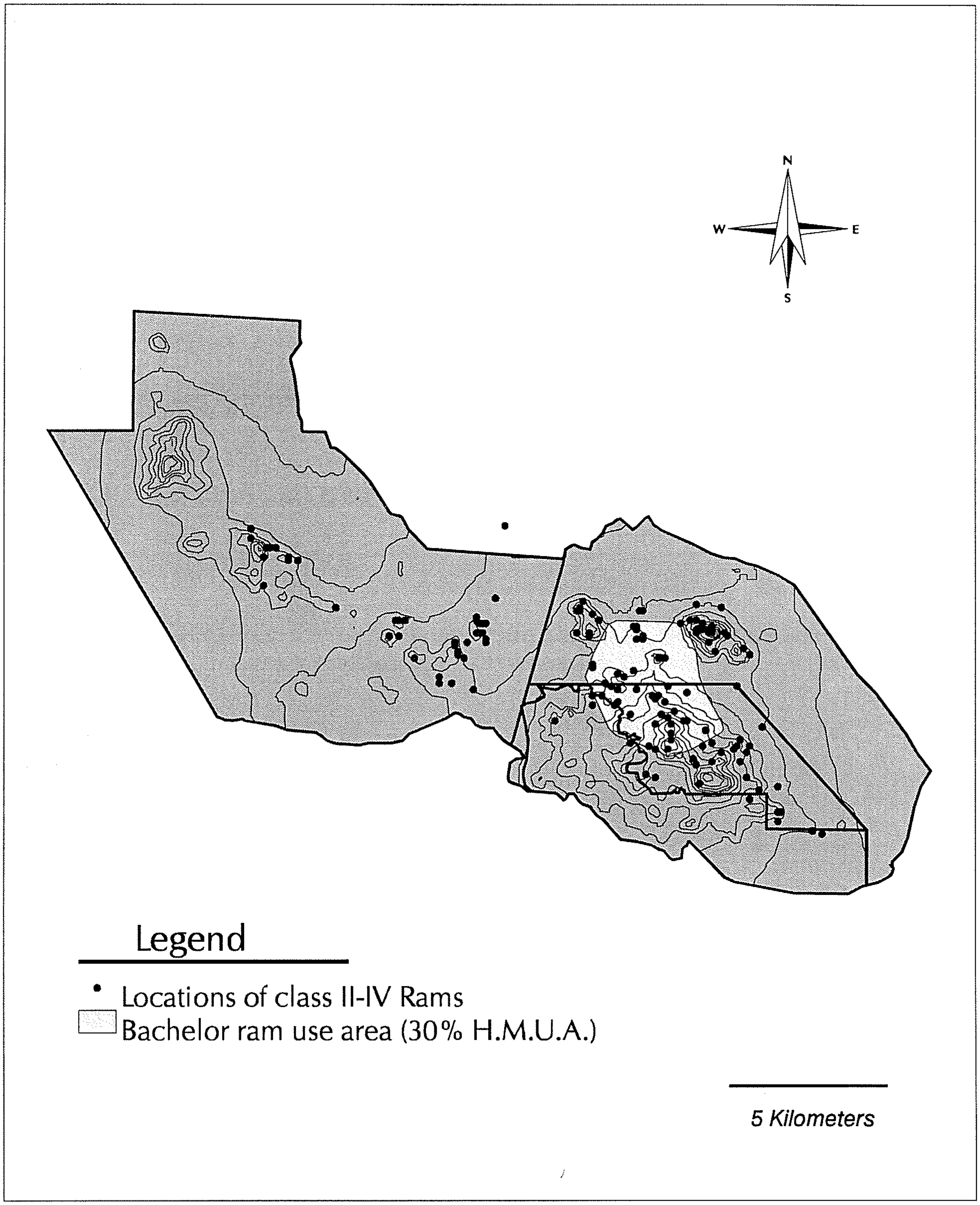


Figure 7. Bachelor ram locations and 30% harmonic mean use area (30% HMUA) within the Silver Bell study area, southern Arizona, 1993-96.

Table 7. Use of areas with different habitat quality ratings by bachelor rams (rams) and ewes with lambs (ewes) compared with availability for habitat ratings within the Silver Bell study area, southern Arizona, Nov. 22 - May 18, 1993-96.

Sex	Habitat quality rating[a]	No. of locations	% of locations	% of area	No. of locations expected	Bonferroni 90% CI	Jacobs' D[b]
Rams	Poor	1	0.5	18.6	34.5	-0.7 - 1.7	-0.96
	Fair	64	34.4	66.2	123.1	26.6 - 42.2	-0.58
	Good	103	55.4	13.9	25.9	47.2 - 63.6	+0.77
	Exc.	18	9.7	1.4	2.5	4.8 - 14.6	+0.77
Ewes	Poor	8	3.9	18.6	38.0	0.9 - 6.9	-0.70
	Fair	8	3.9	66.2	135.0	0.9 - 6.9	-0.95
	Good	109	53.4	13.9	28.3	45.6 - 61.2	+0.75
	Exc.	79	38.7	1.4	2.8	31.1 - 46.3	+0.96

[a] Habitat quality rating excluding the human use component.

[b] Use differed from availability for rams ($X^2 = 386.5$, 3 df, $P < 0.001$, $n = 186$) and ewes ($X^2 = 2{,}446.5$, 3 df, $P < 0.001$, $n = 204$). Jacobs' D indicates direction and magnitude of avoidance or selection.

We seldom located mature rams on the Silver Bell Mine property.

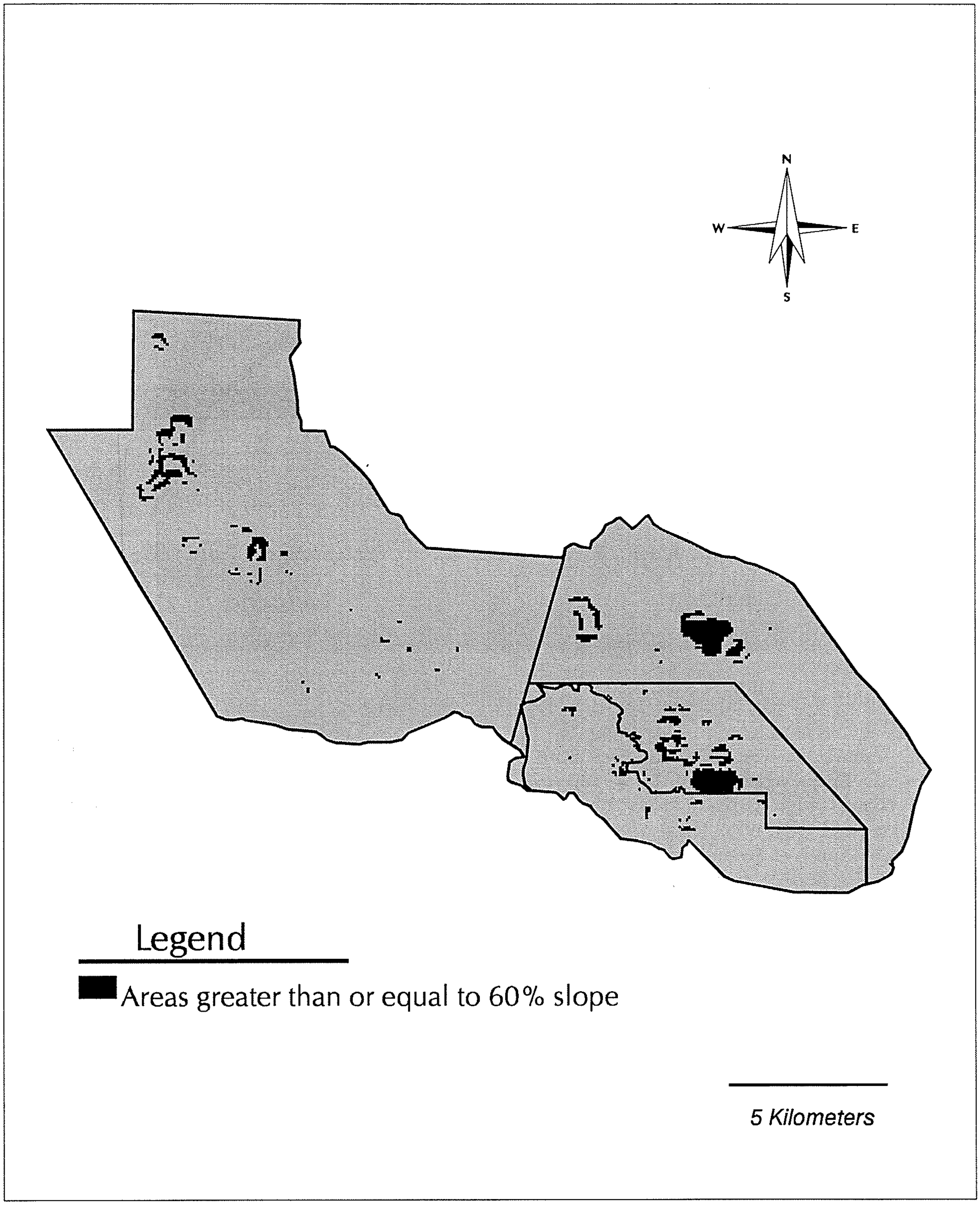


Figure 8. Desert bighorn sheep escape terrain within the Silver Bell study area, southern Arizona, 1993-96.

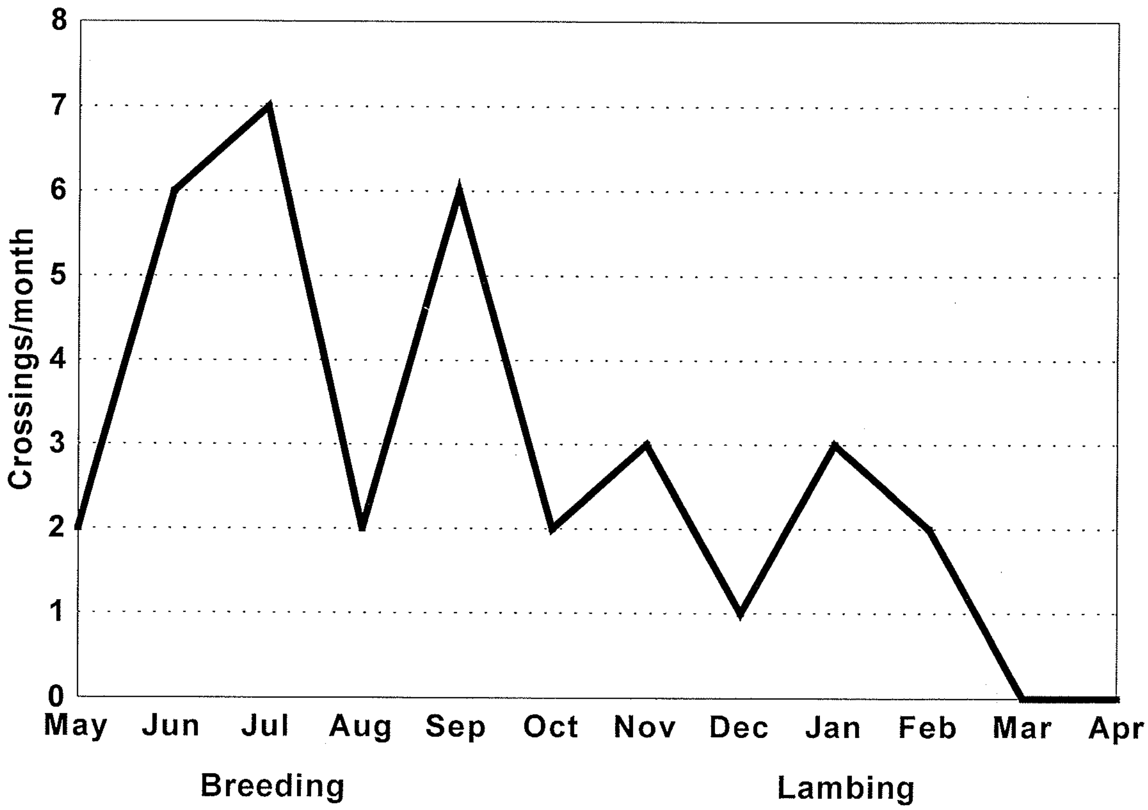


Figure 9. Number of crossings by marked rams of the intermountain area by month within the Silver Bell study area, southern Arizona, 1993-96.

the end of the breeding season. There were 16 crossings from east to west and 17 crossings from west to east. Fifty-five percent of the marked rams made crossings, with a median number of crossings of 3 for 1994 and 1 for 1995. Total crossing rate was not significantly different between years (U = 17, P = 0.554). Because rams were the only marked animals to make crossings, we used only the annual population estimates for rams to estimate the total number of crossings made each year. The estimated total number of annual crossings was 43 for 1994 and 33 for 1995.

Using the remote telemetry units, we recorded 7 intermountain area crossings by marked sheep, but were unable to narrowly define the movement corridor. Two rams crossed on the north side of the units (5 crossings), and 1 crossed on the south (2 crossings, Fig. 10). Individual rams consistently crossed on the same side of the units. We visually observed 2 crossings by rams (Fig. 10); both traveled essentially in a straight line. On each occasion the ram had been disturbed by the observer that may have altered its travel route.

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. We did not include these areas in the study area because we did not think that desert bighorn sheep used them. However, this ram was observed with ewes on 5 of 6 occasions when it was in the Waterman Mountains; because none of the marked ewes made intermountain crossings, these ewes were probably residents of the Waterman Mountains.

Behavior

Distribution of behavior classes differed among ewes of mined (SBP) and unmined (RTP-WSB) subunits during both lambing (X^2 = 30.26, 8 df, P < 0.001) and breeding seasons (X^2 = 22.95, 8 df, P = 0.003). Ewe behavior within SBP was classified more often as flight (9%) and travel (8%), and less often as feeding (36%) than for ewes within RTP-WSB. In RTP-WSB the percentage of ewe locations that were classified as flight, travel, and feeding were 2, 4, and 50%, respectively.

Desert bighorn sheep always (n = 67) fled when the observer was above them, therefore, we excluded those observations from our analyses of reaction to observer. We recorded 128 desert bighorn sheep observations in which a flight response was elicited when the observer was below

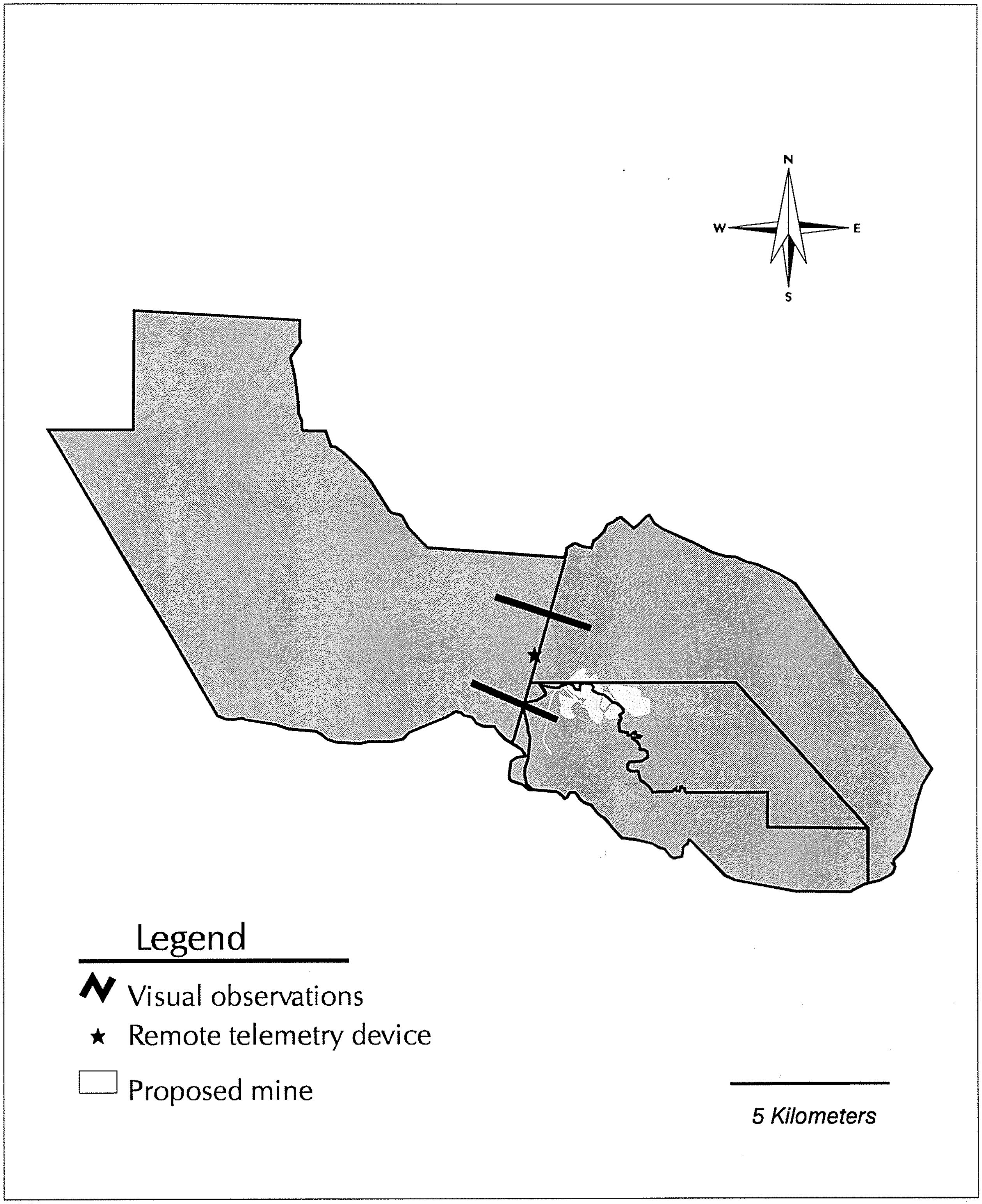


Figure 10. Intermountain movements of marked rams within the Silver Bell study area, southern Arizona, 1993-96.

them; 54 during the lambing season and 74 during the breeding season. Within sexes distance fled did not differ between seasons, however, among ewes response distance was greater during the lambing season (Table 8). During the lambing season, when rams and ewes were more segregated, distance fled was greater for bachelor rams (Table 9).

We recorded 58 observations of ewe groups that resulted in flight: 4 in WSB, 45 in SBP, and 9 in RTP. Response distance ($KW\ X^2 = 0.072$, $P = 0.965$) and distance fled ($KW\ X^2 = 1.16$, $P = 0.560$) by ewe groups did not differ among subunits.

Habitat Use

Desert bighorn sheep use of slope classes >20% differed from availability ($X^2 = 5{,}090$, 4 df, $P < 0.001$). Selection coefficients were greatest for slope classes >80% (Jacobs $D = 0.95$). The greatest difference in selection of slope classes by sex was during the lambing season; ewes with lambs exhibited strong selection for slope classes >40%, >60%, and >80% (Table 6). Median slope values were significantly different among ewe groups of different subunits during both the breeding ($KW\ X^2 = 60.88$, 4 df, $P < 0.001$) and lambing seasons ($KW\ X^2 = 46.59$, 4 df, $P < 0.001$). Therefore, we used locations obtained during both seasons for investigating selection and avoidance of slope classes within subunits. Throughout all study area subunits, ewe groups consistently selected the steepest slope classes available (Table 10).

Throughout SBSA desert bighorn sheep selected areas ≤1 km from permanent water sources ($X^2 = 2{,}013.9$, 6 df, $P < 0.001$, Jacobs' $D = 0.81$). Ewes with lambs were located ≤2 km from permanent water more often (99.5%) than were rams (82.7%, Fig. 11). Within the RTP, SBP, and WSB subunits ewe groups selected areas ≤1 km from permanent water. In SBP and WSB subunits, where water sources were farther from steep terrain (Fig. 12), selection coefficients were not as divergent relative to distance to permanent water sources (Table 11).

Desert bighorn sheep use of vegetation types differed from availability ($X^2 = 1{,}820.1$, 4 df, $P < 0.001$). Throughout SBSA desert bighorn sheep selected for the jojoba-mixed scrub vegetation type (Jacobs' $D = 0.81$). When jojoba-mixed scrub was unavailable, ewe groups used the palo verde-mixed cacti vegetation type (Table 12). Ewe groups in RTP avoided palo verde-mixed cacti, which was used according to availability in WSB and SBP. Use of vegetation types by rams and ewes was consistent between seasons except that ewes selected areas classified as bare rock during the lambing season (Table 5).

Rams used vegetative cover classes that were more dense than those used by ewes for breeding ($X^2 = 20.68$, 2 df, $P < 0.001$) and lambing seasons ($X^2 = 55.26$, 2 df, $P < 0.001$). Use of vegetative cover densities by ewe groups differed among subunits ($X^2 = 55.26$, 2 df, $P < 0.001$). Ewe groups within SBP used cover classes that were less dense than those used by ewe groups within RTP-WSB.

Aspect use differed among ewe groups within different subunits for breeding ($KW\ X^2 = 20.90$, $P = 0.001$) and lambing seasons ($KW\ X^2 = 6.84$, $P = 0.033$). Locations of ewe groups within WSB exhibited the widest range in seasonal aspect values. Median aspect values for WSB were 300° for the breeding season and 162° for the lambing season. Ewe groups within SBP were located on southern aspects more often than ewe groups within WSB or RTP subunits. Distance to escape terrain did not differ among ewe groups within different subunits during both breeding ($KW\ X^2 = 4.60$, $P = 0.100$) and lambing seasons ($KW\ X^2 = 0.18$, $P = 0.914$).

Throughout the study when rams and ewes were ≤1 km from disturbed habitats they used isometric buffer areas according to availability ($X^2 = 8.01$, 4 df, $P = 0.081$). However, during the lambing season rams selected areas ≥800 m and avoided areas ≤200 m from disturbed habitats (Table 13). Only 21% of ram locations during the lambing season were ≤1 km from disturbed habitats compared to 50% for ewes during the same season. During the lambing season, when ewes were ≤1 km from disturbed habitats they selected for areas 600-800 m from disturbed habitats (Table 13).

The total area proposed to be impacted within the newly acquired ASARCO property was 2.7 km². This area was composed of 38% good, 60% fair, and 2% poor quality desert bighorn sheep habitat. The percent overlap of key habitats with the proposed mine (main pits, haul roads, and leach dumps) is 10% bachelor ram harmonic mean use area, and 3.5% escape terrain (Fig. 13). Bachelor ram groups made up 95% of the locations obtained within the proposed mine area.

Home Ranges

We calculated annual home ranges (100% MCP), core areas (50% MCP) and $\bar{x}$ distance moved between consecutive locations for 18 of 22 marked desert bighorn sheep within SBSA (9 M, 9 F) (Appendix A). Rams had significantly larger home ranges ($U = 9.0$, $P = 0.005$), core areas ($U = 0.0$, $P < 0.001$), and $\bar{x}$ distances between consecutive locations ($U = 2.0$, $P < 0.001$) than ewes (Table 14). Ewe home ranges were restricted within subunit boundaries, while 5 of 9 ram home

Table 8. Behavioral reaction of desert bighorn sheep rams and ewes to observer presence by season within the Silver Bell Study area, southern Arizona, 1993-96.

Variable[a]	Sex[b]	Season[c]	Median	n	U [d]	P
Response distance	rams	breeding	200 m	31		
	rams	lambing	175 m	34	U = 457.5	0.359
Distance fled	rams	breeding	1,000 m	35		
	rams	lambing	1,000 m	41	U = 656.5	0.520
Response distance	ewes	breeding	200 m	13		
	ewes	lambing	250 m	47	U = 243.5	0.262
Distance fled	ewes	breeding	800 m	13		
	ewes	lambing	500 m	47	U = 288.0	0.752

[a] Response distance = distance to the observer when a flight response was elicited, Distance fled = distance animals traveled in response to observer presence.
[b] Rams = groups of desert bighorn sheep consisting of males exclusively, ewes = groups of desert bighorn sheep consisting of females, or females with lambs.
[c] Lambing season = Nov. 22 - May 17, Breeding season = May 18 - Nov. 21.
[d] Results of Mann-Whitney U test.

Table 9. Behavioral reaction of desert bighorn sheep to observer presence among 3 group composition classes by season within the Silver Bell study area, southern Arizona, 1993-96.

Variable[a]	Sex[b]	Season[c]	Median	n	$KW\ X^2$ [d]	P
Response distance	rams	lambing	150 m	41		
	ewes	lambing	250 m	47		
	mixed	lambing	150 m	7	3.244	0.198
Distance fled	rams	lambing	1,000 m	41		
	ewes	lambing	500 m	47		
	mixed	lambing	600 m	7	12.657	0.002
Response distance	rams	breeding	200 m	35		
	ewes	breeding	200 m	13		
	mixed	breeding	200 m	21	0.591	0.744
Distance fled	rams	breeding	1,000 m	35		
	ewes	breeding	800 m	13		
	mixed	breeding	1,000 m	21	1.311	0.519

[a] Response distance = distance to the observer when a flight response was elicited, Distance fled = distance animals traveled in response to observer presence.
[b] Rams = groups of desert bighorn sheep consisting of males exclusively, Ewes = groups of desert bighorn sheep consisting of females, or females with lambs, Mixed = groups of desert bighorn sheep consisting of males and females.
[c] Lambing season = Nov. 22 - May 17, Breeding season = May 18 - Nov. 21.
[d] Results of Kruskal-Wallis ANOVA test.

Table 10. Use of slope classes by ewe groups compared with slope availability within the Ragged Top Peak (RTP), Silver Bell Peak (SBP), and West Silver Bell (WSB) subunits of the Silver Bell study area, southern Arizona, 1993-96.

Subunit	Slope Class	No. of locations	% of locations	% of area	No. of locations expected	Bonferroni 90% CI	Jacobs' D[a]
RTP	0-20%	73	19.3	90.4	341.6	14.6 - 24.0	-0.95
	21-40%	99	26.2	6.4	24.1	20.9 - 31.5	+0.68
	41-60%	142	37.6	2.5	9.6	31.8 - 43.4	+0.92
	61-80%	27	7.1	0.5	2.1	4.0 - 10.2	+0.99
	>80%	37	9.8	0.2	0.7	6.2 13.4	+0.99
SBP	0-20%	124	35.1	73.5	259.4	29.4 - 40.8	-0.67
	21-40%	148	41.9	21.5	75.8	36.0 - 47.8	+0.45
	41-60%	55	15.6	4.2	14.9	11.3 - 19.9	+0.62
	>60%	26	7.4	0.8	2.8	4.3 - 10.5	+0.82
WSB	0-20%	14	25.4	91.2	50.2	12.3 - 38.5	-0.94
	21-40%	20	36.4	7.1	3.9	21.9 - 50.9	+0.76
	41-60%	21	38.2	1.6	0.9	23.5 - 52.9	+0.95
	>60%	0	0.0	0.1	0.1	0 - 0	-1.0

[a] Use differed from availability for RTP (X^2 = 4,448.8, 4 df, $P < 0.001$, n = 378), SBP (X^2 = 301.9, 3 df, $P < 0.001$, n = 353), and WSB (X^2 = 542.5, 3 df, $P < 0.001$, n = 55). Jacobs' D indicates direction and magnitude of avoidance or selection.

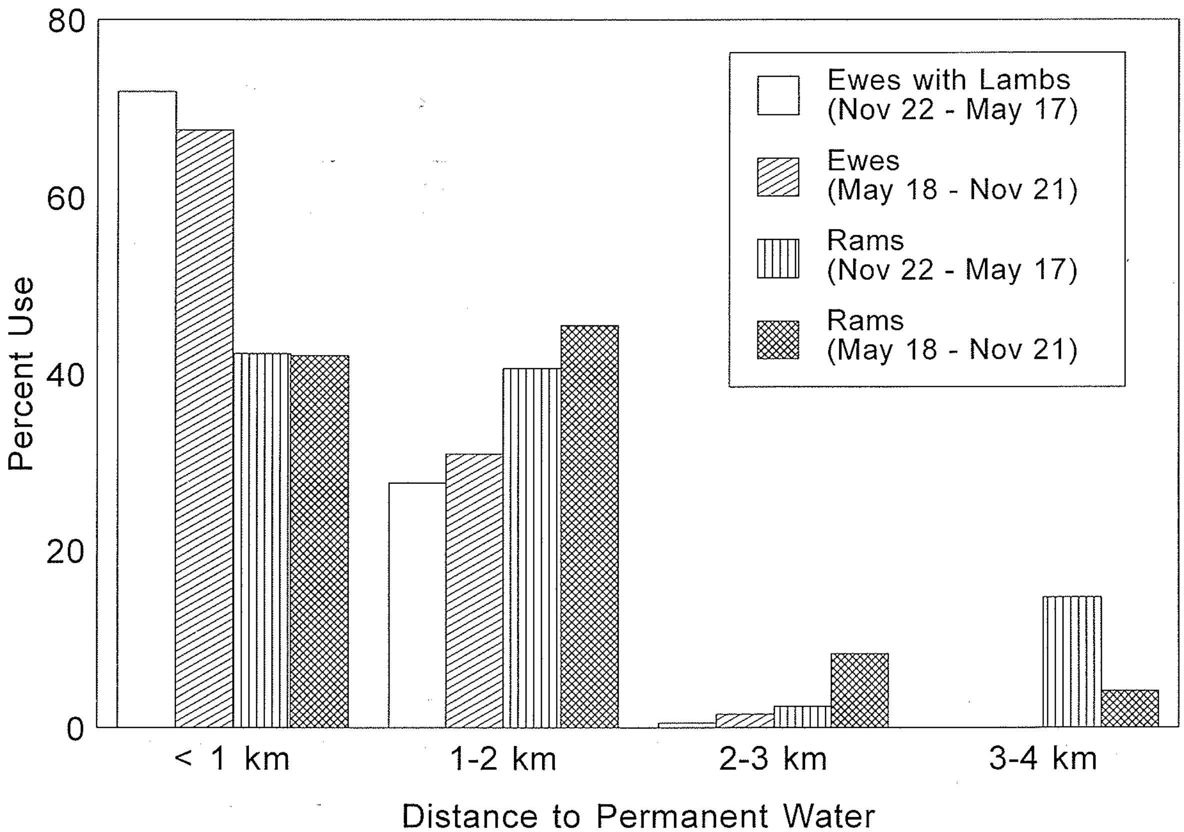


Figure 11. Percent of desert bighorn sheep locations within distance to permanent water classes within the Silver Bell study area, southern Arizona, 1993--96. Use differed from availability for: mixed groups (X^2 = 739.9, 6 df, $P < 0.001$), ewes with lambs (X^2 = 398.7, 6 df, $P < 0.001$), rams 11/22 - 11/17 (X^2 = 128.3, 6 df, $P < 0.001$), and rams 5/18 - 11/21 (X^2 = 34.7, 6 df, $P < 0.001$).

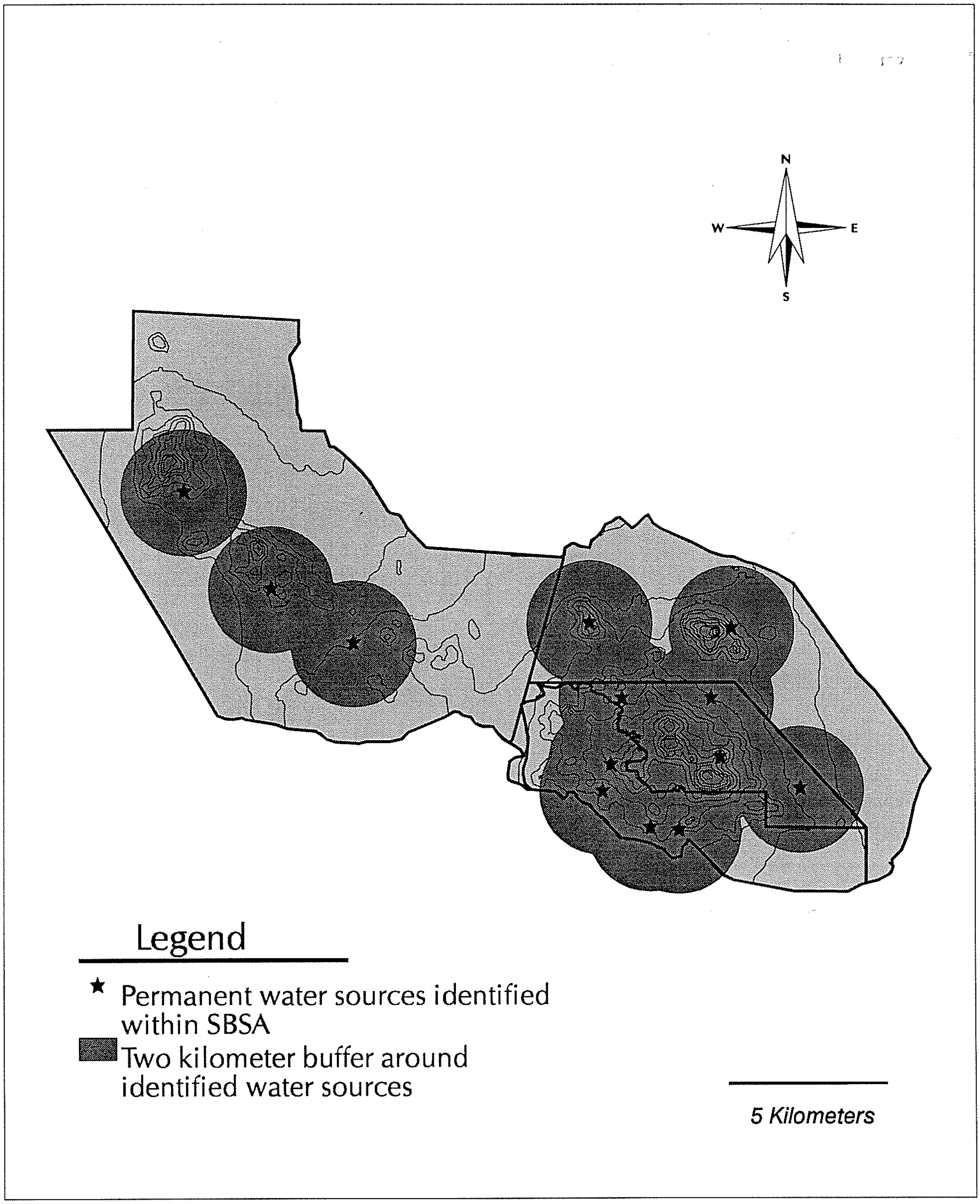


Figure 12. Location of recorded permanent water sources within the Silver Bell study area, southern Arizona.

Table 11. Distances of ewe group locations from identified water sources compared with percent area within isometric distance buffers from water sources within the Ragged Top Peak (RTP), Silver Bell Peak (SBP), and West Silver Bell (WSB) subunits of the Silver Bell study area, southern Arizona, 1993-96.

Subunit	Distance Class	No. of locations	% of locations	% of area	No. of locations expected	Bonferroni 90% CI	Jacobs' D^a
RTP	0 - 1 km	315	83.3	13.8	52.2	78.8 - 87.8	+0.94
	1 - 2 km	62	16.4	39.1	147.8	12.0 - 20.8	-0.53
	2 - 3 km	1	0.3	30.2	114.1	-0.4 - 1.0	-0.99
	3 - 4 km	0	0.0	16.7	63.2	0 - 0	-1.0
	4 - 5 km	0	0.0	0.2	0.7	0 - 0	-1.0
SBP	0 - 1 km	227	66.6	39.0	133.0	60.9 - 72.3	+0.51
	1 - 2 km	114	33.4	40.2	137.1	27.7 - 39.1	-0.15
	2 - 3 km	0	0.0	17.2	58.6	0 - 0	-1.0
	3 - 4 km	0	0.0	3.6	12.3	0 - 0	-1.0
WSB	0 - 1 km	23	41.8	7.8	4.3	25.5 - 58.1	+0.79
	1 - 2 km	28	50.9	23.2	12.8	34.4 - 67.4	+0.55
	2 - 3 km	2	3.6	30.0	16.5	-2.6 - 9.8	-0.84
	3 - 4 km	0	0.0	25.1	13.8	0 - 0	-1.0
	4 - 5 km	2	3.6	9.7	5.3	-2.6 - 9.8	
	5 - 6 km	0	0.0	3.8	2.1	0 - 0	-1.0
	> 6 km	0	0.0	0.4	0.2	0 - 0	-1.0

[a] Use differed from availability for RTP (X^2 = 1,548.9, 3 df, $P < 0.001$, n = 378), SBP (X^2 = 141.2, 3 df, $P < 0.001$, n = 341), and WSB (X^2 = 130.0, 4 df, $P < 0.001$, n = 55). Jacob's D indicates direction and magnitude of avoidance or selection.

Table 12. Use of vegetation classes by ewe groups compared with vegetation class availability within the Ragged Top Peak (RTP), Silver Bell Peak (SBP), and West Silver Bell (WSB) subunits (SU) of the Silver Bell study area, southern Arizona, 1993-96.

SU	Vegetation Type	No. of locations	% of locations	% of area	No. of locations expected	Bonferroni 90% CI	Jacobs' D^a
RTP	bare rock	12	4.1	1.6	5.0	1.5 - 6.7	
	riparian	3	1.0	3.0	8.6	-0.3 - 2.3	-0.50
	palo verde	138	46.6	93.5	265.4	40.1 - 53.1	-0.89
	jojoba	143	48.3	1.6	5.0	41.8 - 54.8	+0.66
SBP	bare rock	19	6.4	14.2	42.0	3.2 - 9.5	-0.41
	riparian	5	1.7	1.7	5.0	0.01 - 3.4	
	palo verde	185	62.7	67.9	201.0	56.4 - 69.0	
	jojoba	86	29.2	16.2	48.0	23.3 - 35.1	+0.36
WSB	creosote	0	0.0	8.8	4.8		
	riparian	2	3.6	4.1	2.2		
	palo verde	53	96.4	87.3	48.0		

[a] Use differed from availability for RTP (X^2 = 3,725.5, 3 df, $P < 0.001$, n = 296), and SBP (X^2 = 44.1, 3 df, $P < 0.001$, n = 295). Use did not differ from availability within WSB (X^2 = 5.3, 2 df, P = 0.073, n = 55). Jacobs' D indicates direction and magnitude of avoidance or selection.

Table 13. Distance of ram and ewe locations ≤1 km of disturbed habitats (roads, pits, leach dumps, etc.) compared with percent area within isometric distance buffers from disturbed habitats within the Silver Bell study area, southern Arizona, Nov - May, 1993-96.

Sex	Distance Class	No. of locations	% of locations	% of area	No. of locations expected	Bonferroni 90% CI	Jacobs' D[a]
Rams	0 - 200 m	6	15.4	37.7	14.7	1.9 - 28.9	-0.54
	2 - 400 m	7	17.9	20.1	7.8	3.7 - 32.3	
	4 - 600 m	7	17.9	15.1	5.9	3.6 - 32.2	
	6 - 800 m	6	15.4	13.8	5.4	1.9 - 28.8	
	8 - 1,000m	13	33.3	13.3	5.2	15.7 - 50.9	+0.53
Ewes	0 - 200 m	29	28.1	37.7	38.9	17.8 - 38.4	
	2 - 400 m	23	22.3	20.1	20.7	12.7 - 31.9	
	4 - 600 m	12	11.7	15.1	15.6	4.3 - 19.1	
	6 - 800 m	29	28.2	13.8	14.2	17.9 - 38.5	+0.42
	8 - 1,000 m	10	9.7	13.3	13.7	2.9 - 16.5	

[a] Use differed from availability for rams ($X^2 = 17.2$, 4 df, $P = 0.004$, $n = 39$) and ewes ($X^2 = 20.0$, 4 df, $P < 0.001$, $n = 103$). Jacobs' *D* indicates direction and magnitude of avoidance-selection.

Bachelor ram groups made up 95% of the desert bighorn sheep located where mining is proposed.

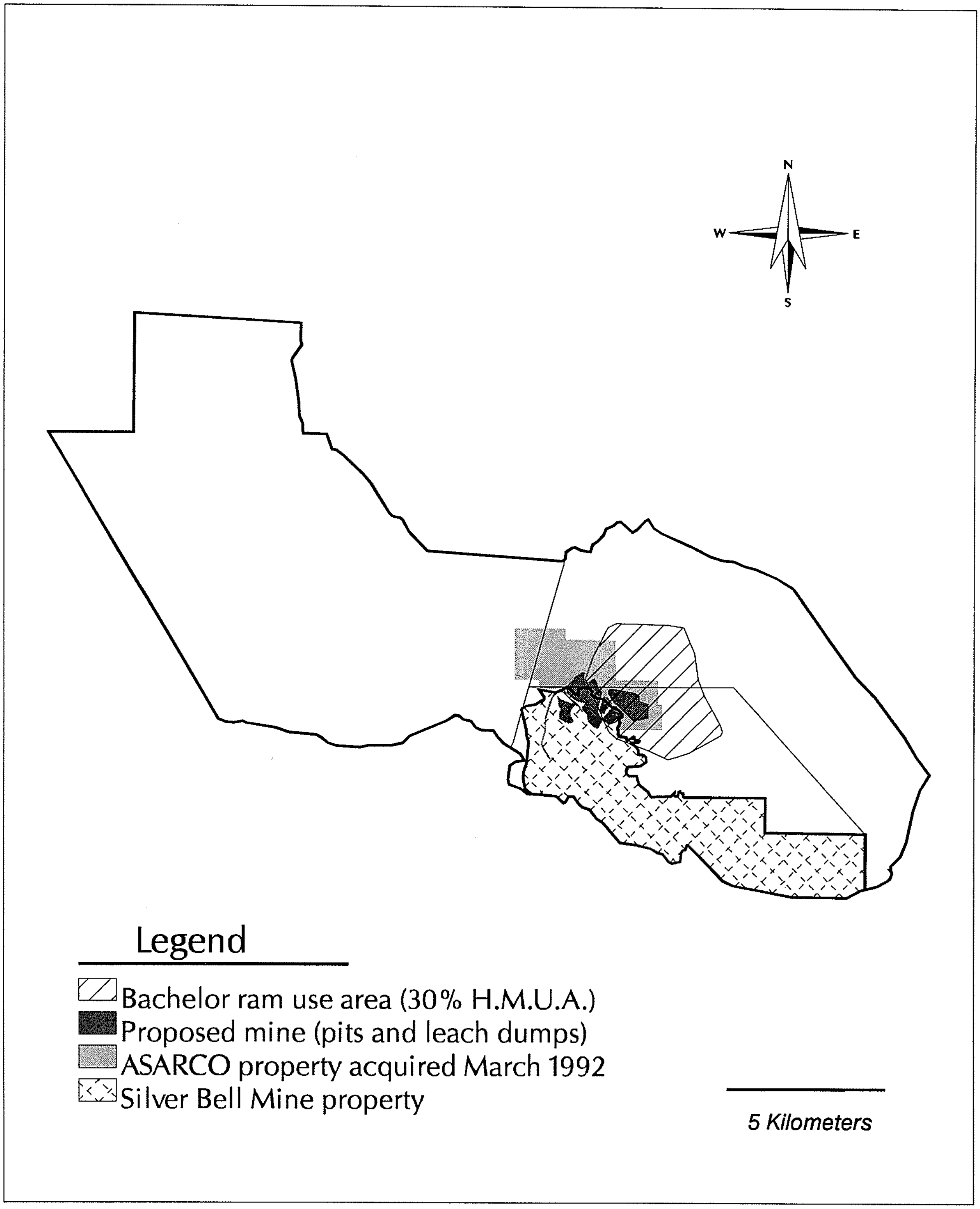


Figure 13. Proposed mine site (haul road, main pits, and leach dumps) and bachelor ram 30% harmonic mean core area within the Silver Bell study area, southern Arizona, 1993-96.

Table 14. 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 km²	50% MCP km²	$\bar{x}$ 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	

[a] 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 $\bar{x}$ movement ($U = 0.0$, $P = 0.021$).

ranges contained portions of all 3 subunits (Fig. 14). 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 14).

Demography

We surveyed and classified 274 different ewe groups 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

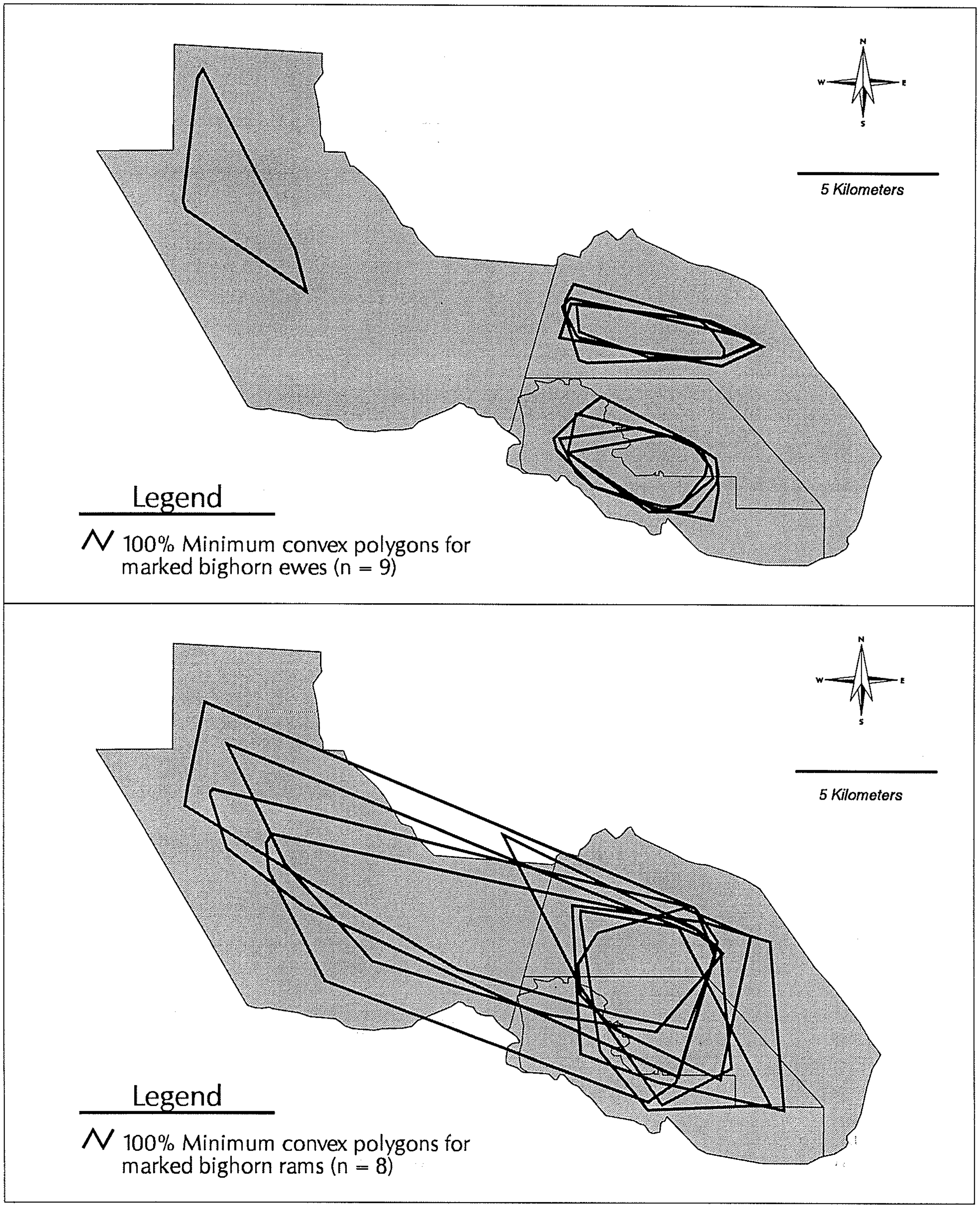


Figure 14. Home ranges (100% MCP) of rams and ewes within the Silver Bell study area, southern Arizona, 1993-96.

ewes or yearlings:100 ewes among ewe groups of different subunits (Table 15). 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 15). For the lambing season of 1995-96 there were no significant difference in lambs:100 ewes or yearlings:100 ewes between SBP and RTP-WSB subunits (Table 15).

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 M:100 F) in 1994, and (22 M:100 F) in 1995.

Nine of 22 (11 M, 11 F) marked desert bighorn sheep died during the study; 2 mortalities were attributed to disease (1 M, 1 F), 2 rams were harvested by hunters, and 5 (3 F, 2 M) were killed 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, ram survival rate was significantly lower than 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 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.

Table 15. 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, southern Arizona, 1993-96.

Variable[a]	Year	Subunit	Mean	SD	Median	n	X^2/U[b]	P
$\bar{x}$ lambs	1993-94	SBP	0.37	0.41	0.33	25		
		RTP	0.46	0.46	0.50	48	$X^2 = 3.42$	0.181
		WSB	0.22	0.35	0.0	17		
$\bar{x}$ yearlings	1993-94	SBP	0.10	0.22	0.0	25		
		RTP	0.09	0.17	0.0	48	$X^2 = 1.25$	0.570
		WSB	0.09	0.26	0.0	17		
$\bar{x}$ lambs	1994-95	SBP	0.55	0.43	0.67	64		
		RTP	0.29	0.33	0.29	48	$U = 1,009$	0.001
$\bar{x}$ yearlings	1994-95	SBP	0.27	0.37	0.0	64		
		RTP	0.51	0.47	0.40	48	$U = 1,024$	0.002
$\bar{x}$ lambs	1995-96	SBP	0.24	0.39	0.0	49		
		RTP	0.15	0.35	0.0	23	$U = 496$	0.288
$\bar{x}$ yearlings	1995-96	SBP	0.44	0.75	0.0	49		
		RTP	0.29	0.34	0.0	23	$U = 549$	0.842

[a] $\bar{x}$ lambs = number of lambs/adult ewe by group, $\bar{x}$ yearlings = number of yearlings/adult ewe by group.

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

DISCUSSION

Habitat Quality

The percentage of good and excellent quality desert bighorn sheep habitat within SBSA was lower than that found by Cunningham (1989), and Ebert and Douglas (1994) in the Black Canyon area of northwestern Arizona. Natural topography and human use were factors that contributed most to the overall low scoring of habitat within SBSA. The SBSA contained a larger proportion of gently sloping hills than the Black Canyon area. Our method of quantifying land surface ruggedness may have underestimated amounts of steep terrain; however, this was the same method employed by Ebert and Douglas (1994) and thus this bias should have been comparable. The design of the habitat rating system may have contributed to the relatively low levels of excellent quality habitat within SBSA.

The habitat quality rating system that we used (Ebert and Douglas 1994) was adapted from a system designed to identify potential translocation sites for desert bighorn sheep (Cunningham 1989). Consequently, there were aspects of the rating system that were not well suited for the purposes of this study. The most obvious of these was the scoring of the human use component. Human use scores were based upon number of user days that an area received, and the economic potential of that area. Areas with high human use and/or high economic potential score low relative to the value to desert bighorn sheep. Including economic potential of the land is important for predicting future land uses that may be detrimental to desert bighorn sheep transplants. However, future land use has no impact upon present desert bighorn sheep habitat use. Therefore, economic potential should not be a factor in habitat models designed to describe current habitat use of desert bighorn sheep.

The Silver Bell Mine site contained large areas that had relatively low levels of human use; however, because the land was owned by the mine, it received a high economic potential and thus scored low relative to the human use component. The mine has been shut down for nearly 10 years and, at the time of this study, had considerably lower levels of human use than during full operation. Desert bighorn sheep regularly used areas of the mine, but these areas received low habitat ratings due to the high economic potential. Thus, when we excluded the human use component, habitat ratings more closely reflected current desert bighorn sheep use at the Silver Bell Mine.

We are not suggesting that the human use component be ignored. Impacts of human activity on desert bighorn sheep populations have been well documented. Jorgenson (1988) found that bighorn sheep may abandon an area associated with high human activity. MacArthur et al. (1979) reported that heart rate of bighorn sheep ewes varied inversely with distance to roads. In response to increased stress indicated by increased heart rate, bighorn ewes attempted to avoid roads (MacArthur et al. 1979). Slight modifications in behavior can have serious implications for bighorn sheep, especially in harsh desert environments (Geist 1975, Bleich et al. 1990*b*). Spraker et al. (1984) described a stress-related bighorn sheep die-off associated with dam construction in Waterton Canyon, Colorado. Environmental stressors including human contact, vehicular traffic, atmospheric dust, noise, and harassment predisposed bighorn sheep to mortality. Clearly accurate methods of measuring and quantifying human use in relation to desert bighorn sheep behavior are necessary to rate its impact on desert bighorn sheep habitat quality and use at the Silver Bell Mine, and elsewhere.

Key Habitats

Seasonal changes in forage and water availability require shifts in habitat use by bighorn sheep (Geist 1971, Simmons 1980, Festa-Bianchet 1986). Rams move from the more rugged areas in the winter and spring after the breeding season (Geist 1971, Simmons 1980, Festa-Bianchet 1986, Bleich 1993). Rams are energetically drained after the breeding season and they move into areas that maximize foraging opportunities (Bleich 1993). Pregnant ewes move to traditional lambing grounds each year to bear young (Russo 1956, Welles and Welles 1961, Geist 1971). This shift in ranges segregates rams from pregnant ewes and reduces competition for resources within key lambing areas that increases reproductive success (Geist and Petocz 1977).

During the lambing season, we found ewes with lambs to be very selective in their use of habitats with respect to slope class, vegetation type, and distance to permanent water. In addition, we found ewes at higher elevations and closer to escape terrain during lambing season. This suggests that ewes were seeking areas with a particular set of habitat characteristics in which to raise their lambs. Steep slopes, high quality vegetation (Dodd and Brady 1988), and proximity to escape terrain and permanent water are all features of lambing-nursery locations; these features are also all relatively rare within SBSA. This pattern of habitat use is typical of desert bighorn sheep ewes. Lambing habitat is usually located in the steepest most rugged terrain available, and ewes traditionally return to the same areas each year (Bates and Workman 1983, Elenowitz 1984).

While lambing-nursery areas contain high quality forage, soil conditions among the rocky outcroppings and steep slopes often result in reduced forage quantity. Bleich (1993) found that forage quality and quantity were lower in areas used by ewes with lambs than those used by rams during the same period. Bighorn sheep ewes will sacrifice optimal foraging opportunities if it promotes security of their lambs (Festa Bianchet 1988, Berger 1991, Bleich 1993). While the proposed mine does not overlap any of the lambing-nursery habitat we identified, it does overlap bachelor ram habitat and may displace rams into lambing-nursery habitats. If these relatively rare habitats are overused then the carrying capacity of the entire area could be reduced.

During the lambing season, bachelor rams were found in areas that were lower in elevation, flatter, and farther from escape terrain than were ewes. These types of areas are much more common within SBSA than lambing-nursery habitat. The area where mining is proposed is typical of this type of habitat. The proposed mine will eventually impact 10% of the bachelor ram core use area (30% harmonic mean use area), and leach dump #1 (Fig. 1), overlaps to the greatest extent on this bachelor ram habitat.

Rams use habitats that maximize their foraging opportunities to prepare for the energetic demands of the rut (Berger 1991, Bleich 1993). Yet we found bachelor rams to be less selective of habitat parameters than ewes, and their habitat use was not significantly different between seasons. The lower selectivity for vegetation type by rams could largely be due to the high availability of the palo verde-mixed cacti vegetation type occurring at lower elevations of SBSA. Furthermore, while the highest quality vegetation types generally occurred at higher elevations, these areas were also occupied by relatively high densities of ewe groups. Forage availability determined by competition may be more important than forage quality (Bowyer 1984). Areas used by rams during the lambing season are probably the most productive areas in terms of forage quantity and quality (Festa-Bianchet 1988).

There may also be social significance to the areas used by bachelor rams. Rams may congregate prior to the rut to interact with conspecifics. These areas may represent traditional pre-rut staging areas where rams gather to test their strength and establish a social hierarchy before the rut (Festa-Bianchet 1986). If these areas held no social significance then it might be predicted that group sizes would not be different from ram-only groups during the rut, since the habitat components were not rare. Average group sizes were greater for rams during the lambing season than at any other time of the year. Although we were unable to test this hypothesis, we often observed social interactions such as butting and clashing suggesting a social component to this congregation.

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 large bachelor ram groups were frequently observed there. 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. Given 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 reestablishing these staging areas if the habitat were lost. 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 result in lower pregnancy rates and ultimately lower herd productivity. Slight changes in productivity could have serious implications for small bighorn sheep populations such as those of the SBSA.

Movement Corridors

Marked ewes did not move between subunits within SBSA; therefore, these areas may represent isolated sub-populations of ewes. Intermountain movements by rams likely 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, Smith et al. 1986). The isolated and fragmented nature of desert bighorn sheep habitat may predispose populations to problems associated with inbreeding (Hansen 1980*b*, Bleich et al. 1990*a*). 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 movement were 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.

We identified 2 potential travel routes for rams between the east and west portions of SBSA (Fig. 10). The majority of movements probably occur ≥1 km north of the proposed mine, and would probably not be directly impacted by the new mine. The potential movement corridor to the south, however, could be directly affected by the proposed mine. These southern and northern routes provide the shortest distance across the relatively flat terrain of the intermountain area and appear as logical travel routes for desert bighorn sheep.

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 traditional movement patterns make bighorn sheep quite conservative relative to dispersal 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 use the northern travel route between the east and west portions of SBSA provided human activity in this area does not significantly increase. The fact 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 breeding season and mature rams were seldom observed at the Silver Bell Mine except during the breeding season. Thus, the urge to reproduce may override a ram's sensitivity to human activities.

Behavior

Ewes on SBP spent more time moving (flight and travel) and less time feeding than ewes in unmined subunits. Increased human disturbance was a possible cause of the higher incidence of flight behavior, however, this also could have been an artifact of the method we used to collect data. The SBP has many roads and we could drive close to steep habitats during ground telemetry efforts. Thus, we were able to approach much closer and were more likely to disturb animals than in the other subunits.

Bighorn sheep can alter their behavior based upon experience rather than relying solely upon natural instincts (King 1985). When bighorn sheep are exposed mainly to benign encounters with humans, they may become habituated to human presence (Geist 1975). While many bighorn sheep populations have become accustomed to humans, behavioral responses to human disturbance vary among different populations (King 1985). Severity of response is related to the level of past human disturbance to which the animals have been exposed (King 1985). In general, animals seek predictable environments in which to live. Thus, human activities that follow a predictable pattern provide the best opportunity for animals to become habituated (Geist 1975). Response distances and distances fled were not different among ewes within different subunits. Therefore, the influence of the present level human activity has not affected the behavior of ewes within SBP such that they are more habituated or sensitive to human activity than ewes within unmined areas.

Distances fled were greatest for rams during the lambing period; this is the time of year that bachelor rams were found using the area where mining is proposed. Rams were not more sensitive to the observer, as response distances were similar between sexes. However, when disturbed, rams reacted more strongly, often moving >1 km. This could be a reflection of terrain, as rams were generally found at greater distances from escape terrain. However, Bleich et al. (1990*b*) found no difference in distances moved by ewes within different terrain types when exposed to the same disturbing stimuli. Bleich et al. (1990*b*) also found rams moved greater distances in response to disturbing stimuli than did ewes. Rams may also be more likely to abandon areas following disturbance as marked rams usually did not return to areas where they had been disturbed for ≥ 2 days.

Habitat Use

Desert bighorn sheep within SBSA used habitat similar to most populations of desert bighorn sheep (Hansen 1980); they consistently selected for steep rugged terrain with high quality vegetation in close proximity to permanent water. Mining can impact all of these habitat parameters. The proposed mine will likely create areas of steep slopes, alter water availability, and reduce vegetation availability.

Throughout SBSA desert bighorn sheep selected areas with steep slopes and in proximity to escape terrain. Ewe groups consistently selected the steepest slopes available. Perhaps the most obvious affect 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 percent 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.

Throughout SBSA desert bighorn sheep selected areas near permanent water. Ewes showed a stronger selection for areas near water than rams. Lactating ewes have the greatest need for free water and, thus, spend more time near water sources (Welles and Welles 1961, Turner 1973). Water availability can be affected by mining as large amounts of water are needed for mineral leaching, dust abatement, and other uses (MacCallum and Geist 1992). The Silver Bell Mine property contained several kilometers of steel pipe used to transport water. Leaks in these pipes provided water for desert bighorn sheep at several sites at the mine. However, the newer flexible plastic pipes currently used in mining operations are much less prone to leakage (D. J. Cooke, ASARCO Inc., pers. commun.); thus the proposed mine will probably not provide many new water sources for desert bighorn sheep.

We found that desert bighorn sheep used water that accumulated near standing pipes used to fill water trucks on the main haul road of the Silver Bell Mine. This water is used for dust abatement on roads and near areas where earth moving equipment is used (D. J. Cooke, ASARCO Inc., pers. commun.). These water uses may increase water availability near the proposed mine and may attract desert bighorn sheep especially during hot dry summer months.

We found water accumulated in large pools at the bottom of the main pits on the Silver Bell Mine. This water was probably a combination of leach solution and accumulated precipitation. This water may be toxic and contain high concentrations of sulfuric acid used in mineral leaching. In addition, large amounts of leach solution that are sprayed on leach dumps to extract minerals contain dilute concentrations of sulfuric acid and collect in small pools accessible to desert bighorn sheep. This leach solution is collected in lined impoundments and pumped to a plant for mineral extraction. We never observed desert bighorn sheep using any of these toxic water sources nor were they even in the vicinity of these areas. Perhaps desert bighorn sheep can differentiate between toxic pools and fresh water sources.

Within the SBP and RTP subunits, desert bighorn sheep exhibited strong selection for areas near permanent water sources. However, selection for proximity to water was not as strong in WSB. One factor that could have contributed to the lower selection for areas near permanent water within WSB could be that the water sources within WSB were located at lower elevations and farther from steep habitats than in other subunits. Bleich (1993) found that suitable terrain constrains the use of water by desert bighorn sheep ewes. Thus, the proximity of desert bighorn sheep locations to water could be a function of the proximity of water sources to steep terrain.

The high degree of selection for areas near permanent water within the RTP and SBP subunits could be due to a sampling bias. Water sources were scored according to topography, vegetative cover, and permanence. Habitat cells were then assigned scores according to their proximity to, and score of the closest water source. Water sources in flat, densely vegetated terrain would score poorly and therefore would reduce the total scores of adjacent habitat cells (Ebert and Douglas 1994). Habitat that may otherwise score well for all components could receive an artificially low score due to its proximity to a low scoring water source. If this water source was never visited by desert bighorn sheep then it should have no influence on desert bighorn sheep habitat quality rating or use. Therefore, when we mapped water sources for the habitat quality rating system, we included only those sources that we determined were visited by desert bighorn sheep. Thus, a majority of the permanent water sources that we recorded were located in proximity to areas of high desert bighorn sheep use. This raises the question of whether the desert bighorn sheep were selecting areas ≤2 km of permanent water, or whether all permanent water sources were ≤2 km of high desert bighorn sheep use areas. According to criteria from Ebert and Douglas (1994), the entire SBSA is well watered as the entire area is ≤6 km from permanent water. The exclusion of water sources that are probably not visited by desert bighorn sheep would restrict water availability to areas of high desert bighorn sheep use. This would tend to increase selection coefficients for areas close to recorded permanent water. However, if factors that reduce the habitat rating score of a given water source also preclude desert bighorn sheep use, then that water source should be unavailable to desert bighorn sheep, and therefore, excluded from any use-availability equations.

Desert bighorn sheep use of water has been well documented (Holloran and Deming 1958, Koplin 1960, Turner 1973). However, it has also been documented that this use is largely limited to hot dry summer months (Monson 1958, Wilson 1971). We found desert bighorn sheep near (≤2 km) permanent water throughout the year (Fig. 11). However, most of the permanent water sources were near steep terrain (Fig. 12). It is not clear therefore, whether the topography or the permanent water sources contributed more to the selection of these areas.

Within RTP desert bighorn sheep selected for the jojoba-mixed scrub vegetation type. Although palo verde-mixed cacti was used more frequently it was not selected for. The high availability of palo verde-mixed cacti lowered Jacobs' *D* values and indicated avoidance within the RTP subunit. However, within WSB and SBP subunits ewe groups used palo verde-mixed cacti according to availability. Although jojoba-mixed scrub was more available within SBP it was not selected as strongly as within RTP. This pattern of selection may have reflected distribution of the habitat type rather than that of the desert bighorn sheep.

Desert bighorn sheep may be avoiding very dense stands of jojoba-mixed scrub within SBP. Jojoba-mixed scrub can occur in dense stands similar to chaparral communities (Turner and Brown 1982). North-facing slopes at higher elevations (>1,000 m) within SBSA were often dominated by dense stands of jojoba. Desert bighorn sheep within SBSA used areas that were classified as ≤25% vegetative cover more frequently than more densely vegetated areas. Bighorn sheep usually avoid areas of dense cover as a predator avoidance strategy (Geist 1971). MacCarthur et al. (1979) found that heart rate was higher for bighorn sheep ewes when traveling through stands of timber than on open slopes. We found that there were large areas of dense jojoba-mixed scrub on the north side of Silver Bell Peak that received relatively low desert bighorn sheep use.

Avoidance of dense vegetative cover may explain the higher percentage of desert bighorn sheep locations on southern aspects. Ewes were consistently found on southern exposures where vegetative cover densities were lowered. However, seasonal aspect values for rams were more divergent than ewes. These analyses support the predator avoidance theory; rams should be less selective of habitats relative to predator avoidance, as they would be less vulnerable to predation than ewes with lambs (Berger 1991, Bleich 1993). Seasonal aspect values for ewe group locations within WSB were more divergent than other subunits. The WSB subunit contained no jojoba-mixed scrub, and had lower vegetative cover densities. The proposed mine will likely reduce vegetative cover near the developed areas, yet this may not necessarily increase desert bighorn sheep use there. MacCallum and Geist (1992) found bighorn sheep were attracted to areas where vegetative cover densities had been reduced, however, these areas had been revegetated with high quality low growing forage species. The proposed mine within SBSA will reduce vegetation densities within disturbed areas which may be more attractive to ewes seeking open escape terrain. However, these areas may have little or no forage value until they are revegetated. Revegetation is a slow process within desert ecosystems.

Desert bighorn sheep used disturbed habitats on the Silver Bell Mine property, however, rams rarely used these areas except during the breeding season. Bachelor rams avoided areas close to disturbed habitats and seldom used the Silver Bell Mine property. It is unclear whether the rams were avoiding the area because of high human use, high use by ewes, or for habitat selection reasons.

Although we found rams moved farther when disturbed, they were not necessarily more sensitive to approaching humans. Therefore, human activity may not be the primary factor limiting the use of disturbed habitats by rams. By definition disturbed habitats were nearly devoid of vegetation, thus rams that are seeking to maximize nutrient intake would likely avoid these areas (Berger 1991, Bliech 1993). Conversely, ewes with lambs may use these areas because of the security from predation afforded by the reduced visual obstruction and steep slopes especially associated with the pits. Rams may avoid disturbed habitats used by ewes to avoid competition with ewes for limited forage. During the lambing season, rams and ewes were segregated in unmined and mined areas.

It will take >12 years before the entire area of the proposed mine is impacted. The haul road is scheduled to be constructed ≤1 year, however, main pits and leach dumps will progress relatively slowly. In terms of habitat alteration the main pits, haul roads, and leach dump sites of the proposed mine will likely have the greatest impact on bachelor ram habitat (Fig. 12). The proposed mine will eventually impact 10% of the core area used by bachelor rams during the lambing season and might displace an unknown number of rams which currently use this area. Given the relative abundance of "bachelor ram habitat," and relatively low selectivity by rams for specific habitat parameters, it appears that rams would be the least impacted by habitat alterations. However, if the area holds some social significance as a traditional pre-rut staging area then the loss of that habitat could have a greater impact.

Home Ranges

The distance moved between consecutive locations represents a measure of movement within an individual's home range and is affected by time elapsed between locations. The maximum number of days between consecutive locations for marked animals ranged from 12 to 35 days ($\bar{x}$ = 19.4, SE = 1.33). Core area sizes also represent a measure of movement within an individual's home range. Since the results of comparisons of core areas and distance moved between consecutive locations were consistent for sexes and subunits, we believe the bias due to unequal numbers of days between consecutive locations was negligible.

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 and Leopold 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 reproduce. 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 the habitat quality assessment do not support the latter.

Demography

Our estimates of the ratio of lambs and yearlings:100 ewes were taken from observations of marked and unmarked ewes. There was a potential for bias towards marked individuals that may not have accurately represented the population. However, given the highly social behavior of desert bighorn sheep ewes, especially during the lambing season, we believe that we surveyed the entire population during each lambing season, and thus, this source of bias should have been minimal and equal among all subunits.

Because data for the ratio of lambs:100 ewes estimates was collected 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 affect upon the ratio of lambs:100 ewes estimates. If neonate mortality was not consistent across the study area then estimates of the ratio of lambs:100 ewes would be biased among subunits.

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. 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.

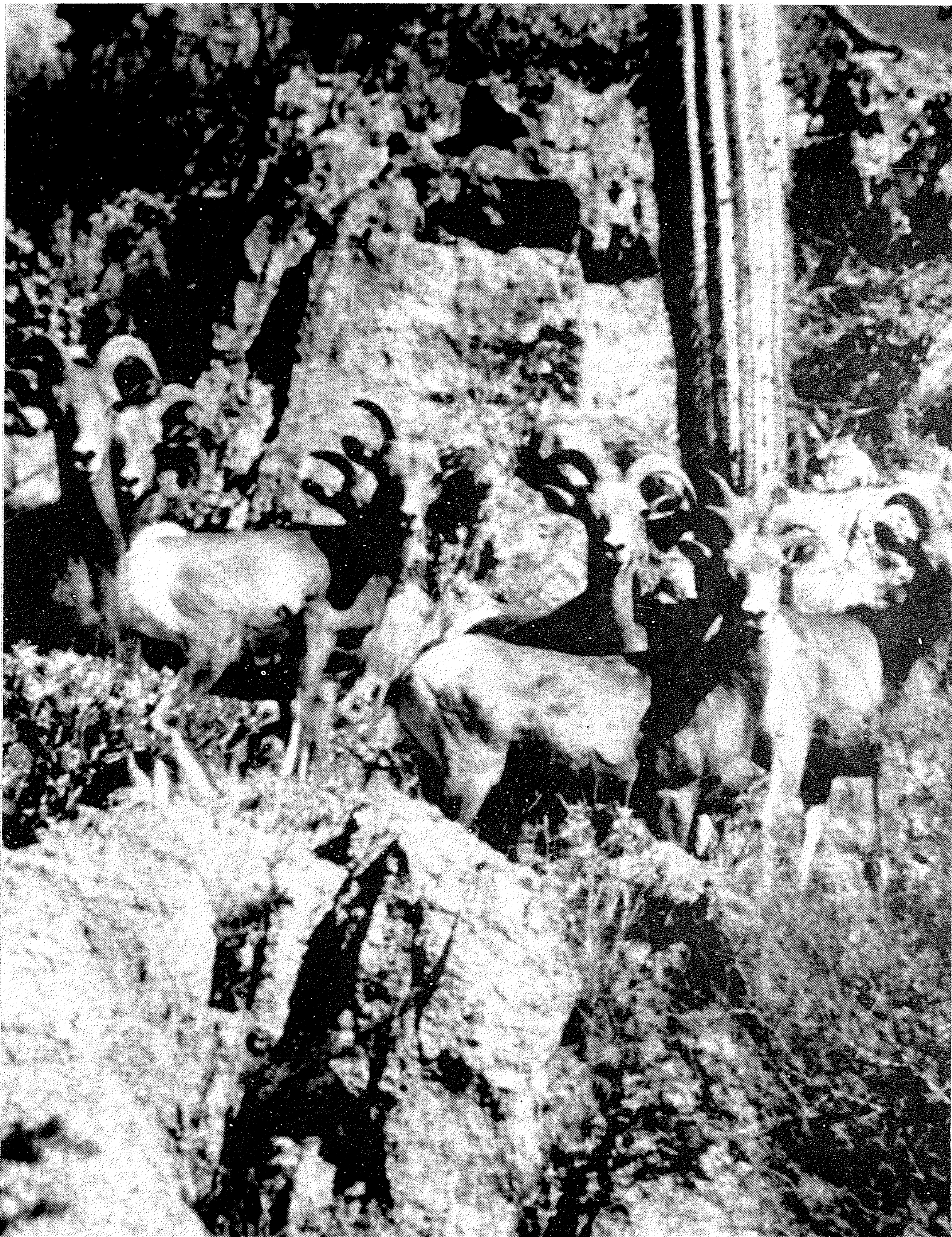
Given the wide confidence intervals, the population estimates for 1994 and 1995 are inconclusive relative to the stability of the desert bighorn sheep population within SBSA. However, the total number of desert bighorn sheep observed for each flight was similar to surveys conducted over the past 10 years (Appendix B) suggesting a stable population. Lambing rates were consistent between years, and the small difference in the ratio of lambs:100 ewes for 1993-94 and the ratio of yearlings:100 ewes for 1994-95 suggested higher recruitment rates than that reported elsewhere in Arizona by Remington (1989). Berger (1990) found that bighorn sheep populations with <50 individuals were more susceptible to rapid extinctions than larger populations. The population estimates for SBSA are close to this minimum size 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 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 10 years indicate that WSB once supported a larger sub-population of ewes (AGFD unpublished data).

We found no significant difference 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 and avoid such areas. 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. Mortality 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 F and 1 cub), and mine workers often report sightings. The only 2 marked ewes within WSB died within the first year of the study; both mortalities were attributed to lion predation. We also found 2 unmarked desert bighorn sheep carcasses which were piled in partially buried "caches" which was suggestive of lion predation.

Mountain lion predation was the largest source of desert bighorn sheep mortality within the Silver Bell study area.



CONCLUSIONS

The area where mining is proposed was used mainly by bachelor rams. We found bachelor rams to be less selective of habitat parameters and the habitats that they used were more common throughout SBSA. Conversely ewes with lambs were more selective of habitat parameters and the habitats used were relatively rare. Therefore the impact of the proposed mine will likely be less than if it were located within key lambing habitat. Because mature rams avoided disturbed habitats within the closed mine, we believe that they will react similarly to the renewed mining. Although rams will likely abandon or reduce their use of habitat within the proposed mine, it appears that there remains sufficient alternate areas of suitable habitat for them to use.

While the habitat used by bachelor rams is more common, there is evidence to suggest that pre-rut staging areas may hold some social significance, and the loss of this type of habitat could have a greater impact than the loss of habitat that held no social significance. The area where mining is proposed (specifically leach dump #1, Fig. 1) is likely part of a pre-rut staging area. The social significance of this area is unknown; however, it was used regularly by mature rams during the lambing period. Given the conservative and traditional nature of bighorn sheep movements, rams may be slow to reestablish these pre-rut staging areas if they are lost.

The mining activity within the area of the proposed mine will likely alter habitat such that it becomes attractive to ewe groups. Increased slopes, reduced vegetative cover, and increased water availability were all factors that ewes selected for on the closed mine. It remains unclear how ewes will react to the increased traffic, noise, and human activity associated with mine development. If desert bighorn sheep are not able to habituate to this increase in activity then they will be unable to take advantage of these beneficial habitat alterations until the mine is closed.

The increase in traffic along the main haul road will likely have the most immediate and greatest impact to intermountain movements of rams. Rams more often used the potential movement corridor on the north side of the exchanged lands, and this area, being farther from proposed mining activities, will be less affected by the proposed mine. 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 or alter a significant portion of important desert bighorn sheep habitat. The bachelor-ram habitat will be significantly impacted, and the effects of this impact are 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. Intensive management in the form of habitat protection and mitigation will be necessary to ensure the long term viability of this important desert bighorn sheep population.

MANAGEMENT OPTIONS

We documented that desert bighorn sheep use areas near an open pit copper mine with reduced mining activity. The nature of this use varied by season and between sexes. The original study plan provided for data collection during the early stages of mine development on and near the mine. However, the start up of the new mine was delayed, thus we were unable to determine how desert bighorn sheep reacted to increased traffic, habitat alteration, and noise associated with full scale ore extraction.

We propose the following options to help reduce and mitigate the potential impacts of the proposed copper mining within the Silver Bell Mountains.

1. Successful reproduction and genetic exchange are essential to maintain a viable population of desert bighorn sheep within SBSA. Marked ewes did not move between the 3 study area subunits and, therefore, any genetic exchange must come from ram movements. Reducing mining activities in the original AGFD requested conservation easement (Fig. 1) could reduce the impact to bachelor ram range and help maintain a corridor for genetic exchange between the Silver Bell and West Silver Bell mountains. Limiting mining activities during the peak of the breeding season (Jun - Aug) could also reduce impacts to normal

rutting behavior and movement corridor use.

We found ewes with lambs using the pits on the closed mine during the lambing season. Planning major excavation activities and developments to avoid the peak lambing season (Dec - Feb) could reduce the potential of negative impacts to ewes with lambs. We did not find ewes with lambs near the site of the proposed mine, however, Britton Peak has been documented as a lambing area (Fig. 5), and thus the conservation easement is more important than previously thought. The northern portion of the conservation easement is ≤400 m (within minimum response distance) from lambing sites on Britton Peak.

2. Protecting key habitats will help to ensure continued existence of the desert bighorn sheep within SBSA. We found that the currently proposed site of leach dump #1 (Fig. 1) is in an area heavily used by rams in the spring and summer (Fig. 13). The area southwest of leach dump #2 (Fig. 1) is not heavily used now by desert bighorn sheep. Moving proposed leach dump #1 (Fig. 1) to the southwest of proposed leach dump #2 (Fig. 1) could reduce the impact to the bachelor ram range.

3. Desert bighorn sheep seek predictable environments in which to live, and may become habituated to human activities if desert bighorn sheep-human encounters at the mine follow a predictable pattern. If mine personnel follow predictable routines, desert bighorn sheep will have a greater opportunity to habituate to their activities. Crews working in the area should also be trained not to disturb desert bighorn sheep further by feeding, approaching, or harassing them in any way (King 1985).

4. According to criteria from Ebert and Douglas (1994), SBSA is well watered; almost the entire study area was ≤6 km from a permanent water source. However, water developments within the WSB subunit were far from steep habitats. Future water developments placed in high, steep, rugged terrain, may benefit ewes with lambs in the WSB subunit.

5. Other studies have demonstrated that closed mines can provide excellent bighorn sheep habitat (Elliot 1984, MacCallum and Geist 1992). A mine closure-rehabilitation plan that maximizes potential for revegetation of native plants in disturbed habitats and ensures that human activity levels return to pre-mine levels could ensure that the area will be used by desert bighorn sheep after mining operations cease.

RESEARCH NEEDS

Initiation of mining within the newly acquired property was delayed, and we were unable to collect information about how active mining impacts desert bighorn sheep. Therefore, we recommend continuing to monitor the desert bighorn sheep population within SBSA to document how they respond to the new mining activity. A 2-3 year study designed to document impacts of increased mining within the exchanged land should be conducted.

Habitat alterations that may mitigate the impacts of habitat lost in the area of the proposed mine should be investigated. Prescribed burns designed to reduce shrub densities on high elevation north facing slopes may increase available lambing-nursery habitat, and improve predator avoidance within these areas. This could reduce the chance of bachelor rams being displaced into key lambing-nursery areas.

Predation by mountain lions was the largest source of mortality for all desert bighorn sheep. A study to investigate the impact of lion predation on movements and behavior of desert bighorn sheep could provide some useful insights to help manage desert bighorn sheep in the Silver Bell Mountains and other small, isolated desert bighorn sheep populations.

The increase in traffic near the proposed mine will likely result in a general increase in human activity within the area. As more people become familiar with the area recreational use will undoubtedly increase. The impact of increased recreational use on the desert bighorn sheep population is unknown. Without close monitoring, it will be impossible to discern the impact of this recreational use from that of the proposed mine. We now have a unique opportunity to measure and document the impacts of industrial development on desert bighorn sheep as they occur and hopefully mitigate or prevent negative impacts.

We found that bachelor rams avoided areas disturbed by mining activities.

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Appendix A. Annual home range sizes (100% Minimum Convex Polygons) for marked desert bighorn sheep captured within the Silver Bell and West Silver Bell mountains, Arizona, 1993-96.

Animal ID #	Sex	Year	100% MCP km2	*n*
61	ewe	1994	13.3	55
62	ewe	1995	6.5	58
62	ewe	1994	6.8	67
63	ewe	1994	12.8	65
63	ewe	1995	9.2	59
64	ewe	1994	7.6	64
64	ewe	1995	10.7	63
65	ewe	1994	5.6	64
65	ewe	1995	3.2	57
66	ewe	1994	6.7	63
66	ewe	1995	5.6	58
67	ewe	1994	10.1	64
67	ewe	1995	10.2	60
70	ewe	1995	9.3	57
72	ewe	1995	7.5	63
54	ram	1994	76.8	61
54	ram	1995	61.1	58
56	ram	1994	33.5	62
57	ram	1994	67.5	61
57	ram	1995	15.1	62
58	ram	1994	61.3	62
58	ram	1995	41.8	61
59	ram	1994	50.8	55
60	ram	1994	23.6	62
61	ewe	1994	13.3	55
71	ram	1995	59.5	54
74	ram	1995	29.3	59
75	ram	1995	29.5	56

Appendix B. Results of annual desert bighorn sheep helicopter surveys within the Silver Bell and West Silver Bell mountains, Arizona, 1984-95.

Year	No. of groups seen	No. of sheep seen	No. of lambs seen	Sheep/hr flight time	Population estimate[a]
1984	14	35	4		47
1985	13	42	9		56
1986	9	42	4		56
1987	16	46	11		61
1988	11	40	3	7.8	53
1989	10	31	4		41
1990	12	42	7	6.3	56
1991	15	40	5	8.0	53
1992	21	74	13	13.4	99
1993	14	39	6	6.7	52
1994	12	46	3	9.4	61
1995	10	38	4	9.3	51

[a] Population estimates based on an observation rate of 0.75.

Layout, design, and typesetting by Vicki L. Webb
Photos by:

Bud D. Bristow (Page 6)
Kirby D. Bristow (Pages iv, 5, 13, 14, 26, 35, 40, 47, 48, 51)
Raymond E. Schweinsburg (Cover, Pages vi, 22)

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