

## **MOUNTAIN SHEEP AND MINING: IMPLICATIONS FOR CONSERVATION AND MANAGEMENT**

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**Opportunities to quantitatively assess responses of ungulates to mineral extraction have been limited. Reasons for this dearth of research include a lack of adequate funding, available personnel, and logistical constraints. In 1992, a request was submitted to the Bureau of Land Management by a mining company for permission to extract and process gold ore in the Panamint Range, Inyo County, California, near a spring presumed to be critically important to mountain sheep, *Ovis canadensis*. Ensuing compliance with the National Environmental Policy Act resulted in funds to monitor effects of mining activities on mountain sheep inhabiting that area. Because funding was not released until ~8 months prior to construction and operation of the mine, we were unable to adequately address the pre-mining ecology of sheep in the “affected” area. We therefore employed a simultaneous treatment-control study designed to test several hypotheses regarding effects of mining activities on habitat selection, demographics, home-range dynamics, foraging activities, and composition and quality of diet for mountain sheep during 1995-1997. During our 3-yr study, we radiocollared and monitored 86% ( $n = 19$ ) of all adult female sheep known to exist within the mined (treatment) and nonmined (control) areas. Size of annual home ranges, composition of diet, and ratios of young to adult females did not differ between female sheep**

inhabiting mined and nonmined areas. The nonmined area contained more annual plants, succulents, and perennial forbs than did the mined area, whereas abundance of shrubs, quality of forage, and relative abundance of carnivores did not differ between sites. During spring, female sheep adjacent to the mine spent more time foraging and had a lower-quality diet than those in the nonmined area. Conversely, during summer and autumn, female sheep from the mined area spent less time foraging than those in the nonmined area, but continued to have a lower-quality diet. All females were nearest water in summer compared with other seasons. During all seasons, females selected sites with more mixed-woody scrub, lower elevations, steeper slopes, and less visibility than available at random locations. We observed the greatest disparities between study areas in time spent foraging and diet quality during summer. In summer, females from the mined area were nearest to the mine; amount of explosives used, frequency of blasting, and amount of ore hauled from the mine were greatest during that period. Because of their reliance on a source of permanent water adjacent to the mine during summer and autumn, we hypothesize that female sheep from the mined area spent more time vigilant during those seasons and, consequently, less time foraging than conspecifics in the nonmined area. If outcomes we observed persist for mountain sheep in the mined area, reduced nutrient intake could have demographic consequences for that subpopulation. Thus, providing a reliable source of water away from the mine, or reducing mining activity during summer, may benefit mountain sheep that currently use areas adjacent to the mine.

## INTRODUCTION

Among ungulates, exposure to human activities has been linked to temporary abandonment of areas of traditional use (Kuck et al. 1985, Bleich et al. 1994), shifts in centers of activity (Van Dyke and Klein 1996), and localized extirpations (DeForge et al. 1981). Quantitative data regarding effects of mineral extraction on mountain sheep, *Ovis canadensis*, however, are few. Some researchers have investigated responses of mountain sheep to activities typically associated with mining (e.g., helicopter disturbance—Stockwell et al. 1991, Bleich et al. 1994; human disturbance—Hicks and Elder 1979, Leslie and Douglas 1980, Krausman and Etchberger 1995, Papouchis et al. 2001; and water development—Krausman and Etchberger 1995), but those authors did not address the issue of mining activities and their effects on mountain sheep.

We studied the ecology of female mountain sheep adjacent to a heap-leach gold mine in the Mojave Desert. We measured variables from two subpopulations of female sheep inhabiting distinct geographic areas within a single mountain range (i.e., mined and nonmined) to test hypotheses regarding potential influences of mining on habitat selection, home-range dynamics, and foraging ecology of those large herbivores. We predicted that if mining had no effect on sheep, there would be no differences in selection of habitat and size of home ranges between females occupying those two areas. We also predicted that after considering potential influences of resources and

predators, female sheep would select habitat in a manner similar to that of sheep from the nonmined area, if there were no effects of mining activities. Among mountain sheep, vigilant behavior increases in areas with low levels of visibility (Risenhoover and Bailey 1985, Frid 1997, Rachlow and Bowyer 1998), and is affected by the presence of perceived threats (Berger 1978, Festa-Bianchet 1988, Berger 1991, Stockwell et al. 1991)—such behavior reduces time spent foraging, and might result in differences between mined and nonmined areas. Therefore, if mountain sheep near the mine were unaffected by mining activities, we hypothesized that after considering availability of forage, there would be no difference in time spent foraging between areas. Further, if quality of forage differed between sites, we predicted that individuals consuming lower-quality forage would spend more time foraging to meet their nutrient requirements (Leslie and Douglas 1979). Finally, if abundance of predators differed between areas, we predicted that after considering availability and quality of forage, mountain sheep in areas with more predators would spend more time vigilant (Berger 1978, Rachlow and Bowyer, 1998) and, consequently, less time foraging (Molvar and Bowyer 1994, Bowyer et al. 2001). Effects of mining cannot be addressed or mitigated without considering influences of these factors on the ecology of free-ranging mountain sheep.

## METHODS

### Study Area

Our study was conducted in the Mojave Desert on the west-facing slope of the Panamint Range, Inyo County, California, USA (Fig. 1). The subpopulation of female sheep living near the mine was centered on Redlands Spring (36°56'37"N, 117°10'43"W) in the southern end of our study area, whereas the center of our control population (i.e., nonmined) was located ~22 km to the north (37°09'34"N, 117°09'50"W) (Fig. 2).

Elevations range from 305 m on the valley floor to 3,368 m at Telescope Peak. Mean ( $\pm$  SE) annual rainfall from 1911 to 1994 at the weather station ~30 km from our study site (Greenland Ranch-Furnace Creek, California) was  $4.7 \pm 0.33$  cm, and temperature was highly variable; daytime high temperatures ranged from  $>40^\circ\text{C}$  during summer (May-August), to  $-7^\circ\text{C}$  during spring (January-April, Fig. 3; Death Valley National Park Service files). We used climatological data collected from Greenland Ranch-Furnace Creek, and data on timing of parturition (Welles and Welles 1961) to define three seasons. Spring was 1 January-30 April, which incorporated most of parturition, and was typified by cool temperatures ( $\bar{x} = 25^\circ \pm 5.7^\circ\text{C}$ ) and relatively greater precipitation ( $\bar{x} = 0.59 \pm 0.99$  cm) than other seasons. Summer was 1 May-31 August; that period was extremely hot ( $\bar{x} = 43^\circ \pm 3.8^\circ\text{C}$ ) with low rainfall ( $\bar{x} = 0.21 \pm 0.51$  cm). Autumn (and the concomitant mating season) extended from 1 September to 31 December, and was characterized by cooler temperatures ( $\bar{x} = 29^\circ \pm 9.9^\circ\text{C}$ ), and lower precipitation than spring ( $\bar{x} = 0.37 \pm 0.77$  cm).

Six vegetation communities were delineated within the study area from a LANDSAT-TM scene with cells of 25-m resolution: 1) alkali playa (305 m elevation), which occurred on relatively flat areas of the valley floor; 2) desert saltbush, *Atriplex canescens*, scrub,

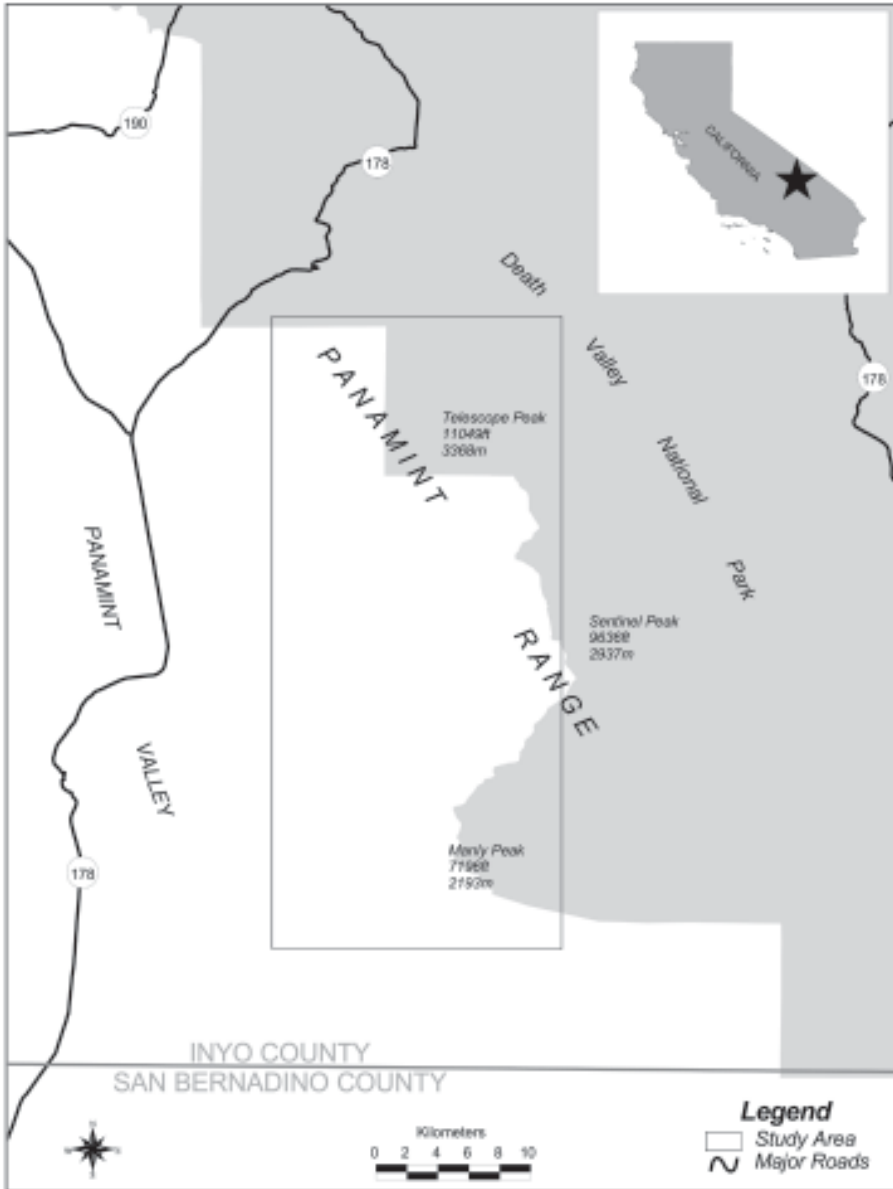


Fig. 1. Location of our study areas in the Panamint Range, Inyo County, California, USA, 1995-1997.

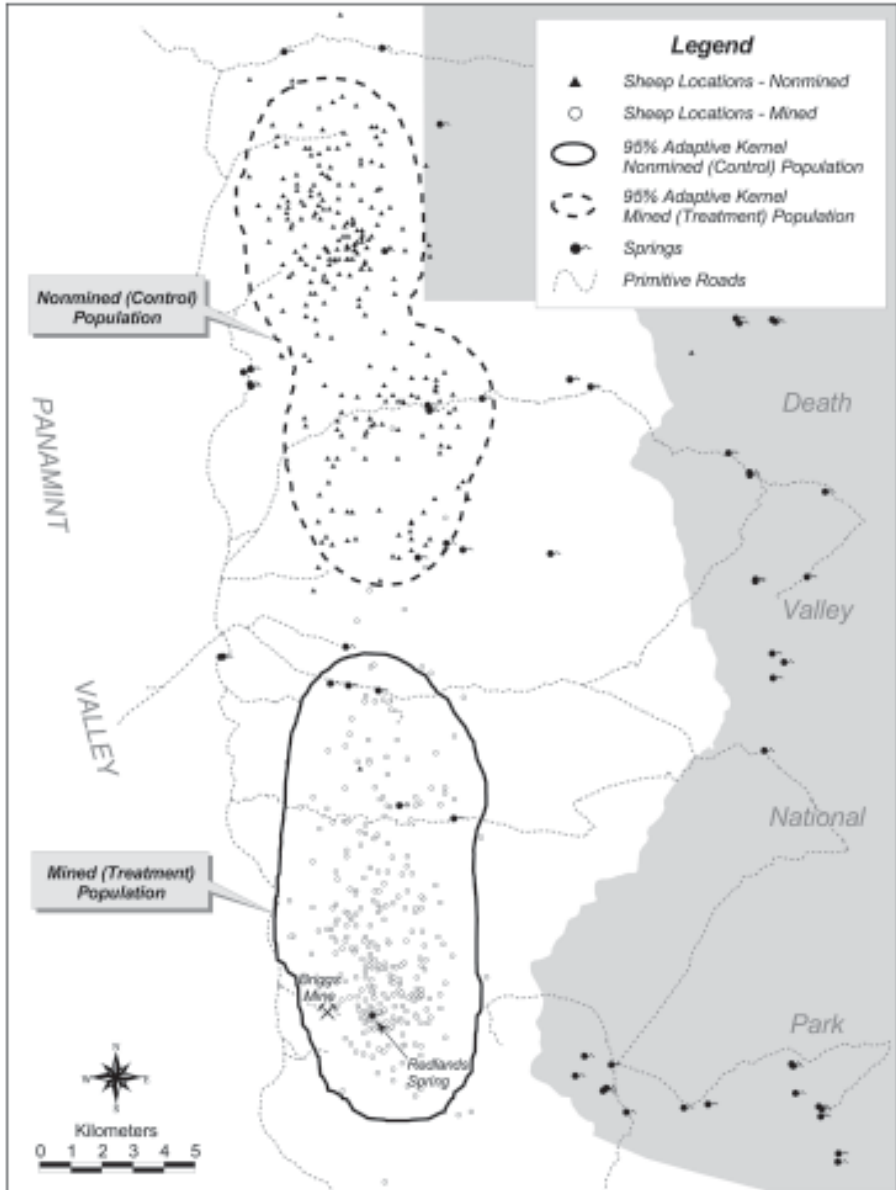


Fig. 2. Telemetry locations of female mountain sheep, and 95% adaptive kernel polygons for populations of sheep from mined and nonmined areas in the Panamint Range, Inyo County, California, USA, 1995-1997.

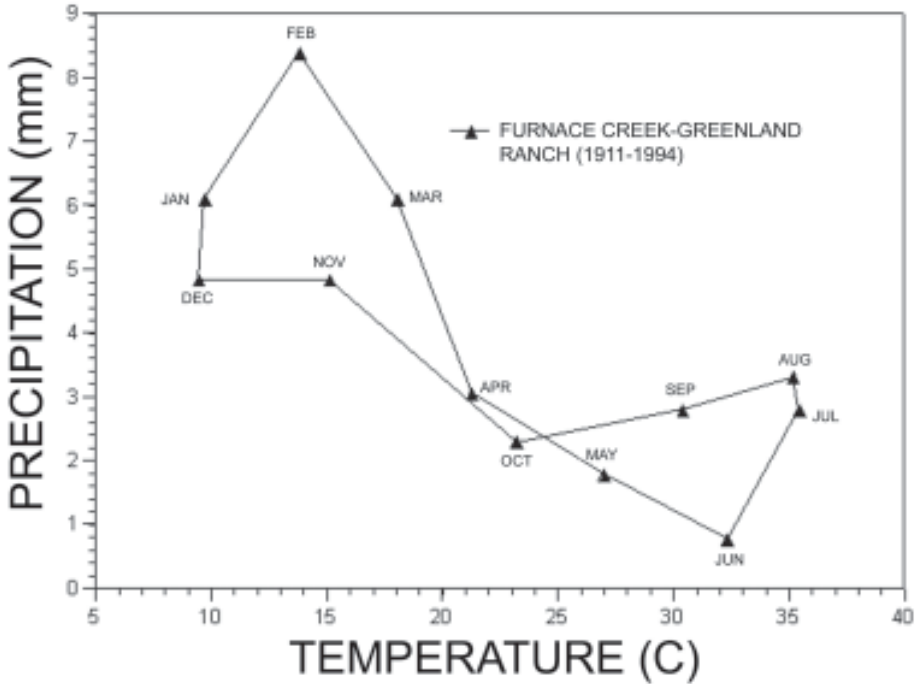


Fig. 3. Climograph of mean monthly temperature and precipitation at Furnace Creek, Inyo County, California, USA, 1911-1994.

which was adjacent to playas and characterized by microphyllous shrubs; 3) creosote bush, *Larrea tridentata*, scrub, which occurred from 300 to 1,640 m elevation; 4) Mojave mixed woody-scrub (1,400-2,300 m elevation), with shadscale, *A. confertifolia*, and blackbush, *Coleogyne ramosissima*, as predominant species; 5) Mojave-woodland scrub (2,300-3,300 m elevation), which was dominated by pinyon pine, *Pinus monophylla*, and juniper, *Juniperus osteosperma*; and 6) bristlecone pine, *Pinus longaeva*, forest, which occurred at elevations >3,300 m. There were 9 and 13 permanent springs, respectively, within mined and nonmined areas.

Mountain sheep occurred in the Panamint Range at relatively low densities (72 adult females/1,000 km; Oehler et al. 2003); other ungulates that inhabit the area include feral asses, *Equus asinus*, and mule deer, *Odocoileus hemionus*. Large mammalian carnivores present include coyotes, *Canis latrans*, bobcats, *Lynx rufus*, and mountain lions, *Puma concolor* (Welles and Welles 1961). Nevertheless, predation on desert sheep by those carnivores was thought to be negligible (Welles and Welles 1961, Weaver<sup>1</sup> 1972).

<sup>1</sup>Weaver, R. A. 1972. Desert bighorn sheep in Death Valley National Monument and adjacent areas. California Department of Fish and Game Wildlife Management Administrative Report 72-4.

Most lands within the study area were administered by the U.S. National Park Service or the U.S. Bureau of Land Management and, as a result of the California Desert Protection Act of 1994, most roads in this area were closed to motorized vehicles. The few roads not included in wilderness areas were accessible only by four-wheel drive vehicles; access was extremely limited. During the cooler portions of the year (November-March), roads open to the public were used by 10-15 vehicles/weekend, and 5-10 hikers/week, whereas in summer vehicular traffic and hiking in those areas was rare (D. Brenner, National Park Service, personal communication).

In December 1995, Canyon Resources Corporation began construction of an open-pit gold mine (hereafter the Briggs Mine) near Redlands Spring (Fig. 2); excavation, crushing, and on-site processing of ore began in March, July, and October 1996, respectively. The Briggs Mine was projected to process ~19.3 million metric tons of ore on site during the 7-year life of the mine, and to disturb 1,333 ha of land within the 2,350-ha project area.

### Capture and Aerial Telemetry of Mountain Sheep

We captured adult (>1 yr old) female sheep during June and October 1995, June 1996, and January 1997 with a helicopter and net-gun (Krausman et al. 1985a); all aspects of animal handling complied with protocols set forth by the California Department of Fish and Game (Jessup et al.<sup>2</sup> 1986), and were consistent with methods adopted by the American Society of Mammalogists (Ad Hoc Committee on Acceptable Field Methods. 1987). We categorized all females and young observed or captured during fieldwork as adults or young (individuals of either sex <1 yr old). We fitted sheep captured in June 1995 with standard VHF telemetry collars (Telonics®, Mesa, Arizona), and animals captured during subsequent efforts with activity-sensing collars (Advanced Telemetry Systems®, Isanti, Minnesota).

We attempted to locate all radiocollared sheep weekly during June, July, and August, and in alternate weeks during the remainder of the year using a fixed-wing aircraft (Krausman et al.<sup>3</sup> 1984). We located collared sheep between 0900 and 1400 h, Pacific Standard Time, and locations were estimated with either LORAN-C or Global Positioning System (GPS) instruments aboard the aircraft. Because of error associated with LORAN-C (Jaeger et al. 1993, Oehler et al. 1996), we derived a correction factor (Patric et al. 1988) to adjust geographic coordinates obtained using that technology. On average, coordinates obtained from LORAN-C technology indicated the aircraft was 41 m west and 127 m north of the target. Global Positioning Systems are less subject to geographic variability in accuracy than LORAN-C (Leptich et al. 1994), and we did

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<sup>2</sup>Jessup, D. A., W. E. Clark, and M. A. Fowler. 1986. Wildlife restraint handbook. Third edition. California Department of Fish and Game, Rancho Cordova, California, USA.

<sup>3</sup>Krausman, P. R., J. J. Hervert, and L. L. Ordway. 1984. Radio tracking desert mule deer and bighorn sheep with light aircraft. Pages 115-118 in *Deer in the southwest: a workshop* (P. R. Krausman and N. Smith, editors.). School of Renewable Natural Resources, University of Arizona, Tucson, USA.

not correct sheep locations obtained via GPS. Accuracy of telemetry locations was 177 m (i.e., a circle with radius of 177 m) for an investigation of mule deer in the San Bernardino Mountains, California (Nicholson et al. 1997). Because we used the same pilot as Nicholson et al. (1997) for our flights, we reasoned that the error within our study area would be similar. To be conservative, and because we occasionally used another pilot, we increased the radius of the circle to 200 m.

### Habitat Analyses

Unless specifically indicated, hereafter our references to “habitat” are general in nature and apply to the suite of variables we analyzed relative to locations of sheep (e.g., slope, aspect, viewshed, vegetation communities, etc.). We tested locations for each animal for lack of independence with the multiresponse-sequence procedure (MRSP) of BLOSSOM statistical software (Solow 1989, Slauson et al.<sup>4</sup> 1991) and eliminated locations until no significant ( $P \geq 0.05$ ) autocorrelation was detected (Nicholson et al. 1997). We pooled telemetry locations of female sheep by area (mined vs. nonmined) to define areas of available habitat and used the program CALHOME (Kie et al. 1996) to construct a 100% minimum convex polygon around those locations. Resulting polygons were buffered by 1,000 m to account for undetected movements (Bleich et al. 1997), and to avoid biases in assessing habitat selection from only within the home ranges of sheep (Kie et al. 2002). We then generated random locations within each buffered polygon with the same frequency as sheep locations used to construct that polygon. Next, we used a Geographic Information System (GIS; ARC/INFO®, Environmental Systems Research Institute, Redlands, California) to generate a circle with a radius of 200 m around each sheep (i.e., potential telemetry error) and random location; area within those circles was used to calculate relative use and availability of habitat attributes (Andrew et al. 1999, Nicholson et al. 1997).

We generated a three-dimensional model of terrain for the study area from USGS 7.5' digital elevation models (DEM) with 30-m resolution using the GRID module of ARC/INFO. The DEM provided information on elevation, slope, and aspect associated with each telemetry location. Because resolution of the DEM was 30 m, the radius of the circle used to assess associated features was 210 m (i.e., 30 m x 7 pixels). We used the product of the *SD* of slope and the mean angular deviation of aspect inside each circle as an index to terrain diversity (Nicholson et al. 1997). We used the GIS to estimate visibility (i.e., the viewshed) from each female sheep and random location to examine the role of visibility in habitat selection among female sheep. The GIS calculated the two-dimensional area that would be visible from a height of 1 m (approximate eye-level of a sheep) within a circle having a radius of 1,000 m.

A GIS layer of vegetation communities was developed for the study area from the LANDSAT-TM scene. Because alkali playa, desert-saltbush scrub, and the bristlecone-

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<sup>4</sup>Slauson, W. L., B. S. Cade, and J. D. Richards. 1991. User's manual for BLOSSOM statistical software. United States Fish and Wildlife Service, National Ecology Research Center, Fort Collins, Colorado, USA.

pine forest represented <0.5% of the available plant communities, and because female sheep were not located in those vegetation types, we eliminated them from further consideration. We also digitized the locations of roads and springs from USGS 7.5' quadrangle maps to evaluate those factors relative to use of habitat by sheep.

We used stepwise logistic regression (PROC LOGISTIC; SAS Institute Inc. 1997) with an  $\alpha$ -to-enter and stay of 0.15 (Agresti 1990) to identify variables that might be important in differentiating random locations from those used by sheep (Nicholson et al. 1997). For our habitat analyses, we treated the individual animals as our sampling unit to eliminate inflated sample sizes associated with using individual telemetry locations as sampling units. Using variables selected by logistic regression, we calculated a vector of means for each female sheep during each season (i.e., three vectors for each female). Because availability of the habitat variables we measured does not change by season, we calculated a single vector of means for those variables at the random locations in each of the mined and nonmined areas. Finally, we generated a vector of differences for each female sheep during each season (i.e., sheep minus the random vector from its corresponding area); resulting vectors became dependent variables in a two-way multivariate analysis of variance (MANOVA; Johnson and Wichern 1988) to test hypotheses regarding selection of habitat. Main effects in the habitat model were area (mined and nonmined) and season (spring, summer, and autumn); significance of the model was determined with Wilks' lambda (Johnson and Wichern 1988). We determined selection or avoidance of habitat variables following the methods of Nicholson et al. (1997) and Bowyer et al. (1999). Additionally, we used a two-way ANOVA (random vs. sheep location, and season, as main effects) to compare distances from the Briggs Mine to sheep locations in mined and nonmined areas.

### Home-range Analyses

Prior to calculating adaptive-kernel home ranges for each female sheep, we used CALHOME to estimate the parameter for the optimum smoothing of the 95% adaptive kernel for that sheep (Worton 1989, Kie et al. 1996). Next, we calculated 95% adaptive-kernel home ranges based on 60-120% (in increments of 10%) of that smoothing parameter; the value that minimized the least squares cross-validation score for each individual data set was then used as the smoothing parameter for calculating 95, 50, and 10% adaptive-kernel home ranges for that animal (Kie et al. 1996). We considered the 10% adaptive-kernel home range to be the center of activity for a particular sheep; we then used the GIS to measure distances from that centroid of the home range to permanent springs and roads.

To determine if we had an adequate number of locations to estimate home ranges for each mountain sheep, we first plotted the area within 95% adaptive-kernel home range against cumulative sample size, and then estimated the sample size necessary to compute the home range using the nonlinear procedure in SPSS (SPSS Inc. 1993): home-range size =  $A(1 - e^{-bn})$ , where  $A$  is the asymptote of the equation,  $e$  is the base of the natural log,  $n$  is the sample size, and  $b$  is a constant. Data sets that did not attain 90% of that asymptotic value were eliminated from further analyses (Nicholson et al. 1997).

We tested hypotheses regarding home-range size with data from seasons combined, because of inadequate numbers of locations within seasons. We analyzed size of home ranges using a two-sample *t*-test, and a one-way analysis of covariance (ANCOVA) with area as the main effect, and distances from the center of activity to nearest spring and road as covariates. We used the multi-response permutation procedure (MRPP) of BLOSSOM statistical software (Slauson et al.<sup>4</sup> 1991) to test our assumption that sheep assigned to mined and nonmined populations inhabited unique geographic areas.

### Foraging Behavior

We collected data on head position (i.e., up vs. down) of female mountain sheep fitted with activity collars (mined,  $n = 8$ ; nonmined,  $n = 10$ ) via two remote recording stations (Receiver Model 2100, Data Logger Model DCC-5400, Advanced Telemetry Systems, Isanti, Minnesota) deployed from March 1996 to September 1997. The telemetry frequency of each sheep was scanned at 15-min intervals until either that frequency was received and a pulse rate could be ascertained, or for a maximum of 1 min. If that frequency was not received within 1 min., the datalogger proceeded to the next frequency in its memory and repeated the previously described process. Each time a frequency was received and a corresponding pulse rate was determined for that frequency, that observation (i.e., an instantaneous scan; Altmann 1974) was coded as either head-up or head-down; the resulting data were then pooled by individual animal at 1-hour intervals. We used a two-sample *Z*-test for proportions (Remington and Schork 1970) to evaluate the ability of the recording system to correctly quantify the proportion of time an animal spent with its head in a particular position, and to compare the proportion of time spent feeding with the position of the head. We further evaluated bias of the recording system following the methods of Hansen et al. (1992).

We conducted validation tests for concordance between direct visual observation and the recording system at the Bighorn Institute, Palm Desert, California, USA. One desert sheep was fitted with an activity collar (Advanced Telemetry Systems, Isanti, Minnesota), and the position of its head was recorded every 30 seconds using our electronic system. We conducted instantaneous-scan sampling (Altmann 1974) simultaneously with the collection of electronic data to serve as a measure of the "true" activity of the collared animal at that instant; we recorded head position (up or down) and the activity in which the animal was engaged (e.g., feeding, bedded, walking, etc.) at the same time the datalogger recorded its observation. We used data on head position to test the system for accuracy, whereas information on feeding was used to establish a relationship between head position and time spent feeding (Bradshaw et al. 1997). During validation of data collection by our remote system, the proportion of head-up and head-down observations recorded by the datalogger and the observer ( $n = 1,277$ ) did not differ ( $Z = 0.775, P = 0.441$ ); the recording system underestimated head-down positions by 1.2%. Additionally, no significant difference existed in the proportion of time in the head-down position (as indexed by the recorder) and the proportion of time spent foraging in direct observations ( $Z = 0.163, P = 0.873$ ). Bias

associated with foraging was minimal with the electronic system, which overestimated observed foraging by 0.2%; consequently, we assumed that a head-down signal indicated a foraging animal, whereas a head-up signal was consistent with activities other than foraging.

### Response to Blasting

Because we knew the days on which blasting occurred at the Briggs mine, we used days since blasting as our measure of response to that potential disturbance. We used a weighted mixed-model ANOVA (PROC MIXED; SAS Institute Inc. 1997) to test for the effect of blasting on head position (i.e., foraging vs. nonforaging); this model is appropriate when data contain both fixed and random components, and exhibit heterogeneous variances (SAS Institute Inc. 1997). Number of observations for each female during a particular day and hour were used to weight proportional data. Fixed effects were area, season, number of days since blasting (day of the blast, 1-3 days post-blasting, and >3 days post-blasting), and time of day (0100-0459, 0500-0859, 0900-1259, 1300-1659, 1700-2059, and 2100-0059 h). Individual animals (nested within area) were considered a random component, and were included to account for individual variation among animals; interactions incorporating that term also were considered random effects (SAS Institute Inc. 1997). The interaction season  $\times$  time period  $\times$  animals nested within area was used to test for differences between areas resulting from ecological processes (i.e., seasonal and diurnal patterns), whereas days since blasting  $\times$  time period  $\times$  animals nested within area was used to test for effects of blasting.

### Forage Abundance and Quality

We quantified vegetation using step-point sampling along 100-m transects that were located randomly (Bowyer and Bleich 1984, Bleich et al. 1997) within mined and nonmined areas. We compared relative abundance between those areas using MANOVA and univariate *F*-tests. Samples of 12 forage species (five samples/species/area/month), consumed by mountain sheep (Bleich et al. 1992), were collected from July 1995 to June 1996 for analyses of percent crude protein (nitrogen  $\times$  6.25), in vitro dry matter digestibility (IVDMD), and moisture content following the methods of Bleich et al. (1992). Species of perennial forbs sampled were desert mallow, *Sphaeralcea ambigua*, desert trumpet, *Eriogonum inflatum*, and Rixford eriogonum, *E. rixfordii*. Perennial grasses were needlegrass, *Stipa speciosa*, and three-awn, *Aristida glauca*; representative species of shrubs included bedstraw, *Galium stellatum*, burro-weed, *Ambrosia dumosa*, desert holly, *Atriplex hymenelytra*, brittle bush, *Encelia farinosa*, Mormon-tea, *Ephedra nevadensis*, California buckwheat, *Eriogonum fasciculatum*, and mesquite, *Prosopis glandulosa*.

We analyzed IVDMD and moisture of perennial forbs and shrubs separately using three-way ANOVA (main effects were area, season, and forage class). Crude protein of perennial forbs and shrubs was analyzed with a three-way ranked ANOVA (Conover and Iman 1981) with the same factors. Because of nonconstant variances when grass

was incorporated into the overall model, that forage class was analyzed separately with a two-way ANOVA (area and season as main effects).

### Diet Quality and Composition

We used a combination of telemetry (aerial and ground-based) and field observations to locate female groups for collection of fresh fecal pellets (i.e., <1-week-old) each month (June 1995-September 1997) within our study areas. We collected samples on approximately the same date each month, and stored them appropriately (Jenks et al. 1990) prior to conducting analyses. Because the California Department of Fish and Game had collared adult males ( $n = 10$ ) in our study area as part of another project, we were able to use telemetry and direct observation to avoid areas inhabited predominantly by males (Bleich et al. 1997), thereby avoiding biases that might be introduced if we included their samples in our analyses. We attempted to collect  $\geq 5$  pellet groups (25 pellets per group) from each area each month. We determined percent fecal nitrogen for each sample as described previously for forage samples; this measure provided an index to diet quality (Bleich et al. 1997).

We used composited fecal samples (Bleich et al. 1997) collected between June 1995 and August 1996 to index composition of diets. Species of plants in fecal samples were determined at the Forage Analysis Laboratory, University of Arizona, with the microhistological technique described by Sparks and Malechek (1968). Plant fragments were categorized as perennial forbs, perennial grasses, shrubs, or succulents for statistical analyses (Bleich et al. 1997). Diet composition was analyzed with a two-way MANOVA with forage classes as dependent variables and area and season as main effects, whereas fecal nitrogen was evaluated with a two-way ANOVA with area and season as main effects.

### Additional Analyses

We indexed relative abundance of carnivores on each area by noting when they were encountered during helicopter flights, and by collecting carnivore feces in the field. Feces were enumerated and pooled within each area, and feces per kilometer of line transect for each area was compared with a  $t$ -test (Bleich et al. 1997).

We compared the ratios of young to adult females observed during fieldwork and helicopter surveys using a binomial approach (Bowyer 1991). We calculated 95%  $CI$  for estimates, and compared ratios between areas for a particular period with the 95%  $CI$ ; where  $CI$  overlapped, we assumed the ratio of young to adult females did not differ during that period (Bowyer 1991).

When multi-factor ANOVA was employed, all individual factor levels and their interactions were evaluated; significant models ( $P \leq 0.05$ ) were explored further with Tukey's honestly significant difference (HSD) to determine where differences occurred. We analyzed data using the software PC SAS (SAS Institute Inc. 1997) and SPSS (Statistical Package for the Social Sciences 1993). We used a Bonferroni correction (Kleinbaum et al. 1988) when conducting multiple comparisons. We examined

assumptions of each statistical test and transformed data as necessary to meet those assumptions. Bivariate correlations were evaluated with a Pearson product-moment correlation (Zar 1984). An  $\alpha = 0.05$  was adopted for all tests. Unless otherwise noted, we present means and standard errors for descriptive statistics.

## RESULTS

### Capture and Aerial Telemetry

We captured 8 female sheep (5 in 1995 and 3 in 1996) in the mined area, and 11 (8 in 1995 and 3 in 1996) in the nonmined area; no deaths of animals occurred during our capture efforts. During 45 h of extensive capture and survey efforts with a helicopter, we observed only 22 individual adult females within the specific area encompassing both study sites (Fig. 2), of which 19 (86%) were radiocollared during some portion of this study. We conducted 70 telemetry flights during June 1995–October 1997; female sheep were located 653 times (340 on the mined and 313 on the nonmined areas); the number of locations/female was  $48.6 \pm 5.8$  on the mined and  $39.1 \pm 3.9$  on the nonmined area. Additionally, our initial assignment of females to discrete populations (Fig. 2; i.e., mined or nonmined) was supported by their differing spatial distributions (MRPP;  $\delta = -124.340, P < 0.001$ ).

### Habitat Selection

Number of independent locations per female sheep in our analyses was  $43.3 \pm 4.4$  in the mined and  $34.1 \pm 3.8$  in the nonmined areas. The logistic-regression model, which exhibited good fit ( $X^2 = 4.54, P = 0.85$ ), identified four variables as useful in distinguishing between random sites and those used by female sheep: percentage of the mixed-woody-scrub plant community ( $X^2 = 108.80, P < 0.001$ ), elevation ( $X^2 = 17.88, P < 0.001$ ), percent slope ( $X^2 = 22.89, P < 0.001$ ), and percent visibility ( $X^2 = 3.03, P < 0.001$ ; Table 1). Females from mined and nonmined areas, however, did not differ in how they used habitat (MANOVA,  $F_{8,70} = 0.988, P = 0.452$ ). When compared to random locations, both groups selected sites in the mixed-woody scrub plant community at lower elevations, on steeper slopes, and with less visibility (Fig. 4).

Distance to permanent springs did not enter the logistic-regression model; however, because of an *a priori* hypothesis concerning its importance to desert sheep, we used a two-way ANOVA (area and season as main effects) to address that variable. When data from both areas were pooled, distance from water to random sites and to those used by female sheep differed significantly ( $F_{5,1151} = 4.34, P = 0.013$ ). After controlling for availability of water, female sheep from the mined area were significantly nearer water than those from the nonmined area during autumn ( $F_{1,364} = 9.27, P = 0.002$ ). During spring and summer, however, distance to water was not significantly different between areas ( $F_{1,232} = 2.69, P = 0.102$  and  $F_{1,544} = 0.06, P = 0.799$ , respectively). In general, females from both areas were nearer water than were random locations during summer (Table 1).

Within the mined area, significant differences occurred in the spatial distribution

Table 1. Habitat characteristics of random locations and of female mountain sheep from mined and nonmined areas in the Panamint Range, Inyo County, California, USA, during 1995-1997. Sample sizes are in parentheses.

Habitat variables	Area												
	Random (576)			Mined			Nonmined			Nonmined			
	$\bar{x}$	SE		Spring (65)	Summer (150)	Autumn (88)	Spring(53)	Summer (124)	Autumn(96)	$\bar{x}$	SE		
Dist. to springs (m)	1,925	40		2,060	1,608	83	1,922	97	2,113	133	84	2,238	89
Dist. toroads (m)	1,846	50		1,501	1,579	56	1,814	83	1,508	133	89	1,363	93
Dist. to Briggs Mine (m)	12,059	367		2,975	2,091	167	3,267	340	19,698	651	21,092	320	20,960
Sin aspect <sup>a</sup>	-0.43	0.02		-0.52	0.03	0.02	-0.43	0.04	-0.48	0.04	-0.40	0.03	-0.45
Cos aspect <sup>b</sup>	-0.07	0.02		-0.04	0.04	0.04	-0.07	0.05	-0.13	0.06	-0.21	0.04	-0.10
Slope (%) <sup>c</sup>	26.1	0.3		27.5	0.8	0.5	28.6	0.6	27.1	0.7	29.9	0.6	26.7
Terrain index <sup>d</sup>	526	12		664	31	545	573	30	575	39	498	20	534
Elevation (m) <sup>e</sup>	1,324	25		1,128	39	1,164	1,256	27	1,112	40	1,250	27	1,157
Visibility (ha) <sup>e,e</sup>	0.61	0.02		47.0	3.4	51.4	45.9	2.8	49.7	3.8	59.6	2.6	55.1
Creosote-bush	7.3	1.0		3.7	2.2	0.9	0.7	0.0	3.9	2.4	0.9	0.6	2.9
Juniper-woodland	11.6	1.3		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.8	1.0
Mixed-woodyscrub <sup>c</sup>	79.56	1.6		95.5	2.6	99.1	100	0.0	96.1	2.4	98.4	1.0	96.0

<sup>a</sup>N-S aspects.

<sup>b</sup>E-W aspects.

<sup>c</sup>V variables selected by logistic regression model for differentiating random locations from those used by female sheep.

<sup>d</sup>SD slope times angular deviation of aspect (Nicholson et al. 1997).

<sup>e</sup>Viewshed analysis from ARC/INFO; area (ha) visible to a sheep (1 m in height) to a maximum distance of 1000 m based on topographic relief.

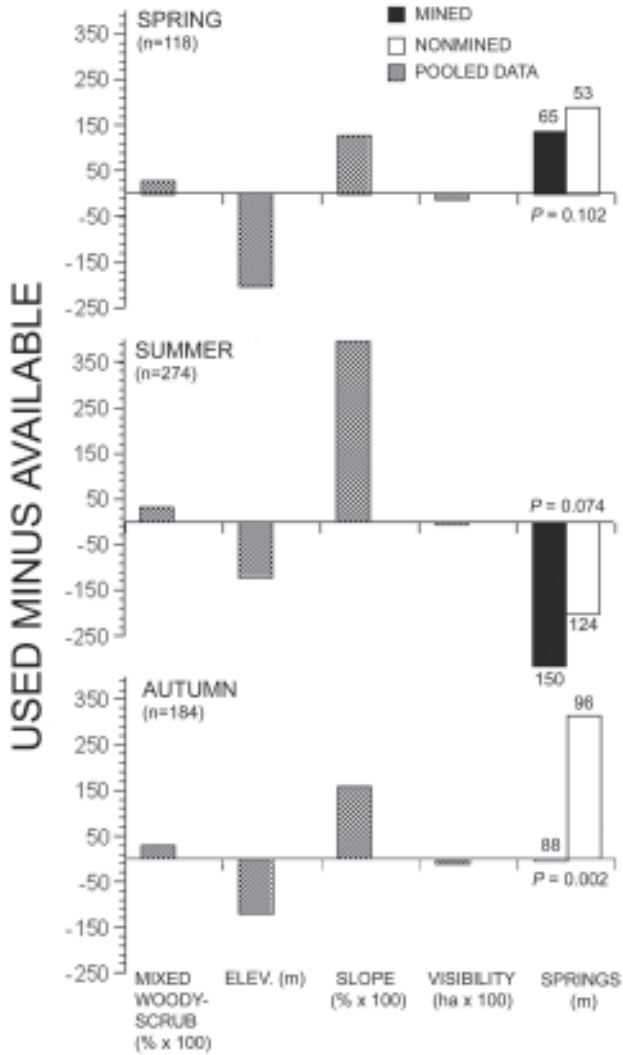


Fig. 4. Selection (used minus available) of habitat variables by female mountain sheep in the Panamint Range, Inyo County, California, USA, during 1995-1997. Mixed woody-scrub, elevation, slope, and visibility were significant variables in a logistic regression model ( $X^2 = 4.54$ ,  $P = 0.85$ ) for differentiating sheep locations from random locations.  $P$ -values for distance to springs are from ANOVA, and numbers above or below bars represent number of sheep locations used in that analysis.

of sheep and random locations relative to the Briggs Mine (two-way ANOVA,  $F_{5,605} = 19.00, P < 0.001$ ); females were consistently nearer the mine than were random locations (ANOVA,  $F_{1,605} = 67.09, P < 0.001$ ). Moreover, there were significant differences between seasons in the distances that sheep occurred from the mine ( $F_{2,302} = 6.68, P < 0.001$ ); female sheep were closer to the mine during summer ( $2,091 \pm 166$  m) than in autumn ( $3,267 \pm 340$  m), whereas during spring they were at an intermediate distance from the mine ( $2,975 \pm 326$  m); distance from the mine in spring did not differ from that in summer.

### Home Range

We determined that a mean minimum sample of  $26.7 \pm 2.4$  telemetry locations in the mined ( $n = 7$ ) and  $26.5 \pm 2.6$  in the nonmined ( $n = 8$ ) areas were required for home range estimation; four individuals lacked an adequate sample and were eliminated from our analyses. Mean sizes of annual home ranges did not differ significantly between areas (Table 2). Moreover, sizes of home ranges did not differ after controlling for effects of distance to the nearest permanent spring (ANCOVA,  $F_{1,12} = 0.482, P = 0.501$ ), or road (ANCOVA,  $F_{1,12} = 0.325, P = 0.579$ ).

Table 2. Size of annual home ranges (ha) of female mountain sheep from mined and nonmined areas in the Panamint Range, Inyo County, California, USA, during 1995-1997. *P*-values from two-sample *t*-tests are for within-row comparisons of mined versus nonmined areas.

Home Range Model	Area						<i>P</i>
	Nonmined ( $n = 8$ )			Mined ( $n = 7$ )			
	$\bar{x}$	SE	CV	$\bar{x}$	SE	CV	
Adaptive Kernel							
95%	6,926	834	34	6,222	806	34	0.557
50%	1,230	193	44	954	118	33	0.260
Min. Convex Polygon							
95%	4,006	445	31	3,467	396	30	0.395

### Foraging Behavior

We collected 10,241 and 7,023 h of data on head position (hereafter foraging, or foraging activity) for sheep inhabiting the mined ( $n = 8$ ) and nonmined ( $n = 10$ ) areas, respectively (Fig. 5). Number of days since blasting occurred had a significant effect on the proportion of time that females spent foraging ( $F_{4,334} = 17.68, P < 0.001$ ). When a reduced model (all main effects and the interaction days since blasting  $\times$  time period  $\times$  animals nested within area) was conducted by season, the three-way interaction was highly significant during all 3 seasons. That effect was greatest in summer ( $Z = 8.07, P < 0.001$ ), intermediate during spring ( $Z = 7.49, P = 0.001$ ), and smallest during autumn ( $Z = 6.81, P = 0.001$ ).

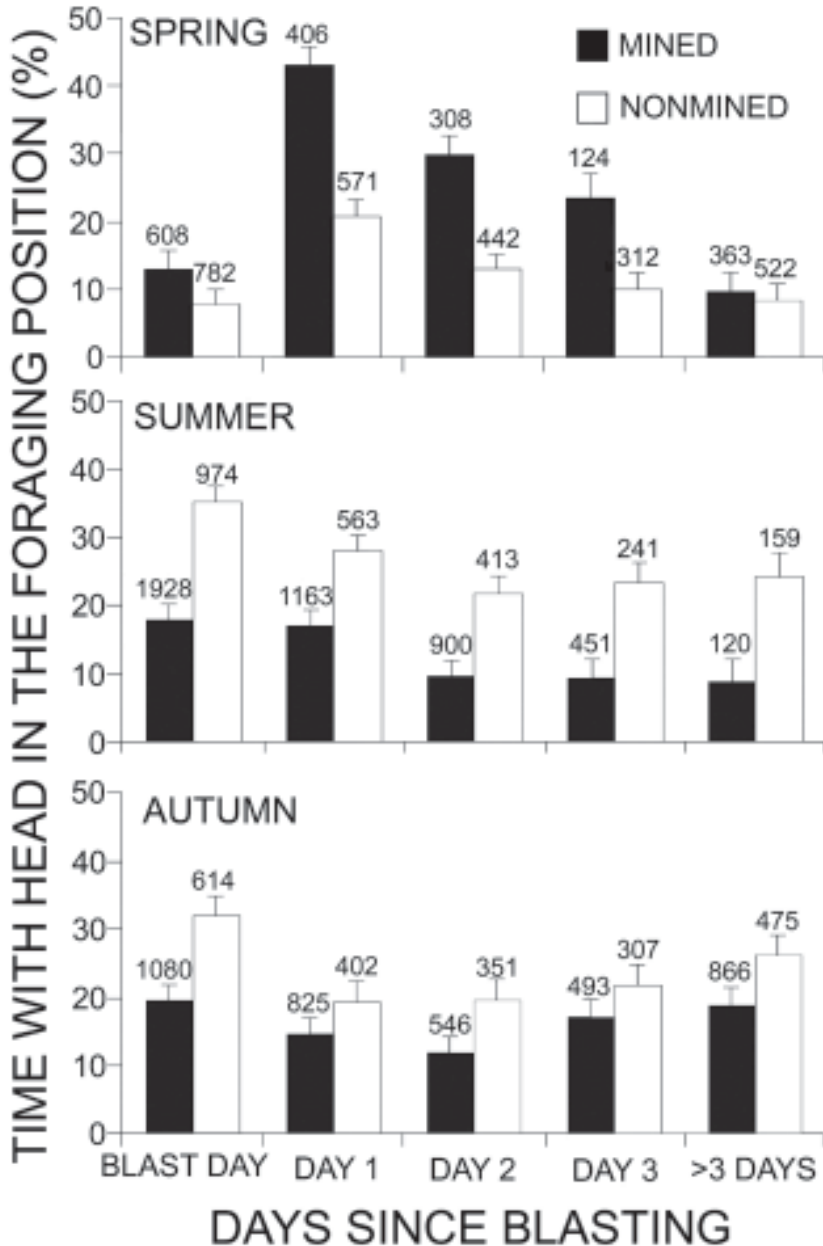


Fig 5. Percent time with the head in a foraging position (indexed by tip-switch collars) for female mountain sheep from mined and nonmined areas in the Panamint Range, Inyo County, California, USA, during 1996-1997. Value of bars (+ 1 SE) are least-squares means from mixed-model ANOVA (PROC MIXED; SAS 1997); numbers above bars are total hours of data collected for that bar.

We further examined number of days between blasts for the mined area with a two-way MANOVA, with days between blasting and amount of explosives per blast as dependent variables, and season as the class variable. We noted significant differences among seasons ( $F_{4,400} = 3.58, P = 0.007$ ), which were not the result of differences in the amount of explosives used per blast during spring ( $20,462 \pm 1,362$  tons), summer ( $23,204 \pm 905$  tons), or autumn ( $22,020 \pm 1,280$  tons) ( $F_{2,201} = 1.61, P = 0.202$ ), but rather number of days between blasts ( $F_{2,201} = 5.76, P = 0.004$ ). There were significantly fewer days between blasts during summer ( $1.5 \pm 0.2$ ) and spring ( $2.2 \pm 0.3$ ) than during autumn ( $3.0 \pm 0.4$ ) ( $F_{2,203} = 5.76, P = 0.004$ ). There were 3,397,878 metric tons of ore removed from the pit during spring, 4,785,498 in summer, and 2,552,166 during autumn. Amount of ore hauled each month was positively correlated with tons of explosives used during that month ( $r^2 = 0.83, P < 0.001$ ).

### Forage Abundance

We quantified vegetation on 24 and 36 transects in the mined, and nonmined areas, respectively (Fig. 6), and documented significant differences between areas in types of ground cover ( $F_{1,58} = 12.21, P < 0.001$ ). Transects on the nonmined area were characterized by more annuals ( $F_{1,58} = 48.55, P < 0.001$ ), forbs ( $F_{1,58} = 7.16, P = 0.009$ ), and bare ground ( $F_{1,58} = 8.41, P = 0.005$ ) than those in the mined area, whereas abundance of succulents ( $F_{1,58} = 3.79, P = 0.056$ ) and shrubs ( $F_{1,58} = 0.00, P = 0.99$ ) did not differ between areas.

### Forage Quality

We collected 1,152 forage samples within mined ( $n = 578$ ) and nonmined ( $n = 574$ ) areas. No significant differences occurred in moisture content of perennial forbs and shrubs between areas, but differences existed among seasons ( $F_{11,191} = 1.88, P = 0.044$ ), with shrubs possessing a higher moisture content than perennial forbs during spring ( $F_{3,77} = 3.35, P = 0.023$ ; Fig. 7). Similarly, there were no significant differences between areas in IVDMD of perennial forbs or shrubs ( $F_{1,191} = 2.90, P = 0.090$ ); nevertheless, IVDMD of perennial forbs and shrubs differed significantly among seasons ( $F_{1,191} = 24.62, P < 0.001$ ). Shrubs had consistently higher IVDMD than did perennial forbs during spring ( $F_{1,77} = 22.15, P < 0.001$ ) and summer ( $F_{1,63} = 6.30, P = 0.015$ ), but that relationship was not as apparent during autumn ( $F_{1,49} = 3.30, P = 0.075$ ). Conversely, when an overall model considered crude protein of perennial forbs and shrubs, there were no area or seasonal effects ( $F_{11,191} = 0.90, P = 0.546$ ).

When perennial grasses were analyzed separately, there were significant differences in protein between seasons ( $F_{5,23} = 7.52, P < 0.001$ ); further examination revealed differences were attributable to perennial grasses having higher protein content during spring in both mined ( $F_{2,11} = 6.55, P = 0.017$ ) and nonmined ( $F_{2,11} = 9.87, P = 0.005$ ) areas. Likewise, significant differences occurred in IVDMD ( $F_{5,23} = 6.42, P < 0.001$ ) and moisture content ( $F_{5,23} = 4.52, P = 0.008$ ) of perennial grasses from mined and nonmined areas. Again, differences were driven largely by the effects of spring; IVDMD was

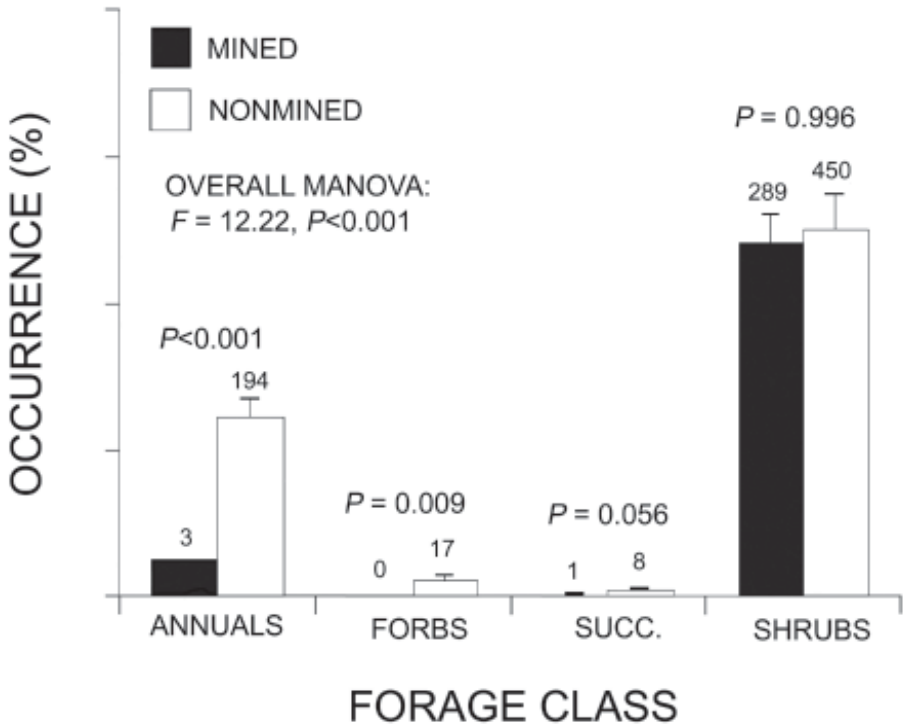


Fig. 6. Mean ( $\pm 1 SE$ ) vegetative cover (%) in habitats used by radiocollared female mountain sheep from mined ( $n = 24$  transects) and nonmined ( $n = 36$  transects) areas in the Panamint Range, Inyo County, California, during 1995-1997. Numbers above bars indicate occurrence (i.e., "hits") of that type of vegetation on all transects, and  $P$ -values are from univariate  $F$  tests. Grasses were not detected on transects in either area, and percentage of bare ground was significantly greater ( $P = 0.005$ ) in mined (87%) than the nonmined area (81%).

significantly higher ( $F_{1,5} = 29.58, P = 0.005$ ) on the mined than the nonmined area ( $\bar{x} = 66.4 \pm 4.7$  and  $\bar{x} = 42.5 \pm 5.9\%$ , respectively) during spring. Moisture content of perennial grasses did not differ between areas ( $F_{2,23} = 2.18, P = 0.157$ ), but was significantly higher in both areas during spring than in autumn ( $F_{2,11} = 7.39, P = 0.013$ ). Overall, there was a clear trend in both areas for increased quality of forage among all classes during spring (Fig. 7).

### Diet Quality and Composition

We collected 175 individual fecal groups from the mined area and 184 from the nonmined area for assessing quality of diet. There were significant area and seasonal effects on quality of diets (two-way ANOVA;  $F_{13,358} = 32.18, P < 0.001$ ; Fig. 8). Female

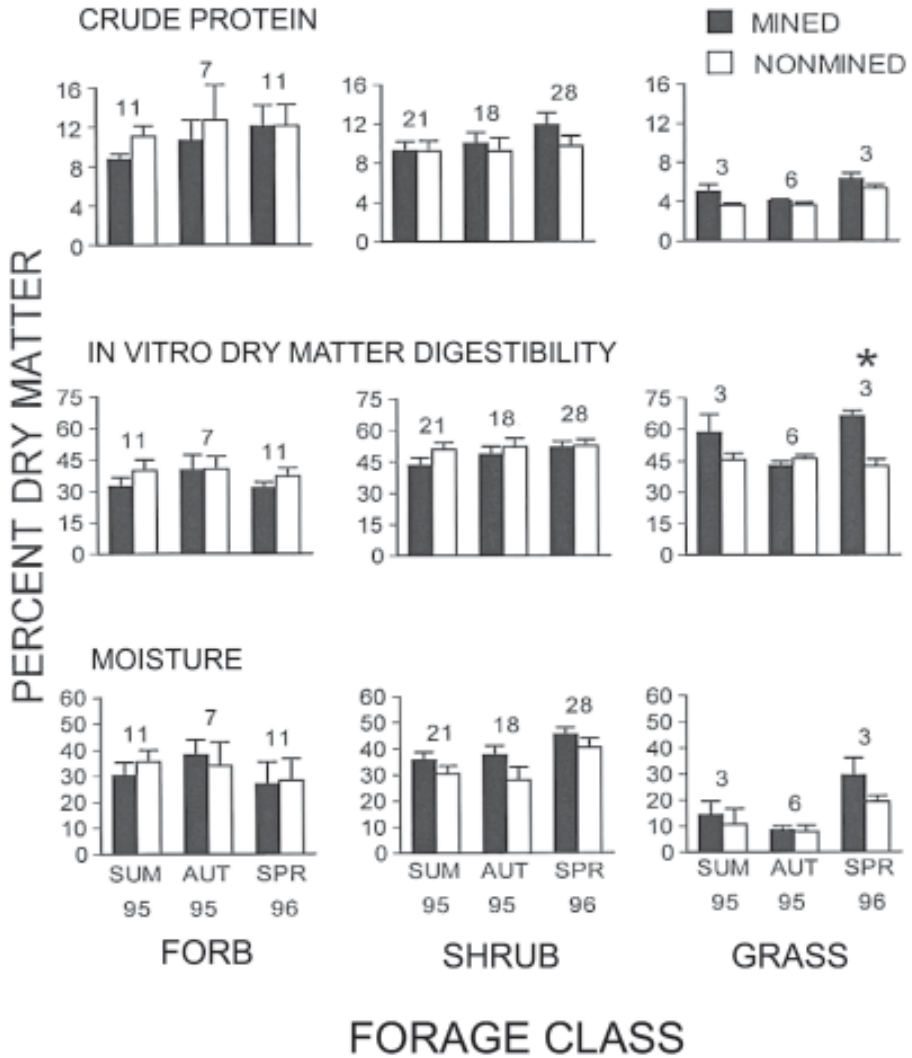


Fig. 7. Percent dry matter crude protein (top), *in vitro* dry matter digestibility (middle), and moisture (bottom) content of forage classes ( $\bar{x} \pm SE$ ) eaten by mountain sheep in the Panamint Range, Inyo County, California, during 1995-1996. Asterisk indicates significant difference ( $P < 0.01$ ) between areas and numbers above bars represent sample size from each area in the comparison.

sheep on the nonmined area had consistently higher levels of fecal nitrogen than conspecifics in the mined area (Fig. 8). Moreover, diet quality was highest during spring (Fig. 8), which was consistent with forage classes having higher levels of crude protein, moisture, and increased digestibility during that season (Fig. 7). Although level of tannins in shrubs may have increased fecal nitrogen, this is unlikely to have occurred because there was not a consistent or significant correlation between fecal nitrogen and the amount of shrubs in the diets of sheep from mined ( $r^2 = 0.882$ ,  $P = 0.118$ ), or nonmined ( $r^2 = -0.268$ ,  $P = 0.732$ ) areas.

No significant differences occurred between areas in the proportions of forage classes in the diet of female sheep (two-way MANOVA,  $F_{8,32} = 1.27$ ,  $P = 0.292$ ). During all seasons, shrubs were the most prevalent vegetation type in diets of females from both areas (Table 3). Overall, diets of female sheep contained an average of 55% shrubs, 30% forbs, 11% succulents, and 4% grasses.

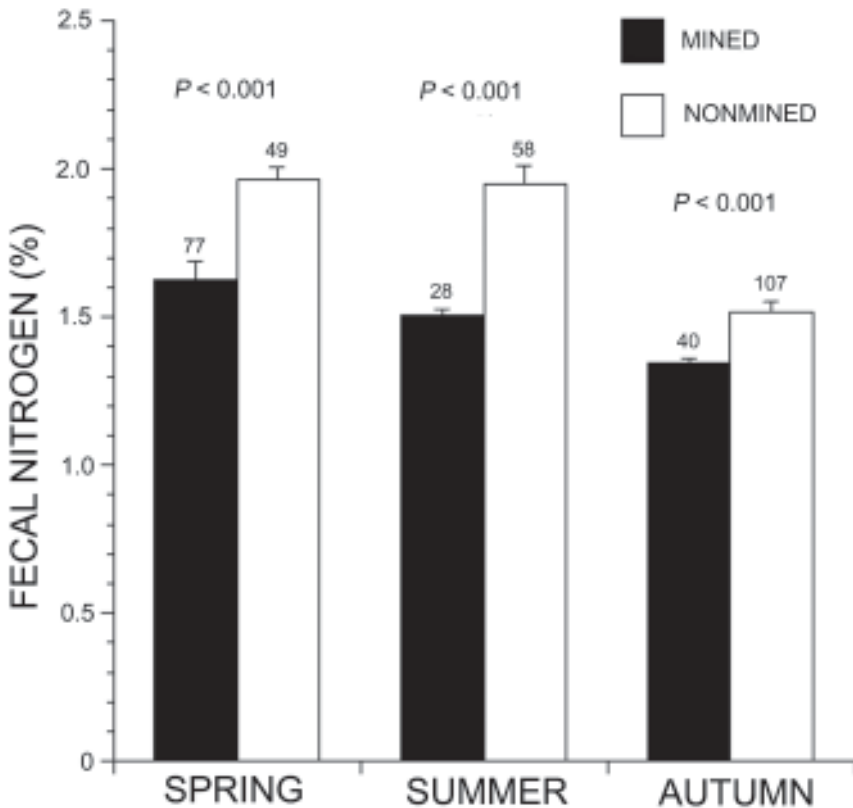


Fig. 8. Mean percent fecal nitrogen of female mountain sheep from mined and nonmined areas in the Panamint Range, Inyo County, California, during 1995-1997. Numbers above bars indicate sample size, bars represent 1 SE, and  $P$ -values are from two-sample  $t$ -tests.

Table 3. Percent of forage classes in the diets of female mountain sheep indexed from microhistological analyses of their feces, from mined and nonmined areas in the Panamint Range, Inyo County, California, USA, during 1995-1996.

Area	Percentage of forage class <sup>a</sup>							
	Forb		Grass		Shrub		Succulent	
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Spring								
Mined (3) <sup>b</sup>	34.4	2.3	1.1	0.6	53.5	2.4	11.1	0.7
Nonmined (3)	26.4	8.3	4.1	0.6	53.9	8.9	15.6	1.0
Summer								
Mined (7)	27.1	3.8	4.5	1.4	59.3	5.1	9.2	1.7
Nonmined (6)	31.0	5.7	5.9	1.0	52.9	4.9	10.3	2.4
Autumn								
Mined (2)	35.4	5.5	1.5	1.5	48.9	3.4	14.3	0.6
Nonmined (4)	31.3	5.2	1.8	1.4	57.5	8.1	9.4	3.8

<sup>a</sup>Overall MANOVA (area and season) was not significant ( $F_{8,32} = 1.27, P = 0.292$ ).

<sup>b</sup>Number of composite fecal samples for that season.

## Mortality and Indices to Predator Abundance

There were seven mortalities of female sheep in the nonmined area, and two in the mined area. In the nonmined area, two mortalities were attributed to predation by mountain lions, one fell to its death, and causes of death for the other four could not be ascertained. Similarly, causes of mortality for two female sheep in the mined area could not be determined. No differences existed in the ratio of young to adult females between mined and nonmined areas (Table 4).

From July 1995 to September 1997, we sampled transects totaling 24 and 34 km in length for carnivore feces from the mined and nonmined areas, respectively. When feces encountered on transects were pooled by area, there was no significant difference ( $t_{22} = -1.91, P = 0.077$ ) in the number of feces/km between mined ( $1.6 \pm 0.3$ ) and nonmined ( $1.0 \pm 0.1$ ) sites. No carnivores were sighted during the course of fieldwork on either study area; however, most work was performed during the day. Additionally, no carnivores were observed on the study area while conducting captures of sheep (~45 h of helicopter flight-time).

## DISCUSSION

Collared mountain sheep constituted 86% of the adult female sheep observed in our two study areas. Overall, we observed few effects that we could attribute to mining on the demography or other characteristics of populations of female sheep inhabiting mined and nonmined areas. For instance, proportion of young to adult females was not

Table 4. Young and adult female mountain sheep observed during aerial surveys near mined and nonmined areas in the Panamint Range, Inyo County, California, USA, during 1995-1997.

Date	Area	Young ( <i>n</i> )	Females ( <i>n</i> )	$P_t^b$	95% CI (P)
Jun 1995 <sup>a</sup>					
	Mined	5	7	0.416	0.132-0.700
	Nonmined	6	8	0.428	0.290-0.909
Oct 1995 <sup>a</sup>					
	Mined	1	4	0.200	0.000-0.551
	Nonmined	6	10	0.375	0.138-0.612
Jun 1996 <sup>a</sup>					
	Mined	4	8	0.333	0.117-0.549
	Nonmined	5	14	0.260	0.007-0.513
Jan 1997 <sup>a</sup>					
	Mined	3	4	0.428	0.054-0.802
	Nonmined	2	4	0.666	0.281-1.000
Oct 1997 <sup>a</sup>					
	Mined	3	4	0.428	0.054-0.802
	Nonmined	3	6	0.333	0.019-0.647

<sup>a</sup>Proportion of young to adult females did not differ between areas during that survey as indicated by overlap of 95% confidence intervals.

<sup>b</sup>Ratio and confidence intervals (CI) determined following methods of Bowyer (1991).

different between areas during any of the 3 years we monitored those subpopulations (Table 4). Moisture content, crude protein, and IVDMD of forage classes were highest for both areas in spring, intermediate in summer, and lowest during autumn (Fig. 7). Those outcomes are consistent with patterns in the quality of forage observed for other ranges inhabited by sheep in desert environments (Bleich et al. 1997, Krausman et al. 1989). Digestibility of grass was highest in the mined area during spring, but that was the only difference we detected in forage quality between areas (Fig. 7). We observed no differences in composition of diets of female sheep from mined and nonmined areas, although differences existed between forage classes consumed across seasons (Table 3). The former outcome is probably the result of the similarity in quality (Fig. 7) and availability of forage species (i.e., shrubs) between sites (Fig. 6), whereas the latter is likely a consequence of how desert plants with differing life-history strategies respond to variation in precipitation (Beatley 1974). Thus, female sheep from both areas used forage classes differentially, depending on seasonal quality and availability. Differences in availability of forage (as indexed by vegetative cover) between areas were minimal and limited to percentage of annual plants and perennial forbs (Fig. 6).

Size of annual home ranges for females did not differ significantly between areas (Table 2). Indeed, there was substantial individual variation and no clear pattern in

those data (Table 2). Berger (1991) suggested that use of steep rocky habitats was more pronounced for post-parturient female mountain sheep when compared with those without young. In contrast, females without offspring were more likely to forage in areas away from escape terrain, where quality of forage was better, but perceived risk of predation higher (Berger 1991)—those factors could result in large home ranges for females without young. Thus, variability in sizes of home range in our study may have occurred because not all collared females had young at heel, a hypothesis we could not test because we were unable to ascertain the reproductive status of every female during aerial telemetry flights. Nonetheless, the large proportion of the population that was collared and the lack of a difference in ratios of young to adult females between study areas make this interpretation unlikely.

Females from both areas selected sites with more mixed woody-scrub, lower elevations, steeper slopes, and less visibility than at random locations during all seasons (Fig. 4, Table 1). Several researchers (Berger 1991, Bleich et al. 1997, and others) have reported that female sheep consistently used steep and rugged terrain that was close to water. That strategy likely represents a tradeoff between decreased forage quality in steep rocky habitats and decreased rates of predation on neonates (Berger 1991, Bleich et al. 1997, Rachlow and Bowyer 1994, 1998). Following precipitation in early spring, the proportion of grasses increased in the diets of sheep from the nonmined area, but not for those in the mined area (Table 3). That females in the nonmined area apparently increased their use of that resource is consistent with other studies that noted an increase in the consumption of graminoids by mountain sheep following periods of precipitation (Wehausen and Hansen 1988, Berger 1991). Berger (1991) proposed that pre-parturient females that foraged at low elevations on open slopes traded an increased risk of predation for the opportunity to maximize nutrient intake, a hypothesis supported by research on other ungulates (Bowyer et al. 1999, Kie 1999, Barten et al. 2001). Females from the nonmined area had higher levels of fecal nitrogen during spring than did those from the mined area (Fig. 8); such an outcome would be consistent with the aforementioned strategy suggested by Berger (1991). Although females from both areas used areas lower in elevation than random locations, females from the mined area may have been reluctant to forage on the lowest elevation slopes adjacent to the mine during spring because of the proximity of those sites to activities associated with the mine.

Patterns of foraging were not similar between subpopulations of female sheep (Fig. 5), and interpretation of those results during spring was not straightforward. If females in the mined area were precluded from foraging on graminoids during spring by mining activities, they may have had to forage more intensively (i.e., spent more time foraging) in steep areas where forage quality was lower (Bleich et al. 1997). Indeed, quality of diet was lower for female sheep in the mined area during spring (Fig. 8). Although mountain sheep may habituate to human-caused disturbances (Morgantini and Worbets 1988), those ungulates have been reported to avoid areas where disturbance was extreme (Leslie and Douglas 1980, Berger 1991, Stockwell et al. 1991), and did not appear to habituate to extreme disturbances such as helicopter overflights (Bleich et al. 1994).

Availability and juxtaposition of water within each area may be the most parsimonious

explanation for differences we observed in foraging ecology between groups of female mountain sheep inhabiting mined and nonmined areas during summer. Indeed, females from both areas were nearer water during summer than other seasons (Table 1). Sources of permanent water were fewer and more dispersed in the mined area. Moreover, female sheep in that area relied almost exclusively on Redlands Spring, which was adjacent to the mine, to meet their metabolic needs for water during summer. In contrast, females in the nonmined area used several springs. Turner<sup>5</sup> (1973) reported that daily needs for water for desert mountain sheep was about 4% of their body mass, and that this amount could not be obtained from forage during the hot summer. Desert sheep have been reported to inhabit ranges without sources of perennial water (Krausman et al. 1985b); nevertheless, that result would not preclude water affecting the distribution of sheep in other areas. For instance, free water strongly affected the distributions of other ungulates, even in situations where water was abundant and therefore could not be limiting those populations (Bowyer 1981, Stewart et al. 2002).

Alderman et al. (1989) reported that in the Little Harquahala Mountains, Arizona, where permanent water was not available, desert sheep likely met their metabolic needs by using pools of free-standing water that accumulated in depressions in the substrate after occasional thunderstorms. During our investigation, however, summer thundershowers were rare (Oehler et al. 2003); the lack of summer rain likely would have limited areas that could be used by desert sheep during that season. As a consequence of their reliance on Redlands Spring during summer, female mountain sheep in the mined area also were closest to the Briggs Mine during that season (Table 1).

Several studies have reported that the magnitude of a response to a disturbance is a function of the proximity to the stimulus (MacArthur et al. 1982, Stockwell et al. 1991, Bleich et al. 1994). Stockwell et al. (1991) concluded that mountain sheep in the Grand Canyon, Arizona, foraged more efficiently as distance from helicopter disturbance increased. Similarly, MacArthur et al. (1982) reported mountain sheep in Alberta, Canada, exposed to low-flying aircraft (90-250 m), exhibited a 3.5-fold increase in heart rate over those exposed to high-flying aircraft (>400 m). Results from our analyses of foraging behavior and diet quality suggest that female sheep in the mined area were disturbed by activities associated with the Briggs Mine during summer. That outcome is consistent with the interval between blasting being shortest during summer ( $1.5 \pm 0.2$  days). Moreover, amount of ore hauled (an index to vehicle activity) from the mine pit also was highest during summer, and was strongly correlated with the amount of explosives used at the mine.

Patterns of decreased foraging by mountain sheep in the mined area during summer and autumn (Fig. 5) may have been the result of those females spending more time vigilant and, concomitantly, less time foraging (Berger 1991, Stockwell et al. 1991). That conclusion is in keeping with sheep in the mined area obtaining lower-quality diets during summer than sheep from the nonmined area (Fig. 8) as a consequence of decreased foraging efficiency (Berger 1991, Stockwell et al. 1991, Molvar and Bowyer

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<sup>5</sup>Turner, J. C. 1973. Water, energy and electrolyte balance in the desert bighorn sheep *Ovis canadensis*. Dissertation, University of California, Riverside, USA.

1994, Bowyer et al. 2001). Likewise, summer was when the greatest disparity in quality of diets of sheep occurred (Fig. 8). Differences in levels of foraging during autumn were similar to those of summer for sheep in the mined area (i.e., consistently lower than the nonmined area; Fig. 5); however, interpretation is less clear than for summer.

During autumn, as daytime temperatures (Oehler et al. 2003) and metabolic needs for water decreased, levels of foraging were most similar between areas, and may have been an outcome of sheep from the mined area moving away from Redlands Spring (Table 1) and, consequently, away from the mine. Moreover, an increased interval between blasts at the mine, and subsequently less ore being removed during autumn than summer, may have ameliorated disturbances to sheep. Quality of forage was lowest during autumn (Fig. 7); however, decreased water requirements (Turner<sup>5</sup> 1973) associated with lower temperatures probably allowed sheep in the mined area to venture further from Redlands Spring in search of higher-quality forage. We hypothesize that the resultant increase in foraging by sheep in the mined area during autumn (Fig. 5), and the small difference in quality of diets between areas (Fig. 8), are the result of those animals moving away from the area of disturbance as physiological demands for water became less severe.

A combination of four factors offers the best explanation for our results: 1) proximity of Briggs Mine to the primary source of water used by females in the mined area; 2) a limited number of permanent sources of water in the mined area; 3) lack of rainfall during summer and autumn (Oehler et al. 2003); and 4) philopatric behavior of female mountain sheep (Geist 1968), which lessened the tendency to disperse from the disturbance caused by mining. In concert, those factors likely resulted in females remaining near the mine where disturbance was greatest, particularly during summer when metabolic needs for water also were highest. Leslie and Douglas (1980) reported that female mountain sheep in Nevada altered their watering patterns in response to construction activities near a primary source of water. In contrast, we did not observe such a result, presumably because of the high degree of fidelity of females to Redlands Spring and the scarcity of other nearby sources of free water.

Demographic consequences in response to disturbance are difficult to document because of high variability in observed population parameters (e.g., young to female ratios); therefore, less-direct measurements are of value for these types of investigations. For example, small changes in diet quality can result in important nutritional changes in females over time, and thereby affect subsequent reproductive efforts (White 1983). Also, nutrition, as affected by forage quality and efficiency of foraging (Berger 1979), can be linked to nutrition of females, and thereby survivorship of young ungulates (Keech et al. 2000). Such consequences can be especially important to desert mountain sheep, particularly in marginal environments, where recruitment is comparatively low (Rubin et al. 2000). If the outcomes we observed persist in the mined area, we hypothesize that reduced nutrient intake could have demographic consequences for that subpopulation.

Because observed differences were most pronounced during summer, a reduction of mining activities during that season may benefit sheep occupying areas near the mine. Most females have young at heel during spring, and shifting mining activity from

summer to spring might be detrimental. Increasing the interval between blasting, which would result in a decrease in overall mining activity during summer, may ameliorate the apparent effects of mining on sheep during that season. Intensity of mining, as indexed by days between blasting, amount of explosives used, and amount of ore hauled from the pit, was lowest during autumn. Although we have no direct data on levels of potential auditory disturbance from the sound caused by blasting, amount of explosives used undoubtedly provides an index to such stimuli. If a shift in mining activity is necessary to offset lost mine production in summer, we suggest that autumn is the best time for the concomitant increase in activities. Creation of additional sources of permanent water away from the mine also may help reduce reliance of females on Redlands Spring and, hence, reduce potential negative effects of mining on foraging behavior. We observed few effects of mining on demography or other characteristics of mountain sheep populations; however, we caution that because of the unique distribution of water in our study area, that our conclusions should not be generalized to other circumstances where the juxtaposition of critical resources might differ, thereby detrimentally affecting the demographics of mountain sheep.

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