THE IMPACT OF HUMAN DISTURBANCE ON DESERT BIGHORN SHEEP (OVIS CANADENSIS NELSONI) IN THE WONDERLAND OF ROCKS / QUEEN MOUNTAIN REGION OF JOSHUA TREE NATIONAL PARK, CALIFORNIA.

A final report prepared for Joshua Tree National Park, CA.

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EXECUTIVE SUMMARY

The Wonderland of Rocks/Queen Mountain region of Joshua Tree National Park (N.P.), California is inhabited by a small population of desert bighorn sheep (*Ovis canadensis nelsoni*). Increasing levels of human recreational use (hiking, rock climbing and picnicking) are occurring in this area and there is concern that this population is at risk from cumulative human disturbance. Unfortunately, there is little information regarding the demography, habitat use, or behavior of this bighorn sheep population. Without this baseline data, natural resource managers at Joshua Tree National Park cannot assess the effects of increasing recreation use on the population. Our goals were to estimate population size, ewe seasonal home ranges, identify areas of critical habitat, obtain data on sheep foraging behavior and activity budgets and determine whether patterns of space and/or habitat use were being affected by recreational activity.

We captured 10 bighorn ewes and attached GPS collars with satellite uplink capability. Over 15,100 location points were collected from these animals. Behavioral data for foraging and daily activity patterns were collected using both scan and focal animal sampling. Levels of recreation activity were estimated by 2 methods. Daily records of vehicles entering the park obtained from the National Park Service were used as an index of recreation activity and trail counters were used to count the number of hikers using specific trails between November 2002 and October 2004.

Systematic flight surveys during the capture operation resulted in a bighorn sheep population estimate of 40 - 50 individuals across the study area. Ground surveys resulted in a total population estimate of 54 bighorn within the study area in 2003 with a 95% confidence interval (CI) of 39 - 68 and an estimate of 59 (95% CI 28 - 89) in 2004. Total distribution of the 10 collared ewes encompassed an area of over 300 km^2 during the study period. Five ewes used the Wonderland of Rocks region during the June-September seasons of both years. The remaining 5 ewes were mostly found in the vicinity of Queen Mountain. We found the logistic regression model containing the variables of slope, ruggedness, elevation, and distance to water to be the best predictor of suitable habitat within the study area, which contained approximately 182.0 km^2 of bighorn habitat.

Total human visitation over the study period was approximately 1.28 million persons per year. Recreation use was greatest during spring months and approximately doubled on weekends compared to weekdays. We compared habitat use and movement patterns of ewes between weekdays and weekend days across the entire study area within each season for each year. During spring months ewes were found on steeper slopes during weekends than on weekdays. Animals in recreation areas bedded farther from trails in April, the month of greatest visitation, than February, a time of similar environmental conditions yet of significantly lower visitation levels. Ewes also traveled significantly farther per day in April than February. The long-term effects of anthropogenic changes upon this population are unknown. The continued monitoring of bighorn habitat use and human visitation levels in and near recreation areas is highly recommended.

INTRODUCTION

Bighorn sheep populations (*Ovis canadensis*) in North American deserts are threatened by many human activities (Papouchis et al. 2001, McCutchen 1995, 1981). Cumulative effects of human disturbance have been implicated in the abandonment of bighorn sheep habitat (and extirpation of the population) in the Pusch Ridge Wilderness, Arizona (Etchberger et al. 1989), the San Gabriel Mountains, California (Graham 1971), and in some areas of southeastern Utah (King 1985). Human disturbance was also a primary factor prompting the listing of the California peninsular population of desert bighorn sheep (O. c. cremnobates) as an endangered population (U.S. Fish and Wildlife Service 1999).

There is evidence that in some circumstances, sheep may habituate to predictable human activity (Wehausen et al. 1977, Kovach 1979), including highway traffic (Horesji 1976), hiking (Hicks and Elder 1979, Hamilton et al. 1982, Holl and Bleich 1987), and aircraft (Krausman et al. 1998). However, even in otherwise optimum habitat, sheep are known to abandon an area, either temporarily or permanently, when the limit of their tolerance to disturbance is exceeded (Welles and Welles 1961, Light 1971, Wehausen 1980, Papouchis et al. 2001). Significant loss of habitat can result in a reduction in the population's carrying capacity (Light and Weaver 1973). Additionally, energetic losses due to flight, loss of foraging time, and an increase in cortisol levels can cause deleterious effects on physiology, behavior and the accumulation of fat reserves, all factors which can cause a reduction in survival and reproductive success of individuals (MacArthur et al. 1979).

Increasing levels of human recreational use (hiking, rock climbing and picnicking) are occurring in the Wonderland of Rocks/Queen Mountain region of Joshua Tree National Park (N.P.), California. The area is inhabited by a small population of desert bighorn sheep (*Ovis canadensis nelsoni*), one of an estimated five populations to occur within the park. As a result of the increase in recreational use, there is concern that this population is at risk from cumulative human disturbance. Public use in 1998 greatly increased at the Keys Ranch watering site after weekend-only tours were increased to seven days a week four times a day, and plans to construct a paved road and parking lot at the Barker Dam trailhead is predicted to cause an increase in visitor use at the Barker Dam watering site.

Unfortunately, there is little information regarding the demography, habitat use, or behavior of this herd. Population status and habitat use studies have been conducted for two of the bighorn sheep populations in Joshua Tree National Park (Douglas and White 1979), but no study has been conducted on the Wonderland of Rocks herd. The current status of desert bighorn inhabiting the Wonderland of Rocks/Queens Mtn area must be assessed so that management decisions can be made to protect these sheep and their critical habitat. Without baseline data on demography, resource use, and behavior, natural resource managers at Joshua Tree National Park cannot assess the effects of increasing recreational use of this population of desert bighorn sheep.

OBJECTIVES:

The objectives of this study were to: 1) Estimate size of the bighorn sheep population in the Wonderland of Rocks/Queen Mountain region of Joshua Tree National Park; 2) Estimate ewe seasonal home range and distribution and determine whether recreational activity is affecting patterns of space/habitat use within their home range; 3) Determine areas of critical habitat for ewes in this population and determine whether ewes are avoiding areas of critical habitat in response to recreation activity; 4) Obtain a baseline for sheep foraging behavior and activity budgets and determine whether ewes are experiencing detrimental changes in their energy budgets as a result of human disturbance from recreation activity; 5) Determine whether mitigation measures at the 49 Palms Oasis are effective in allowing sheep to use the water source.

METHODS:

Study Area

The study area for this project is defined geographically as a rectangular area with the northwest corner at UTM coordinates 567000E, 3777000N and the southeast corner at 602000E, 3758000N. This area is known as the Wonderland of Rocks/Queen Mountain region of Joshua Tree National Park, California. Elevation is between 680m and 1775 m and topography is generally steep and rocky with large granite boulders covering some areas. Dominant vegetation is strongly associated with elevation (Leary 1977), and consists of *Larrea tridentata-Ambrosia dumosa* associations at lower elevations (700 m – 1,000 m); *Yucca shidigera, Yucca brevifolia,* and *Coleogyne ramosissima* associations at the mid-elevations (900 m – 1,400 m); and *Juniperus californica* associations at the higher elevations (1,100 m – 1,775 m) (Leary 1977). The Wonderland of Rocks area lies within the high elevation association and is east and adjacent to Queen Mountain. Wonderland of Rocks is a granitic outcrop habitat type with a relatively lower density of vegetation (Leary 1977, Lowrey pers. observ.). Average rainfall is < 10.0 cm per year, with most occurring in the winter and summer months.

Bighorn Capture Operation

On 29-30 October 2002, 11 desert bighorn sheep (*Ovis canadensis nelsonii*) ewes were captured within the Wonderland of Rocks/Queens Mountain region of Joshua Tree National Park, California (Fig. 1). Cooperating agencies involved in the capture operation were the U.S. Geological Survey, National Park Service, California Fish and Game, and the University of Nevada Las Vegas. Ewes were captured using a net-gun fired from a helicopter. They were then blindfolded, immobilized with leather straps (or hobbles) and transported to a central processing area located at UTM 579300E, 3772050N. Blood, mucous, fecal samples, and physiological measurements were also taken. Ewes were then fitted with satellite GPS/VHF radio collars (Telonics Inc., Mesa AZ). After processing, bighorn were transported by helicopter back to their respective capture locations. GPS collars were TGW-3580 store-on-board units with ARGOS satellite uplink capability.

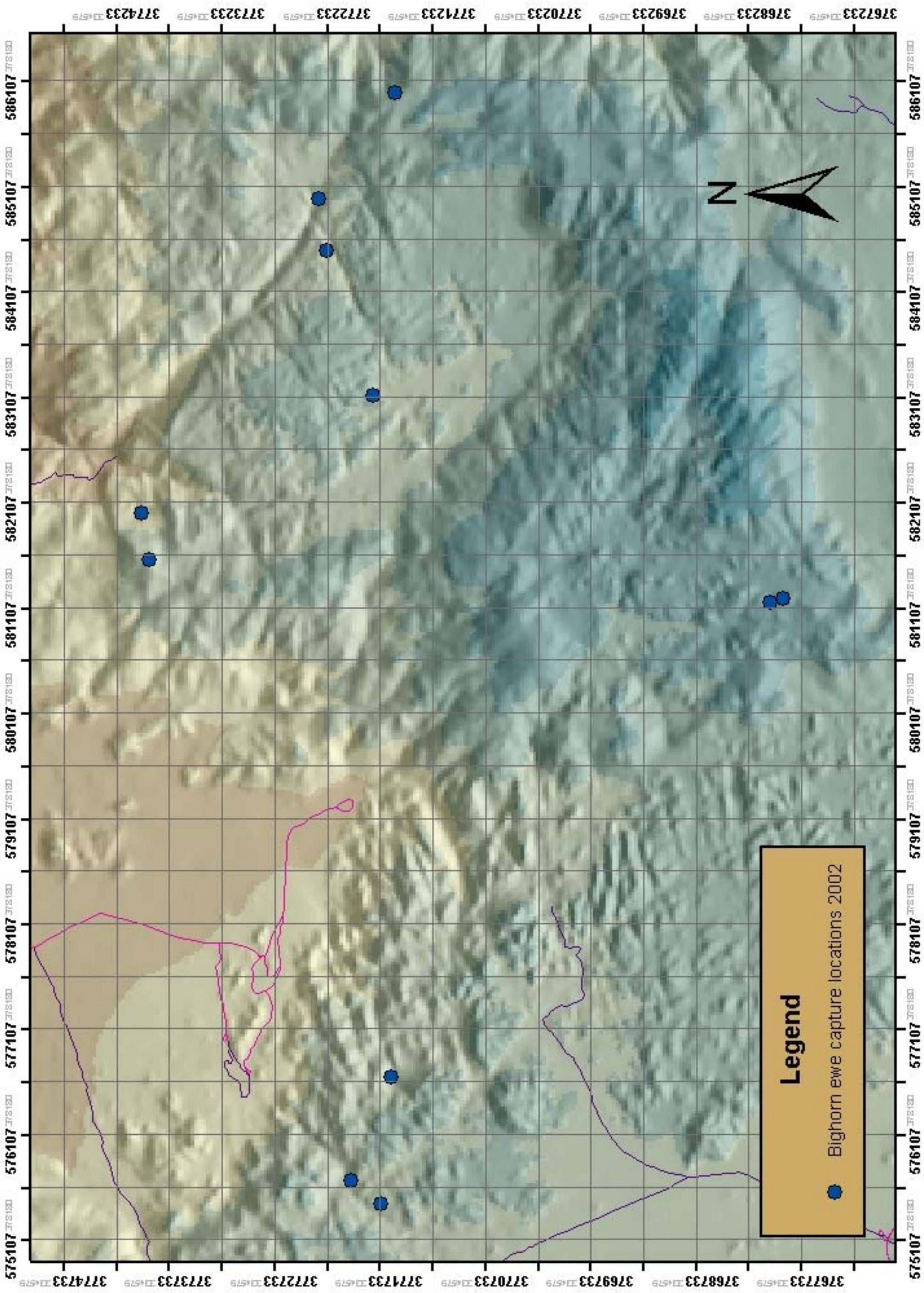

Figure 1. Capture locations for bighorn ewes, October 2002, in the Wonderland of Rocks/Queen Mountain region, Joshua Tree National Park, California.

Location data were recorded three times per day, at 0500, 1200, and 2000 hours (Pacific Standard Time). Collars were also fitted with an automatic breakaway collar release and mortality sensor. GPS location data were up-linked to ARGOS satellites every two days.

Population Estimation

Population size of bighorn sheep in the study area was estimated using two independent approaches. Using more than one approach improves accuracy, and increases the credibility of estimates (Minta and Mangel 1989, Skalski 1994, Gardner 1996). First, a helicopter population survey was conducted simultaneously with the capture effort. An experienced pilot and three observers experienced in bighorn sheep identification physically counted all bighorn seen while conducting low-level flights that systematically covered the Wonderland of Rocks/Queen Mountain area. The population estimate was calculated by assuming only a percentage of animals were actually seen (Bodie et al. 1995, Vern Bleich, Calif. Dept. Fish and Game, pers. comm.).

As a second approach, ground surveys were conducted across the study area from November 2002 to October 2004. Ground surveys were conducted randomly within recreation and non-recreation areas. Because the study area was too large to survey simultaneously, approximately 20 km^2 were surveyed per month. Both collared and uncollared bighorn were counted (Hein and Andelt 1995, Gardner 1996, White 1996). The formula used for estimating population size was based on the proportion of collared and uncollared animals using the following formula: [(*total animals with collars*)*(*total animals sighted* + 1) / (*animals with collars sighted* + 1)]. The *total animals with collars* variable was those collared animals within the field observers' potential view at time of survey, which was known from GPS collar location data. Remaining formula variables were counted by observers in the field. This mark-resight method has been demonstrated to be accurate for species that have unequal sightability due to differences in terrain, and has successfully estimated populations of large mammals (Minta and Mangel 1989). Population size was calculated as the sum of estimates of non-overlapping geographic areas (Skalski 1994, Pisani 2002). Although satellite location data assured no double counting of collared animals, uncollared animals may have been counted more than once. Double counting may positively bias an estimate.

Habitat Use

We used GPS collar location data to determine habitat used by bighorn and create predictive, seasonal habitat models to allow management to make informed decisions concerning potential human impacts within the Wonderland of Rocks/Queen Mountain region. Bighorn habitat was determined by measuring the variables of slope, distance to permanent water, ruggedness, and elevation underlying known collared bighorn locations. These variables are known to be good predictors of desert bighorn occurrence, and have been successfully used to model habitat (Holl 1982, Bleich et al. 1997, Zeigenfuss 2000, Sappington et al. *in press*). All variables were calculated with a GIS (ArcMap 9.1). The ruggedness index was calculated by quantifying the terrain angles within each 30 m x 30 m grid cell across the study area (Sappington et al, *in press*).

Locations were separated before analyses into seasons based on weather patterns and bighorn biology. Seasons were defined as three four-month time periods per year: February-May included the lambing period, relatively greater rainfall, and relatively greater forage availability; June-September included the mating season, months of poor forage, and extreme weather; October-January included cooler weather and winter forage availability (Monson and Sumner 1981, Shackleton 1985, Rubin et al. 2000).

We first used logistic regression analyses to determine if habitat variables are predictive of bighorn locations (Menard 1995, Manly et al. 2002). Since comparing bighorn locations to areas of unlikely occurrence (i.e. flat areas) is of little use, we constrained random points to areas of slope greater than 20% (Etchberger et al. 1989, Bangs et al. 2005). We entered the seasonal logistic regression equations into an ArcMap GIS raster calculator to generate resource selection function (RSF) values. These values are proportional to the probability of animal occurrence across the available habitat (Boyce and McDonald 1999). We scaled the RSF values into 10 percentiles to rank and map bighorn habitat across the study area (Boyce and McDonald 1999, Keating and Cherry 2004). The areas defined by the lowest percentile(s) of RSF values incorporating ≥ 90% of bighorn locations were interpreted as suitable bighorn habitat.

Seasonal Home Ranges, Core Areas, and Movement Patterns

Bighorn seasonal home range was defined as extent of area used within seasons with a 95% probability of occurrence (Millspaugh and Marzluff 2001). Core areas were defined as areas with a 50% probability of occurrence within these seasonal home ranges (Bingham and Noon 1997). Seasonal home ranges and core areas were estimated with a GIS (ArcView 3.2: Animal Movements extension) (Hooge and Eichenlaub 2000) using the fixed-kernel method. The fixed kernel is believed to have lower bias and better surface fit than other methods (Seaman and Powell 1996, Millspaugh and Marzluff 2001). Two weaknesses in this method (and most home range estimators) are that location error and time-sequence information are not incorporated into home range calculations (Powell 2000). Since no objective method exists to tie the bandwidth value (width of the kernel or h) to location error or the time-sequence of location points, it is often the judgment of researchers to choose this value using knowledge of these parameters. A bandwidth value of 500 was chosen as this resulted in home range estimates that conformed to known location error and known average distance moved by bighorn between location points (Worton 1989, Powell 2000, Millspaugh and Marzluff 2001).

We measured movement patterns in terms of distance traveled per day (24 hours) by collared bighorn using GPS collar location data taken at 7-8 hour intervals. Distance traveled was calculated across the three-dimensional surface (i.e. the line between points followed the terrain) using an ArcView extension (Jenness 2005). The distance traveled measurements resulted in negatively biased estimates of distance moved, as animals were clearly moving beyond the line measured between location points during the 8-hour time interval. However, regardless of this bias, we believe the large number of repeated, verified locations used resulted in relatively precise estimates of movement, permitting biologically meaningful statistical analyses and interpretation (Reynolds and Laundré 1990).

Recreation Activity

Recreation activity in Joshua Tree N. P. occurred year round; however, there were periods of greater and lesser use. Levels of recreation activity were estimated by two methods. Daily records of vehicles entering the park obtained from the National Park Service were used as an index of recreation activity. The most reliable daily visitation data in terms of temporal continuity and proximity to the study area came from vehicle entry data at the west entrance station (UTM 588885E, 3771225N). We therefore used this entrance station data to estimate and compare daily recreation use. We assumed a direct, positive linear relationship between number of vehicles entering and number of persons using the trails, campgrounds, and backcountry areas of the park. Secondly, trail counters (TrailMaster model TM 550, Goodson and Assoc. Lenexa, KS.) were used to count the number of hikers using specific trails between November 2002 and October 2004. Counters were placed along the 49 Palms Oasis trail (UTM 582610E, 3774100N); Pine City (UTM 586680E, 3767300N); Barker Dam (UTM 578902E, 3766169N); Wonderland Wash (UTM 579301E, 3766264N) and Rattlesnake Canyon trails (UTM 579475E, 3771511N) by U.S.G.S. researchers and Joshua Tree N. P. personnel. Trails were categorized into three levels of recreation use: high, moderate, and low. These categories were developed from trail counter data, Joshua Tree N.P. staff observations, and observations of researchers. Vehicle entry and trail counter data were then used to categorize greater-use and lesser-use time periods as greater recreation and low recreation time periods, respectively.

Effects of Recreation on Habitat and Movement Patterns across the entire Study Area

We first tested the hypothesis that recreation activity affected habitat and movement patterns of bighorn ewes across the entire Wonderland of Rocks/Queen Mountain region. Variables of distance traveled per day, elevation, ruggedness, distance to trails, distance to permanent water, and slope underlying collared bighorn locations at 1200 hours were measured with a GIS on 2 weekdays (Tuesday-Wednesday), termed “non-recreation days” and 2 weekend days (Saturday-Sunday), termed “recreation days”. Bighorn ewe habitat use (Payer and Coblentz 1997) and behaviors (Rubin et al. 2000) change between seasons; therefore, data were analyzed within-seasons to remove confounding environmental effects. Habitat variables were compared between recreation and non-recreation days with repeated measures MANOVA. The repeated measures technique was used to account for the same 10 animals being measured on both recreation and non-recreation days (Zolman 1993). An available-hours-of-daylight variable (measured per day within the City of Joshua Tree, California. Source: U.S. Naval Observatory) was used as a covariate to adjust for within-season changes in light availability.

Effects of Recreation on Habitat and Movement Patterns among and within Specific Areas

We tested the hypothesis that recreation activity affected habitat and movement patterns of bighorn ewes differently between different regions of the study area. We first categorized different regions into non-recreation (or undisturbed) and recreation areas then compared ewe habitat use and movement patterns between and among these areas. Using a GIS, we randomly designated an area consisting of steep, rugged terrain that was > 2 km from any trail as the non-recreation area (Fig 2). This area was relatively inaccessible and thus received very little recreational use by humans during the study period (Lowrey, pers. observ.). We then identified three recreation areas that had similar size and habitat availability as the non-recreation area: Barker Dam, which included Wonderland of Rocks and Ryan camp areas; Pine City, which included the Split Rock area; and the area surrounding 49 Palms Oasis (Fig 2). We assigned recreation levels to two time periods within the February to May season. The period of low recreation activity was the first four weeks of February and the period of greater recreation activity was the first four weeks of April (data from both years were pooled). February and April were chosen to compare bighorn habitat use and movement among lower and greater recreation time periods during similar weather and bighorn behavior patterns (Rubin et al. 2000). Within February and April, we further separated time periods more specifically into low recreation weekdays (Tuesday-Wednesday) and greater recreation weekend days (Saturday-Sunday).

After categorizing areas and time periods, we measured elevation, ruggedness, distance to trails, distance to permanent water, and slope underlying the locations of bighorn ewes at 0500, 1200, and 2000 hours each day within recreation and non-recreation areas. We further measured movement (distances traveled per day) by ewes within these areas. Habitat and movement variables were then compared among recreation and non-recreation areas between February and April, and between recreation and non-recreation areas within February and within April with a MANOVA. No collared animal moved between areas during the time periods of comparison. We then analyzed potential effects of recreation more specifically within February and April by comparing habitat use among recreation and non-recreation areas between weekdays and weekend days with a MANOVA. This approach, using precise measures of variables taken at consistent time periods, is considered optimal when analyzing temporally autocorrelated location data (Reynolds and Laundré 1990, McNay and Bunnell 1994, Otis and White 1999).

Behavior

We measured behavior of ewes in recreation and non-recreation areas and during high and low recreation days to determine whether recreation activities were detrimentally affecting behavior. Recreation and non-recreation area classifications were attributed to

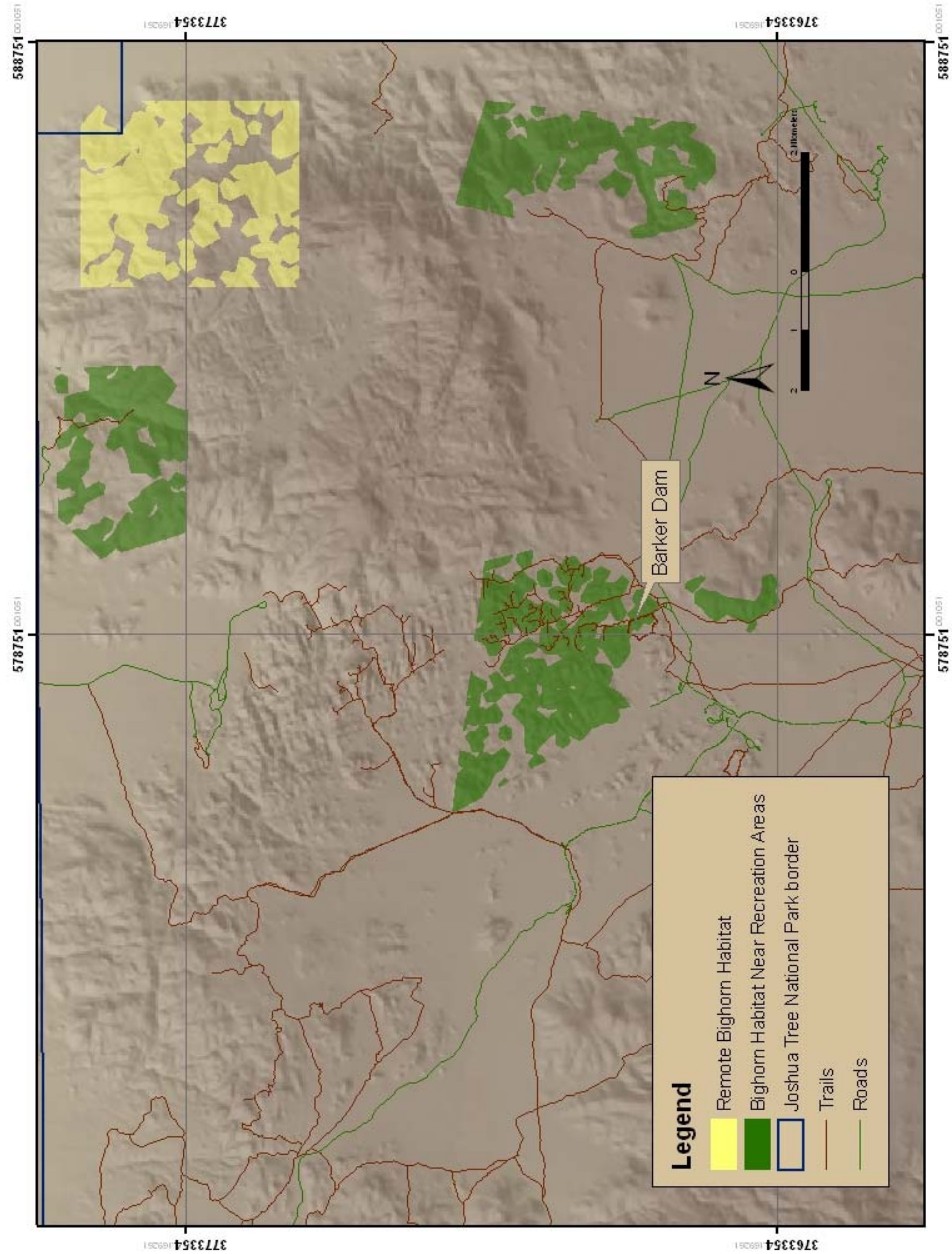

Figure 2. Critical desert bighorn habitat in remote (non-recreation) and selected recreation areas within the Wonderland of Rocks/Queen Mountain region of Joshua Tree National Park, California.

each location where behavior data were collected, and were developed from trail counter data, Joshua Tree N.P. staff observations, and observations of researchers Foraging efficiency was quantified as the proportion of time that an animal is actually feeding (versus searching, vigilance and other behaviors) during a foraging bout. Foraging behavior was observed and recorded using a combination of focal animal and scan sampling techniques (Altman 1974). Bighorn were observed with a Meade 125x telescope. Records were made of location, distance to escape terrain, vegetation type within 2 meters, group size, and composition of all groups and individual bighorn sheep encountered. Once a group of sheep had been located and ≥ 60% of the group was feeding, a focal animal was randomly selected and observed continuously for 5 minutes. All behavioral activities were recorded continuously into a voice recorder. Following the focal animal sample, another bighorn was randomly chosen, excluding the previous animal until all members of the group had been observed. Behavioral data were transcribed using a stopwatch to measure scan durations to the nearest second and enable calculation of the proportion of time spent at each behavioral activity. An analysis of covariance (Sokal and Rohlf 1998) with group size as the covariate was used to examine the effect of recreation activity and group size on foraging efficiency.

Five-minute interval scan sampling (Altman 1974) was used to obtain behavioral data for daily activity patterns. Activities were categorized as feeding, bedded, standing, moving, and social interactions. Percent activity was defined as the number of times a particular behavior was recorded divided by the total number recorded behaviors. For each activity, a univariate ANOVA with group size as a covariate was used to determine the effect of season, group size, and recreation intensity on mean percent activity.

49 Palms Oasis Mitigation Measures

Our original goal was to analyze the efficacy of National Park Service mitigation measures in allowing bighorn to use water sources at the 49 Palms Oasis. However, we found no consistent mitigation measures in place during the study. We therefore conducted an additional study of historic and extant water sources to examine potential changes of bighorn ewe habitat availability within Joshua Tree National Park based on current and historic water occurrence.

Historic and Present Day Water Sources

Based on GPS locations of bighorn ewes from 2002-2004, we used logistic regression (see previous) and a GIS to model past and present availability of critical summer ewe habitat within the park. Critical summer ewe habitat is that habitat within 3.5 km of a permanent water source (Monson and Sumner 1981). We then used these GIS-based models to predict how the loss of man-made water sources could affect habitat availability. We established locations of historic, permanent water sources within the park by researching historic mining claims, legal documents, county records, and other official documents found in the Joshua Tree National Park library archives. We then determined locations of extant permanent water sources within the park boundaries from current maps, Joshua Tree N. P. staff, and researcher observations. We separated extant permanent water sources into natural and man-made categories (Fig 3), and further separated man-made features into guzzlers and dams

We measured total area of historic and existing summer habitat, and calculated the potential loss of summer habitat that would occur if man-made guzzlers were removed from the park or became inoperable. We eliminated man-made dams from the calculation of potential habitat loss due to the low probability of the removal of dams from the park, and the ephemeral nature of water availability behind dams.

RESULTS:

Capture Operation

Eleven bighorn ewes were captured during the collaring operation. One bighorn ewe died during the capture. Dr. Ben Gonzales, a California of Fish and Game wildlife veterinarian, conducted a gross field necropsy and collected tissues for further laboratory analyses unrelated to this study. Nine of 10 collared animals survived for the duration of the two-year study period. One animal died in September 2004 and its collar was taken into Los Angeles, California by unknown persons and not recovered. Three collars malfunctioned: one stopped sending location signals in July 2004; one did not release from the animal although continued to send location data for the study duration; one collar released prematurely in August 2004 and was recovered. The remaining seven collars automatically released from the bighorn on 5 October 2004. In total, seven of the 10 collars were recovered.

Three locations daily (at 0500, 1200, and 2000 hours) per animal were downloaded directly from these seven collars. Locations from the three un-recovered collars were derived from satellite over-flights taken during the study period. Over 15,100 collar-generated location points were collected. Although satellite-dependent data from the three un-recovered collars was generally less reliable in terms of temporal consistency than data derived directly from collars, no fewer than 480 locations were collected for any one animal. Erroneous location points resulting from satellite signal malfunctions (< 0.5% of total) were removed. All location outliers (possible errors) were checked for accuracy by confirming previous and subsequent locations were within reasonable (approx. 0.5 km) proximity to the outlier. Any unconfirmed outliers were removed. All seven collars retrieved from the field were found within 10 m of the last GPS coordinates reported via satellite.

Population Estimates

Systematic flight surveys during the capture operation resulted in a bighorn sheep population estimate of 40-50 individuals across the study area. Formal confidence intervals are not calculated with this method. A second estimate of population size was

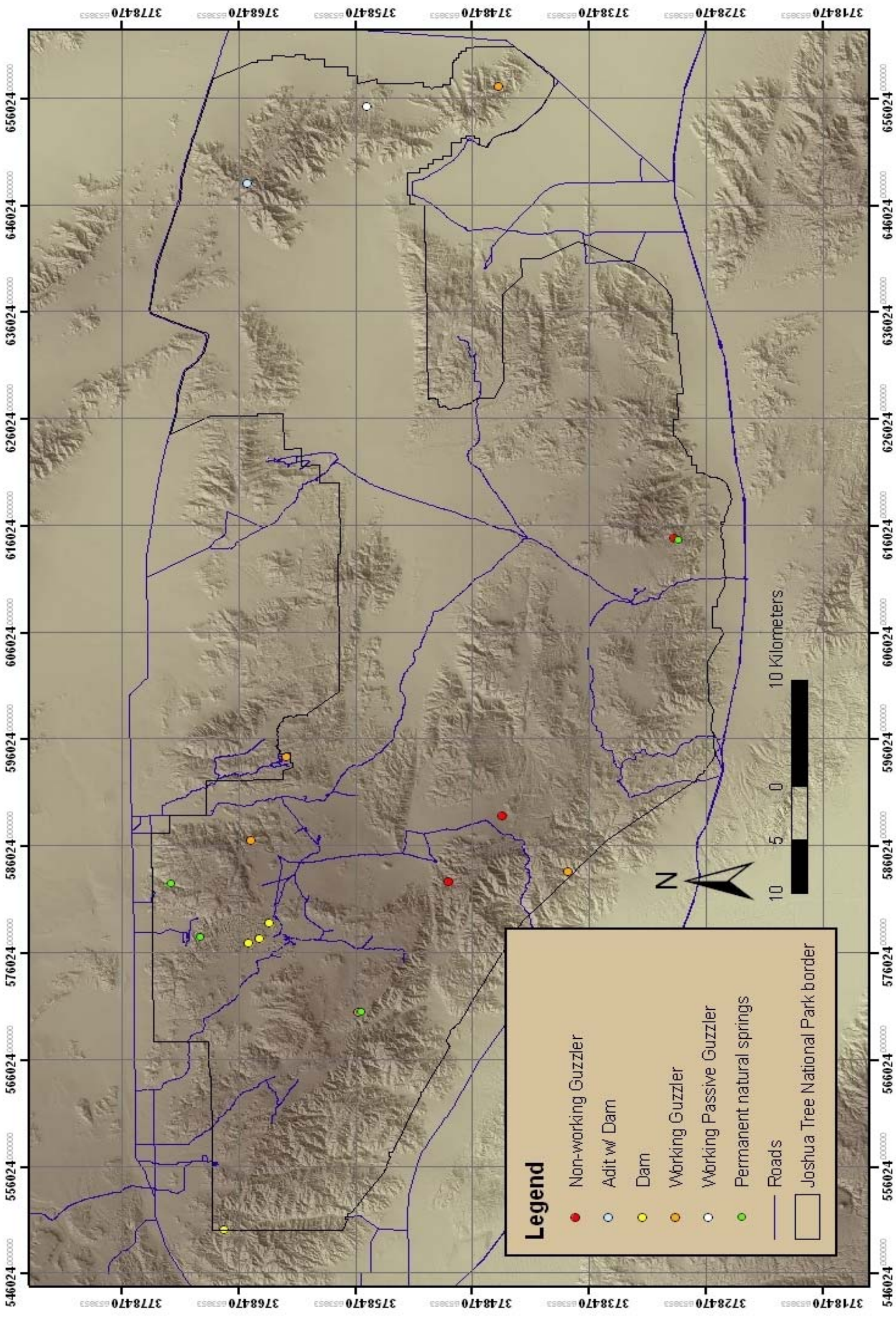

Figure 3. Extant permanent natural springs and man-made guzzlers and dams within Joshua Tree National Park, California as of 2004. (Source: Joshua Tree National Park, California)

conducted using a mark-resight technique described previously. We completed 132 ground surveys (five to six ground surveys per month) across the study area from November 2002 to November 2004. Ground surveys resulted in a total population estimate of 54 bighorn within the study area in 2003 with a 95% confidence interval (CI) of 39 - 68 and an estimate of 59 (95% CI 28 - 89) in 2004. Density of bighorn within the study area was approximately 0.5 animals per sq. km. per year.

Habitat Use

For each season, we tested six different combinations of habitat variables as models for suitability of bighorn habitat (Table1). For each of the three seasons, we found the logistic regression model containing the variables of slope, ruggedness, elevation, and distance to water to be the best predictor of suitable habitat within the study area (June-September: $\chi^2 = 842.2$, $P < 0.001$, df = 4; October-January season: $\chi^2 = 587.1$, $P < 0.001$, df = 4; February-May: $\chi^2 = 924.9$, $P < 0.001$, df = 4) (Table 2). Resource selection functions (RSF) from the logistic regression models were derived with a GIS, and seasonal maps of areas predicted as suitable habitat were generated from these RSF values (Fig. 4). For all three seasons, the highest 20% of RSF values incorporated > 90% of known bighorn locations. We therefore interpreted the areas defined by this percentile as suitable bighorn habitat (Boyce and McDonald 1999). We found approximately 182.0 sq. km of suitable bighorn habitat within the study area for each season. The relative importance of specific variables differed among seasons. Slope was the most important variable for explaining ewe occurrence during the February to May (Wald Chi-square 298.84, $P < 0.001$) and October to January (partial $\chi^2 = 192.40$, $P < 0.001$) seasons. Distance to water was the most important variable in the June to September season: bighorn ewes were found closer the permanent water sources of Pine City guzzler, 49 Palms Oasis, Johnson Spring, and Barker Dam than expected by chance (partial $\chi^2 = 224.92$, $P < 0.001$). Statistics for each variable for each season are given in Table 2.

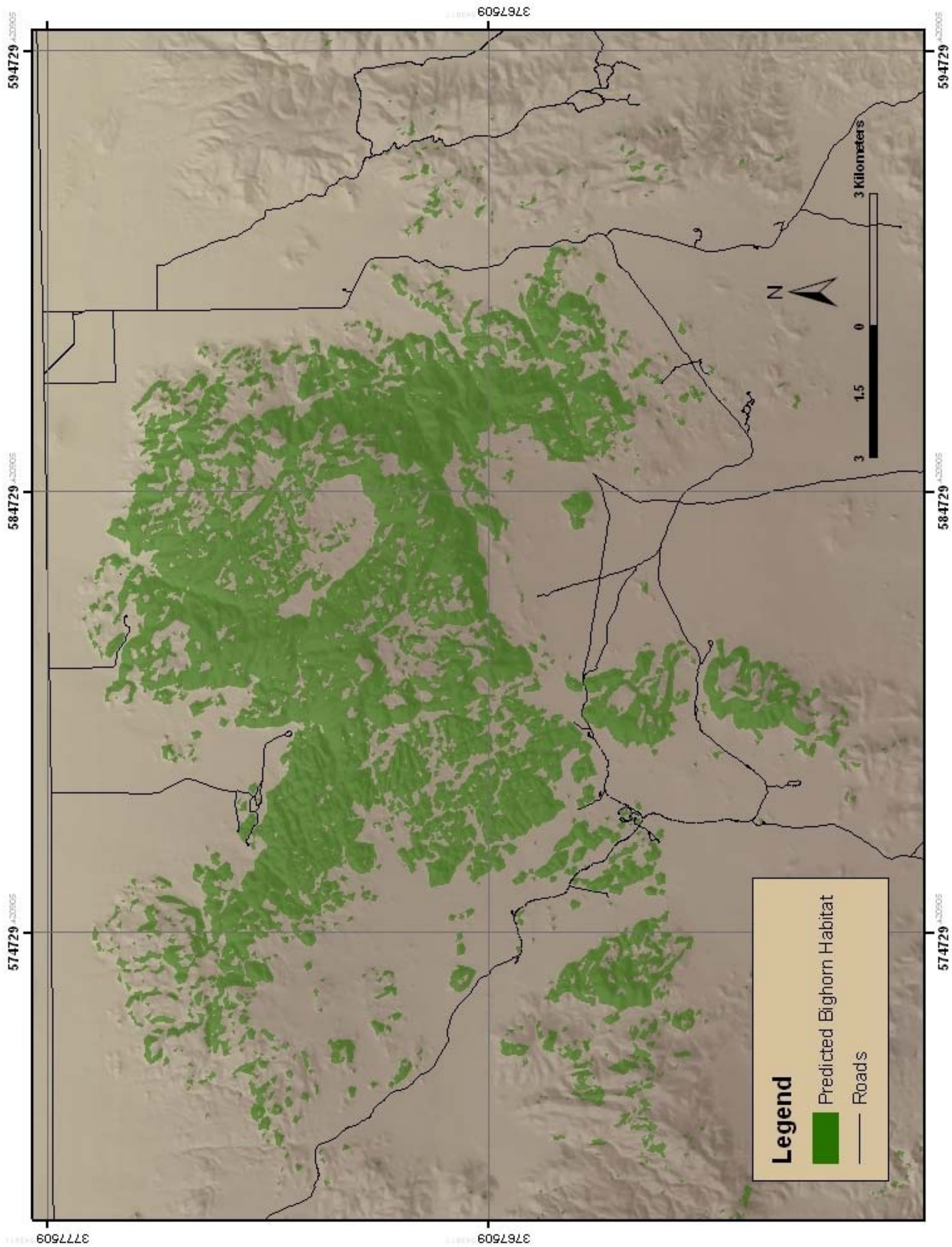

Figure 4. Predicted bighorn ewe habitat within the Wonderland of Rocks/Queen Mountain region of Joshua Tree National Park, California, 2004.

Table 1. Desert bighorn habitat models compared within the Wonderland of Rocks/Queen Mountain region of Joshua Tree N.P., California. 2002-2004.

Season	Model	χ^2	% correct*	Sig
Feb-May	slope, ruggedness, distance to water, elevation	924.8	75.6	< 0.001
Feb-May	slope, ruggedness, distance to water	848.6	74.5	< 0.001
Feb-May	slope, ruggedness, elevation	813.9	74.1	< 0.001
Feb-May	slope, distance to water, elevation	803.4	72.5	< 0.001
Feb-May	slope, distance to water	719.5	71.9	< 0.001
Feb-May	ruggedness, distance to water, elevation	556.2	70.1	< 0.001
June-Sept	slope, ruggedness, distance to water, elevation	842.2	81.4	< 0.001
June-Sept	slope, distance to water, elevation	789.9	82.7	< 0.001
June-Sept	slope, ruggedness, distance to water	788.5	81.2	< 0.001
June-Sept	slope, distance to water	733.4	80.1	< 0.001
June-Sept	ruggedness, distance to water, elevation	691.7	82.4	< 0.001
June-Sept	slope, ruggedness, elevation	501.6	69.2	< 0.001
Oct-Jan	slope, ruggedness, distance to water, elevation	587.1	75.9	< 0.001
Oct-Jan	slope, ruggedness, distance to water	565.5	76.2	< 0.001
Oct-Jan	slope, distance to water, elevation	565.5	74.4	< 0.001
Oct-Jan	slope, distance to water	539.8	74.3	< 0.001
Oct-Jan	slope, ruggedness, elevation	370.2	68.1	< 0.001
Oct-Jan	ruggedness, distance to water, elevation	362.5	73.9	< 0.001

* Percent of actual bighorn locations correctly predicted by model

Table 2. Wald chi-square statistics from seasonal logistic regression analyses of bighorn sheep locations in Joshua Tree National Park, California.

Season	Habitat Variable	Wald	df	Significance
June - Sept	Dist to water	224.9	1	< 0.001
June - Sept	Ruggedness	45.5	1	< 0.001
June - Sept	Slope	131.0	1	< 0.001
June - Sept	Elevation	50.8	1	< 0.001
Oct - Jan	Dist to water	168.9	1	< 0.001
Oct - Jan	Ruggedness	20.4	1	< 0.001
Oct - Jan	Slope	192.7	1	< 0.001
Oct - Jan	Elevation	21.2	1	< 0.001
Feb - May	Dist to water	100.3	1	< 0.001
Feb - May	Ruggedness	100.5	1	< 0.001
Feb - May	Slope	298.8	1	< 0.001
Feb - May	Elevation	72.0	1	< 0.001

Distribution, Mean Habitat Use, Home Ranges, Core Areas, and Movement Patterns

Total distribution of the 10 collared ewes encompassed an area of over 300 km^2 during the study period (Fig. 5). Five GPS-collared ewes used the Wonderland of Rocks region during the June-September seasons of both years. Use of this region by collared ewes declined to one in the February to May seasons and to zero in the October to January seasons of both years. The remaining ewes were mostly found in the vicinity of Queen Mountain. Two ewes traveled from the Queen Mountain Range east to the Pinto Range (approximately nine km) and back to the Queen Range. One of these animals traveled this route twice. Movements by ewes between these ranges were previously unknown. Mean and standard deviation of habitat variables underlying ewe locations during the entire study period are given in Table 3. Table 4 gives these parameters within each season. Total home range was defined as the maximum area used over a one-year period (Smith and Smith 2001). However, total areas used by ewes increased with time throughout the two-year study period. Therefore, total home range estimates for this herd should not be calculated for time periods of less than two years. Seasonal home ranges, defined as area used by bighorn during a particular four-month season, were calculated at the 95% and 50% (core area) probability of occurrence and are presented in Table 5. An example of seasonal home ranges is presented in Fig. 6. Average daily distance traveled is presented in Table 3.

Table 3. Mean values of habitat variables measured from all locations of collared bighorn ewes from November 2002 to October 2004 in the Wonderland of Rocks/Queen Mountain region of Joshua Tree National Park, California. Sample size: 15,128 locations.

Habitat Variable	Mean	SD	SE	Range
Slope (%)	41.8	19.1	0.2	0 - 119
Distance to slope >60% (m)	105	115	1	0 - 1155
Ruggedness (index)	0.016	0.016	0.001	0 - 0.147
Distance to rugged > 0.03 (m)	90	81	1	0 - 1008
Elevation (m)	1242	150	2	673 - 1722
Distance to permanent water (m) †	2796	1912	16	0 - 13860
Distance to trails (m)	1246	1118	9	0 - 9094
Distance to low use trails (m)*	1924	1521	12	0 - 9141
Distance to mod use trails (m)*	2355	2255	18	0 - 12689
Distance to hi use trails (m)*	3320	2324	19	0 - 13788
Distance traveled/24hr day (m)	1423	1160	17	33 - 11223

† Potential ephemeral sources were not considered.
* Low, moderate, and high use trails were combined into single category for analyses.

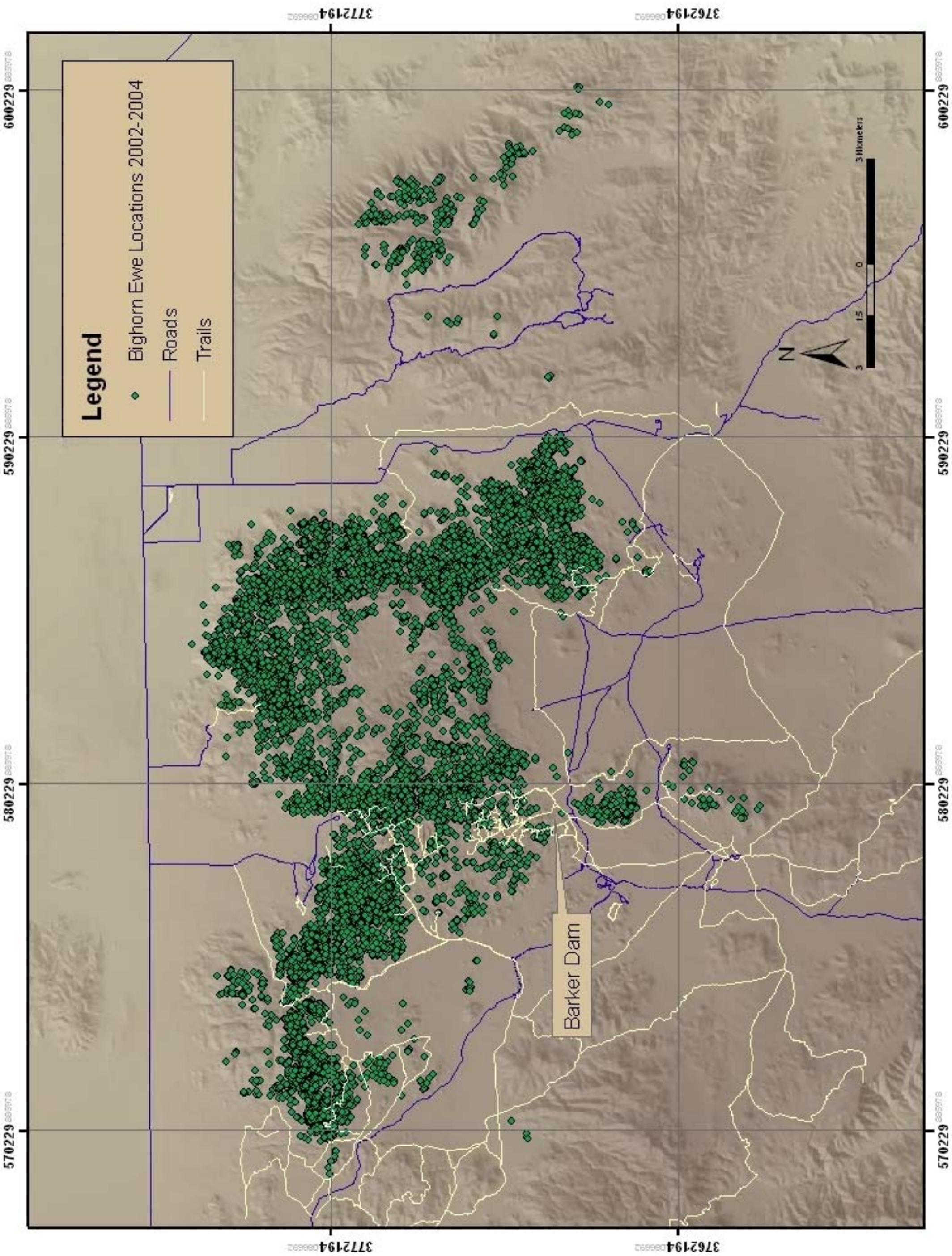

Figure 5. Total distribution of 10 collared desert bighorn ewes across the study area from October 2002 to October 2004, Joshua Tree National Park, California.

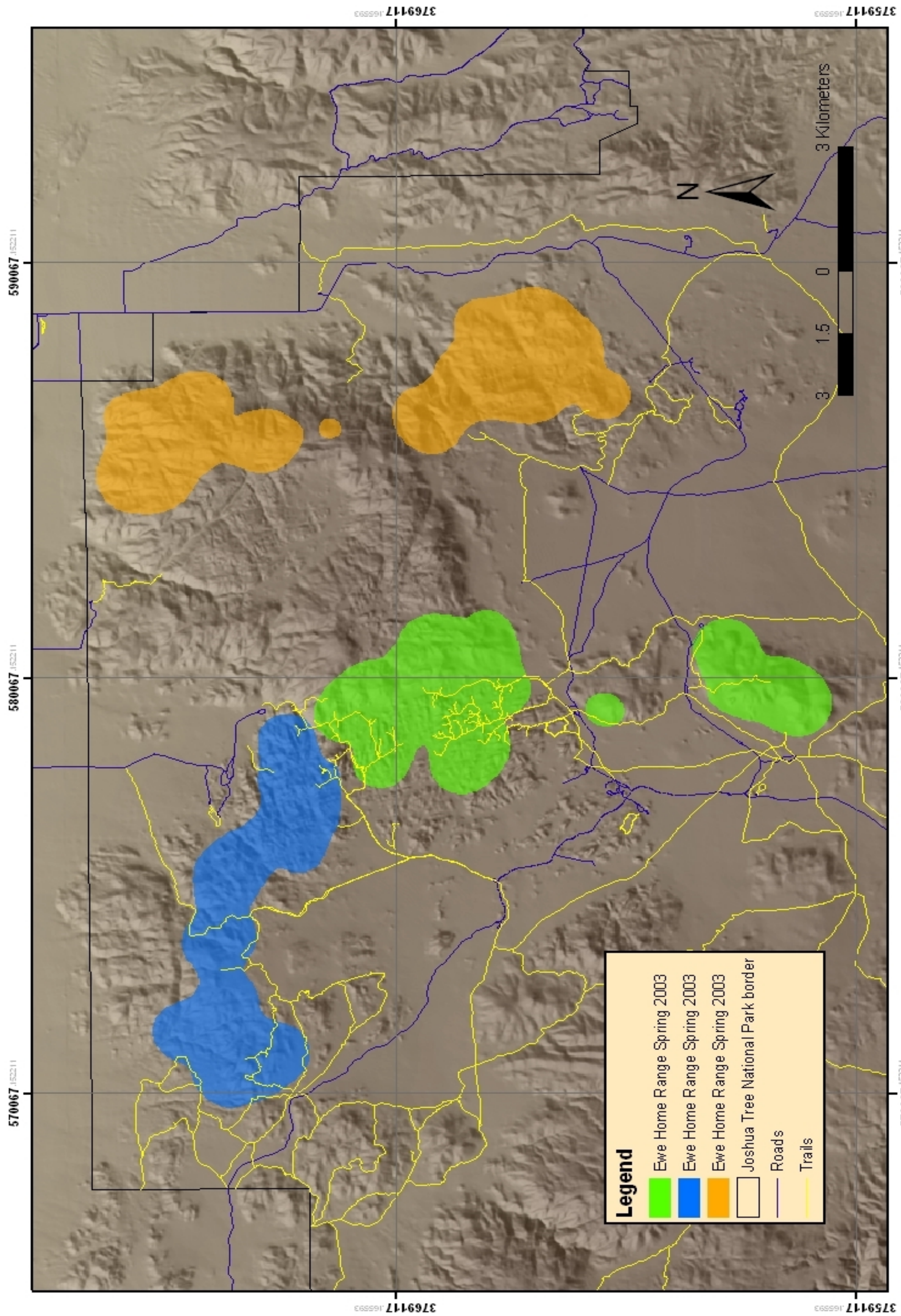

Figure 6. Map showing home ranges of three collared bighorn ewes from February 2003 to May 2003 in Joshua Tree National Park, California.

Table 4. Means and standard deviations of habitat variables for bighorn sheep ewe locations measured during three seasons from November 2002 to October 2004, in Joshua Tree National Park, CA.

Year	Season	Habitat variable	Mean	SD
2002-03	Oct-Jan	Ruggedness (Index)	0.015	0.015
2003-04	Oct-Jan		0.014	0.014
2002-03	Oct-Jan	Slope (%)	40.9	17.8
2003-04	Oct-Jan		39.5	16.7
2002-03	Oct-Jan	Distance to water (m)	2817	1844
2003-04	Oct-Jan		3052	1692
2002-03	Oct-Jan	Distance to trails (m)	1325	1115
2003-04	Oct-Jan		1419	1058
2002-03	Oct-Jan	Elevation (m)	1190	166
2003-04	Oct-Jan		1239	136
2003	Feb-May	Ruggedness (Index)	0.018	0.017
2004	Feb-May		0.018	0.018
2003	Feb-May	Slope (%)	43.4	20.1
2004	Feb-May		45.7	19.4
2003	Feb-May	Distance to water (m)	3052	2365
2004	Feb-May		2957	2071
2003	Feb-May	Distance to trails (m)	1410	1432
2004	Feb-May		1256	1143
2003	Feb-May	Elevation (m)	1237	153
2004	Feb-May		1272	124
2003	June-Sept	Ruggedness (Index)	0.015	0.013
2004	June-Sept		0.016	0.014
2003	June-Sept	Slope (%)	39.6	19.1
2004	June-Sept		40.8	20.5
2003	June-Sept	Distance to water (m)	2756	1741
2004	June-Sept		1992	1235
2003	June-Sept	Distance to trails (m)	1109	950
2004	June-Sept		892	724
2003	June-Sept	Elevation (m)	1247	158
2004	June-Sept		1251	145

Table 5. Seasonal area used by collared bighorn ewes in the Wonderland of Rock/Queen Mountain region of Joshua Tree National Park, CA. 2002-2004.

	95% Probability Area			50% (core) Probability Area		
Season	Mean	±SE	Range	Mean	±SE	Range
Feb-May 03	24.21	1.83	18.4-32.42	2.46	0.29	1.07-3.72
Feb-May 04	19.61	3.28	14.2-47.44	2.78	0.49	1.27-6.31
June-Sept 04	18.01	2.96	7.67-34.97	2.56	0.60	1.03-4.64
June-Sept 03	26.00	1.76	18.35-35.16	2.76	0.36	1.13-5.35
Oct-Jan 02-03	20.97	2.18	11.28-36.57	2.45	0.54	1.05-5.97
Oct-Jan 03-04	26.00	1.76	6.35-17.05	2.76	0.36	1.06-3.64
Total Mean	20.14	1.08	7.16-47.44	2.51	0.18	0.49-6.31

Recreation Levels

Total visitation over the study period was approximately 1.28 million persons per year. There were significant differences in monthly visitation between seasons ($F_{2, 21} = 33.25$, $P < 0.001$) (Fig. 7). Spring visitation was greater than fall, which was greater than summer visitation. The greatest visitation occurred during March and April, averaging approximately 175,000 persons per month. Using vehicle entrance data, there was a significant difference between weekdays and weekend visitation ($F_{1, 98} = 107.0$, $P < 0.001$) (Fig. 8). Weekend use was on average 97% greater than weekday use.

Habitat Use and Movement Patterns within Seasons across the entire Study Area Relative to Recreation Use

We compared habitat use and movement patterns between weekdays and weekend days across the entire study area within each season each year. Within the February to May season, ewes were found on steeper slopes (> 17% greater) during weekends than weekdays for both years of the study (2003: $F_{1, 260} = 6.06$, $P = 0.0145$) (2004: $F_{1, 288} = 3.37$, $P = 0.057$). Ewes traveled greater distances (0.4 km, or 24% farther) during weekends than weekdays within the February to May season of the first year ($F_{1, 220} = 6.36$, $P = 0.0123$). However, ewes did not travel greater distances on weekends within the same season of the second year ($F_{1, 274} = 0.054$, $P = 0.4$).

Within the October to January season, ewes traveled greater distances during weekends of the second year ($F_{1, 237} = 5.77$, $P = 0.017$). However, they did not travel greater distances on weekends within the same season of the first year ($F_{1, 191} = 0.95$, $P = 0.33$). Although not statistically significant, the following trends may be of biological importance to desert bighorn conservation in the park: during April when locations were measured at 2000 hours, a time when animals were least active, ewes were found > 0.67 km farther from permanent water during weekends than during weekdays. When locations were measured at 1200 hours within the month of April, animals were > 0.54 km farther from permanent water during the weekends than during the weekdays.

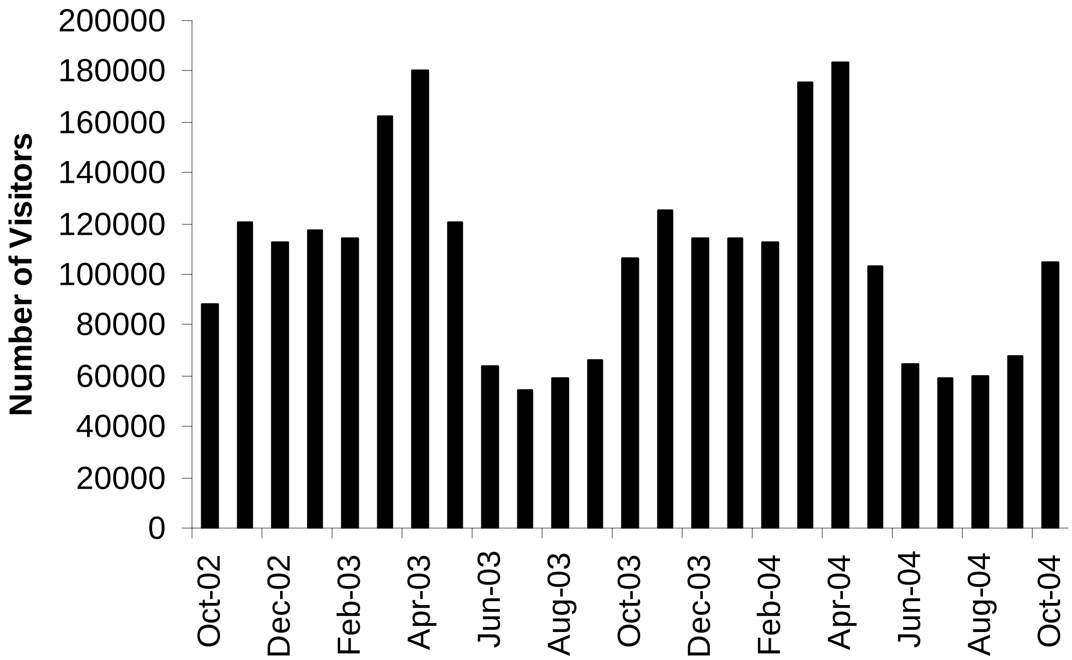

Figure 7. Monthly visitation to Joshua Tree National Park, California, showing peak seasonal activity during March and April and low activity from June-September. No variance estimates were reported. Source: Joshua Tree National Park, California.

<u>Comparison of Habitat Use and Movement Patterns between recreation and non-recreation areas between February and April</u>

To address the potential effects of time and area on habitat use, we analyzed habitat use and movement patterns among bighorn ewes in the four areas (three recreation and one non- recreation) between the February (low recreation) and April (greater recreation) time periods. We analyzed differences among the four areas (area effects), between the two time periods (period effects), and whether area effects were specific to a time period or whether period effects were specific to an area (period by area interaction effects). All four areas had similar availability of measured habitat variables except the Barker Dam area, which had an average of 10% lower slopes than the 49 Palms and non-recreation areas. We first combined all three recreation areas into a single category. There were significant period by area interactions in terms of distance to trails, distance to water, and ruggedness of habitat used. Ewes in recreation areas were 60% closer to trails in February than in April ($F_{1, 203} = 16.97$, $P < 0.001$). Ewes in recreation areas were farther from permanent water ($F_{1, 203} = 3.77$, $P = 0.052$). Ewes in both area types used more rugged terrain in February than April ($F_{1, 203} = 4.13$, $P = 0.04$).

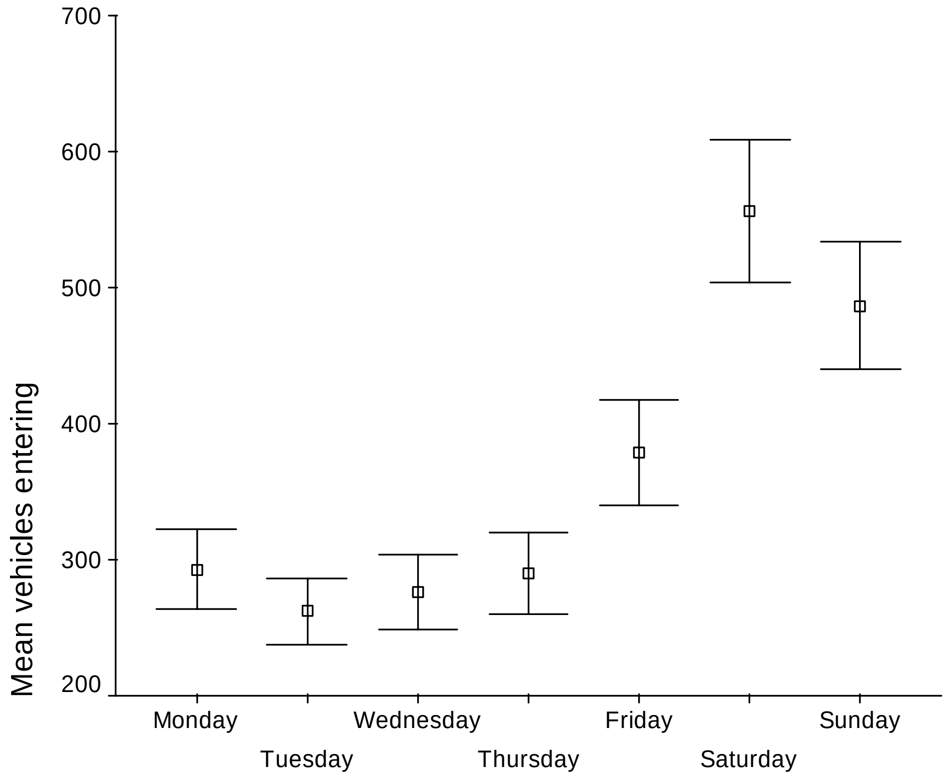

Figure 8. Comparison of daily means for number of vehicles entering Joshua Tree National Park, California at the west entrance station between 15 October 2002 and 15 October 2004. Bars represent +/- 2 standard errors. Source: National Park Service, Denver, Colorado

<u>Comparison of Habitat Use and Movement Patterns between recreation and non-recreation areas within February and April</u>

We compared recreation areas (combined) to non-recreation areas separately for February and April. During February, ewes were using greater slopes in recreation areas than non-recreation areas ($F_{1, 279} = 7.57$, $P = 0.006$). Also in February, ewes occurred in more rugged areas ($F_{1, 279} = 3.87$, $P = 0.05$), and traveled greater average distances per day ($F_{1, 279} = 5.39$, $P = 0.021$) in non-recreation than recreation areas. In April, ewes used more rugged areas ($F_{1, 265} = 4.37$, $P = 0.037$) in recreation than in non-recreation areas.

<u>Comparison of Habitat Use and Movement Patterns within Specific Areas between February and April</u>

We compared habitat use within each individual recreation and non-recreation area in order to identify specific areas potentially affected by recreation activities. Areas were compared between and within specific time periods. GPS-collared ewes in the non-recreation areas were found in habitat 175% more rugged in February (a relatively lower recreation period) than April. In the 49 Palms and Barker Dam recreation areas; however, ewes were located on more rugged terrain in April than February ($F_{3, 283} = 2.92$, $P = 0.022$). Animals were also found farther from trails ($F_{4, 293} = 4.29$, P = < 0.001) in April than February in these two areas. These two findings occurred at 0500 and 2000 hours, time periods when most bighorn are least active. Ewes were found on lower slopes in April than February in the 49 Palms area ($F_{3, 254} = 4.36$, $P = 0.002$), occurring on average in areas over 24% steeper in February. Ewes traveled significantly greater distances per day ($F_{3, 254} = 6.57$, $P < 0.001$) in April than February in the 49 Palms area, traveling on average over two km, or over 450% farther.

Comparison of Habitat Use and Movement Patterns between Specific Areas within February and April

In our comparison of habitat use between specific recreation and non-recreation areas within February, ewes used greater slopes in the 49 Palms area relative to the non-recreation area ($F_{3, 277} = 29.774$, $P < 0.001$). Ewes were found in less rugged terrain in the 49 Palms and Pine City areas relative to the non-recreation area ($F_{3, 277} = 6.912$, $P < 0.001$). Ewes traveled less distance per day in the 49 Palms area relative to the non-recreation area ($F_{3, 263} = P < 0.001$). In April, ewes were found in more rugged terrain in the Barker Dam area relative to the non-recreation area ($F_{3, 263} = 19.225$, $P < 0.001$).

Behavior

Desert bighorn ewe foraging behavior and activity pattern data were collected in both recreation and non-recreation areas from February 2003 to August 2005. Foraging behavior data were collected from 66 individual ewes representing 15 groups: 29 individuals within 8 groups in recreation areas and 37 individuals within 7 groups in non-recreation areas (Fig. 9). Foraging behavior data for each season are given in Table 6. We found no difference in foraging efficiency between recreation and non-recreation areas ($F_{1, 29} = 0.083$, $P = 0.920$) and no effect of group size ($F_{1, 29} = 0.034$, $P = 0.855$). Location within a recreation area did not affect the amount of time sheep foraged during foraging bouts. The proximity of observed bighorn to a potential human disturbance within each area was unknown.

Activity pattern data were collected from 132 sheep within 29 groups: 51 animals within 16 groups in recreation areas and 81 animals within 13 groups in non-recreation areas. A total of 555 scan samples was collected: 299 from recreation areas and 256 from non-recreation areas. We observed 9 groups, 2 in recreation (12 animals) and 7 in non-recreation areas (36 animals), during the February to May (greater recreation) season. Within this season (pooled across years) bighorn spent less time moving ($F_{1, 6} = 8.624$, $P = 0.024$) with a significant group size effect ($F_{1, 6} = 6.495$, $P = 0.044$) during the day in recreation than in non-recreation areas. Ewes spent less time moving as group size increased. Ewes spent a greater time observing within the February to May seasons ($F_{1, 6} = 6.36$, $P = 0.033$) also with a significant group size effect ($F_{1, 6} = 11.03$, $P = 0.016$) in recreation than in non-recreation areas. Ewes spent less time observing as group size increased. Activity pattern data for each season are given in Table 7.

Table 6. Bighorn ewe foraging behavior data for each season from 2003 to 2004 in the Wonderland of Rocks/Queen Mountain region of Joshua Tree National Park, California.

Season	Foraging Efficiency (%)	±SE	Group Size Mean	Group Size Range
February - May	62	4	7	1 - 13
June - September	66	2	4	2 - 6
October - January	62	4	7	4 - 9

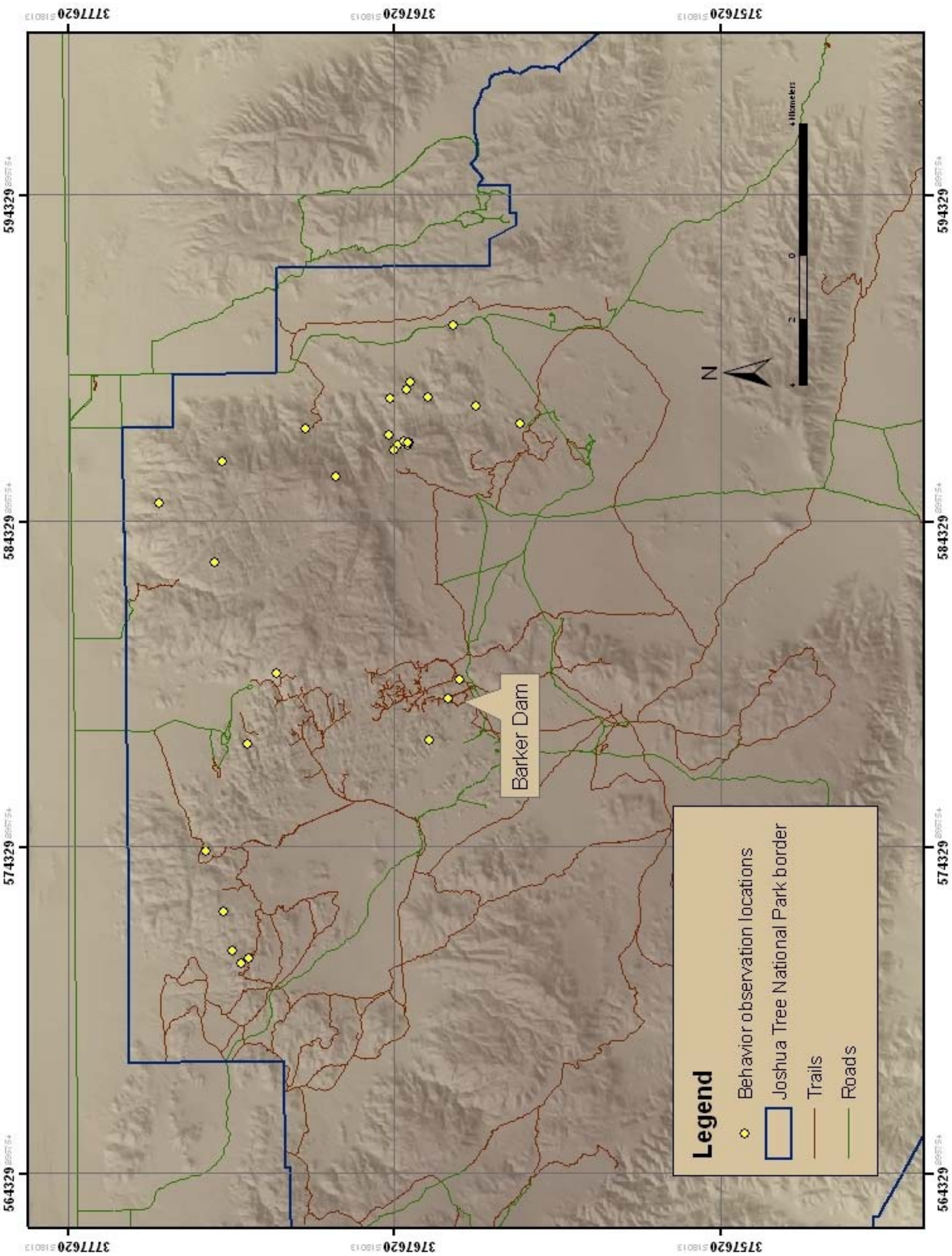

Figure 9. Bighorn behavior data observation locations. Observations made from 1 November 2002 to 1 November 2004. Joshua Tree National Park, California.

Table 7. Bighorn sheep activity pattern data are shown for each season from 2003 to 2004 in the Queen Mountain/Wonderland of Rocks region of Joshua Tree National Park, California. Group size mean = 4. SE = 1. Group size range: 1 -12.

Season	Activity	Mean % time at activity	± SE
February - May	Bedded	17	7
February - May	Observing	14	4
February - May	Feeding	44	6
February - May	Drinking	0	0
February - May	Moving	26	4
February - May	Social Interaction	2	1
February - May	Nursing	0	0
June - September	Bedded	17	7
June - September	Observing	29	5
June - September	Feeding	24	6
June - September	Drinking	0	0
June - September	Moving	31	4
June - September	Social Interaction	1	1
June - September	Nursing	0	0
October - January	Bedded	23	23
October - January	Observing	17	6
October - January	Feeding	31	13
October - January	Drinking	0	0
October - January	Moving	27	9
October - January	Social Interaction	2	2
October - January	Nursing	0	0

Critical Summer Habitat Analyses relative to Historic, Present Day, Man-Made, and Natural Water Sources

Logistic regression analysis of habitat use indicated that distance to permanent water was the most important contributor explaining desert bighorn ewe summer locations (χ^2 = 1274.4, R^2 = 0.720, 88.2% locations predicted correctly) in the Wonderland of Rocks/ Queen Mountain region. During the summer season mean distance of ewes from a permanent water source was 3.04 km (SE = 0.075 m). Based on our examination of the archives, we found evidence for a minimum of 18 previously existing natural springs within the park boundary. These springs were known to have had either flowing or standing perennial water prior to 1950. As of 2004, there were 5 naturally occurring perennial water sources and 10 working man-made guzzlers and/or dams within the park (Table 8, Fig. 3). We developed models of historic and present-day critical summer bighorn ewe habitat using these water sources. Our results indicate that prior to1950 there may have been over 212 km^2 of critical summer habitat available for desert bighorn (Fig. 10). We found a total of 229.0 km^2 of critical summer habitat presently available in Joshua Tree National Park: 43.0 sq kilometers of critical summer bighorn habitat surround natural water sources (Fig. 11) 145.7 km^2 surround guzzlers; and 57.3 km^2 surrounds dams (Fig. 12). If man-made guzzlers were removed from the park a potential loss of 145.6 km^2 of critical summer habitat, or 63% of the present-day total, may occur.

Table 8. Known water sources potentially available to bighorn sheep in Joshua Tree National Park, California as of 2004. Stubbe Spring is both a guzzler and a natural spring. Coordinates are in UTM. Natural springs and guzzlers have water available throughout the year.

Water Source	Type	Easting	Northing
Pine City	Guzzler	586634	3767419
Russis rocks	Guzzler	657120	3746201
Stubbe Spring	Guzzler	570482	3758218
Coxcomb	Guzzler	655295	3757454
Eagle Mtn	Guzzler	638761	3746916
Barker dam	Dam	578878	3765882
Cow Camp dam	Dam	577385	3766642
Keys Ranch dam	Dam	577000	3767637
Coxcomb Adit dam	Dam	648014	3767747
Rattlesnake dam	Dam	550185	3769708
49 Palms Oasis	Natural Spring	582560	3774290
Johnson Spring	Natural Spring	577456	3771799
Lost Palms Oasis	Natural Spring	614712	3730825
Stubbe Spring	Natural Spring	570482	3758218
Buzzard Spring	Natural Spring	636897	3743665

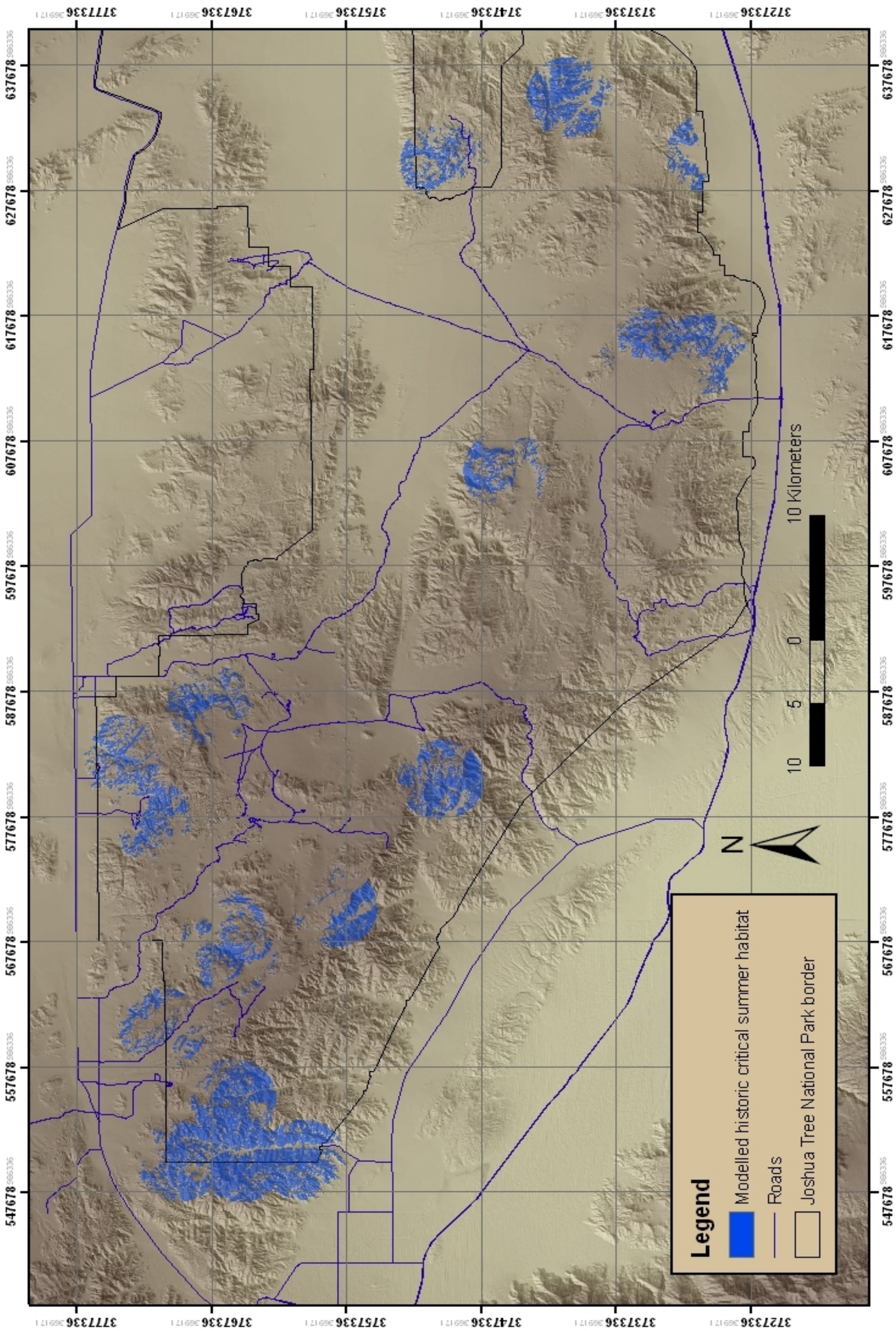

Figure 10. Map of Joshua Tree National Park, California showing modeled critical summer bighorn sheep habitat surrounding historic (prior to 1950) permanent water sources. Source: Joshua Tree National Park Archives.

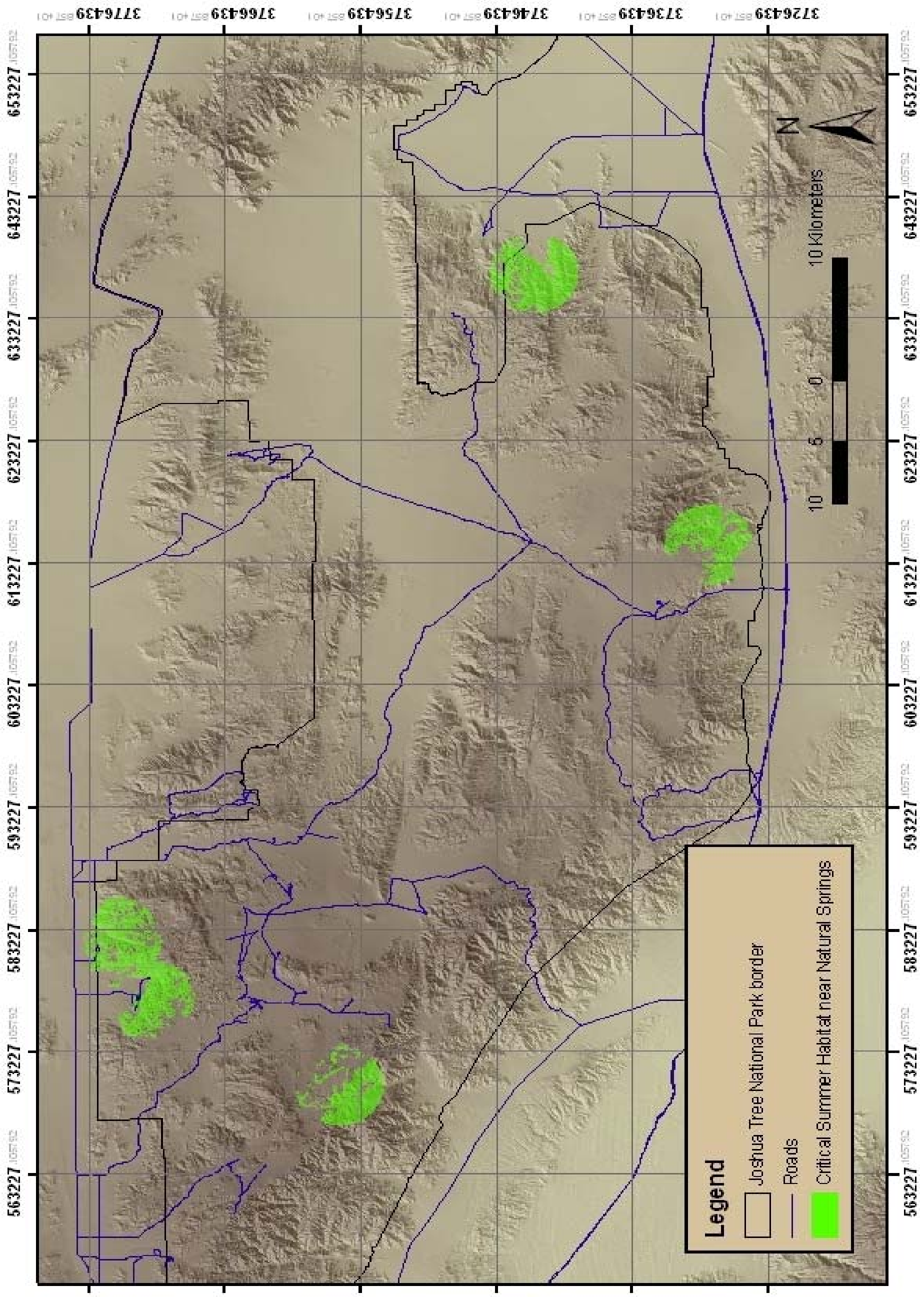

Figure 11. Desert bighorn critical summer habitat near extant permanent natural springs during 2002-2003 within Joshua Tree National Park, California.

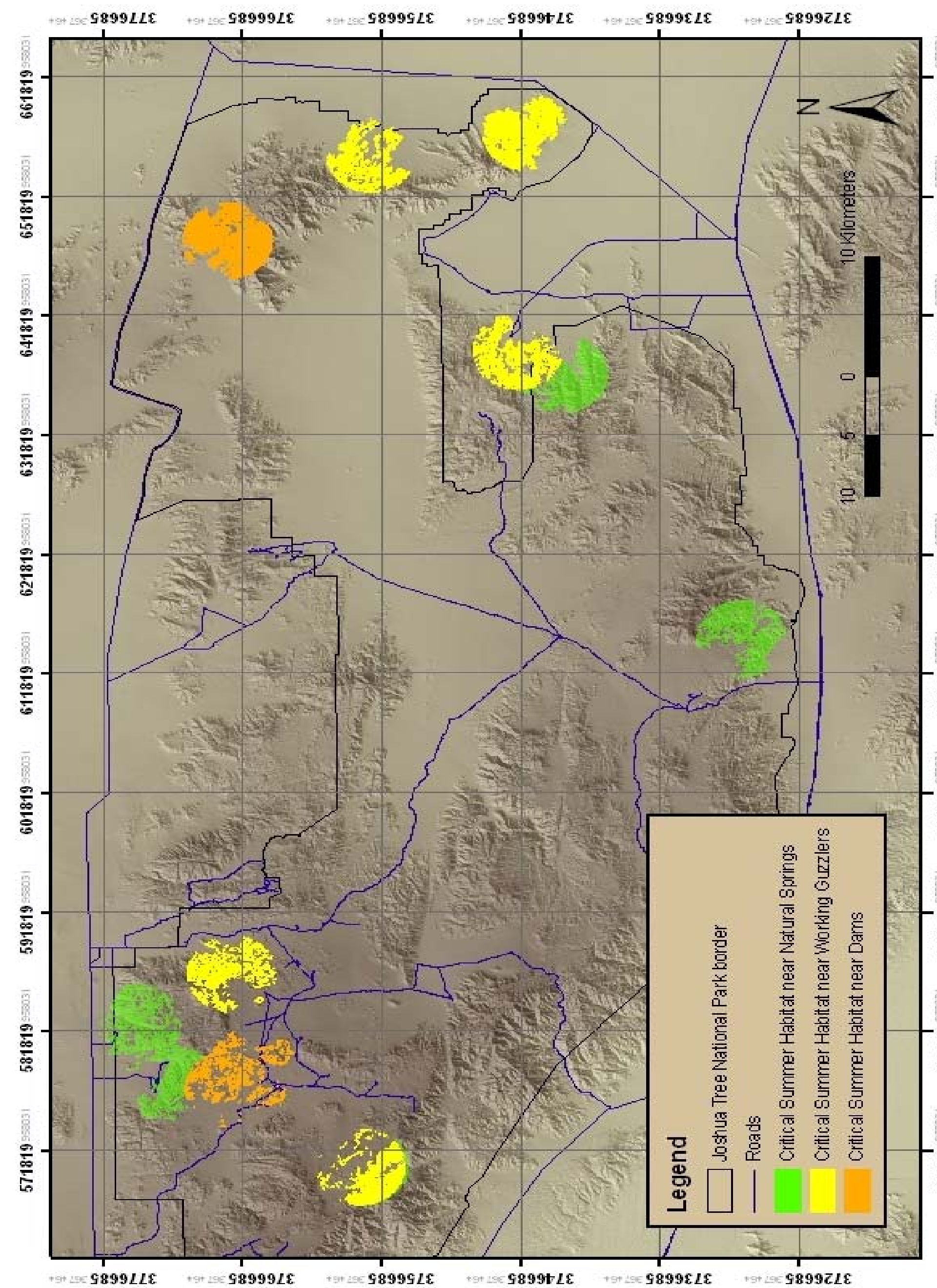

Figure 12. Desert bighorn critical summer habitat near existing water sources during 2002-2003 within Joshua Tree National Park, California.

DISCUSSION

Population Size

Our population estimate of approximately 60 desert bighorn in the Wonderland of Rocks/Queen Mountain region of Joshua Tree National Park, California is slightly larger than the last known estimates from Torres et al. (1994), who estimated 25 - 50 animals from this area. Whether this population estimate is a cause for immediate concern is debatable. Berger (1990) found desert bighorn populations of ≤ 50 were likely to go extinct within 50 years, while a test of this prediction by Wehausen (1999) did not support this conclusion. Most authors agree however, that desert bighorn populations of ≤ 50 should be of serious concern to managers (Krausman 1993, Ehrenfield 1994, Berger 1999). It is possible that the Wonderland of Rocks/Queen Mountain population is near carrying capacity. However, most populations of desert bighorn, including those within 15 western national parks (Joshua Tree N.P. was not included in the study) have not recovered from the catastrophic declines of the late 1800s and early 1900s (Singer et al. 2000).

Our observation that animals are traveling between adjacent mountain ranges suggests that bighorn in the study area are part of a larger metapopulation. Paved roads completely encircle the study region, and human use of the park has increased substantially in recent years (source: National Park Service). This increased traffic may impede movement to other mountain ranges, leading to diminished gene flow and lower population persistence times (Bleich et al. 1990, Singer et al. 2000). In a study of desert bighorn across 27 mountain ranges including those within Joshua Tree N.P., Epps et al. (2005) found an up to 15% decline in genetic diversity due to anthropogenic isolation. Therefore, both the habitat and the probable routes between these mountain ranges should be incorporated into conservation plans (Bleich et al. 1990).

Habitat Use

Habitat use analyses describe areas that provide security from predation, access to water, protection from human disturbance, and opportunities for dispersal (Bleich et al. 1990, Singer et al. 2000, Papouchis and Singer 2001). Our results suggest that bighorn ewes in the Wonderland of Rocks/Queen Mountain region of Joshua Tree N.P. are temporarily displaced from habitat during periods of higher human recreation use. Although some bighorn may habituate to human presence (Papaouchis et al. 2001), even bighorn that demonstrate no outward response to human presence may still be under physiological stress (MacArthur et al 1979, Deforge 1981). One of the areas of highest human presence is the Wonderland of Rocks region. Five collared ewes (50 percent of the total) used the Wonderland of Rocks region during the June-September seasons. Although relative plant density is low, vegetation in this area is able to produce green growth later into the dry season due to the narrow canyons and washes which retain water for longer periods of time (Lowrey pers. observ.). Bighorn ewes may be attracted to this area during periods when green vegetation is scarce. The presence of water (except during drought years) behind dams in this region is also an attractant.

Proximity to permanent water was an important habitat variable throughout the year and was the strongest predictor variable during the summer months. Proximity of perennial water is predictive of desert bighorn in other regions of the southwest as well (Epps et al. 2004, Turner et al. 2004), and our models demonstrate that bighorn habitat and recreation areas overlap considerably near water sources, of which there are four (permanent) and three (ephemeral) within the study area (Fig. 3). Un-habituated bighorn are known to avoid areas of high human activity (Papouchis et al. 2001), and the convergence of bighorn habitat, water sources, and high recreation activity suggests access to water and habitat may be temporarily constrained by human activities within the study area. In the Wonderland of Rocks/Queen Mountain region of Joshua Tree N.P., difficulties resulting from displacement from water sources may be amplified by the lack of alternative sources.

Comparison of Habitat Use and Movement Patterns Relative to Recreation Time Periods across the entire Study Area

We believe the most probable explanation for differences in bighorn habitat use between weekends and weekdays was the influence of human activities. Steeper habitat is known to have lower forage quality (Bleich et al. 1997); use of steeper slopes during weekends suggests recreation activities are constraining ewes to less suitable foraging areas. We further found animals traveled significantly farther during the weekends of the high (spring) and moderate (fall) recreation seasons, suggesting both general disturbance of ewes and a greater expenditure of energy. This latter pattern was not repeated during both years.

Comparison of Habitat Use and Movement Patterns between recreation and non-recreation areas between February and April

We found bighorn may be moving away from human activities to rest or bed down. Animals in recreation areas bedded farther from trails in April, the month of greatest visitation, than February, a time of similar environmental conditions yet of significantly lower visitation levels. Bighorn were found farther from roads in high-use recreation areas relative to low-use recreation areas in the Canyonlands N.P, a desert southwest park with much less visitation than Joshua Tree N.P. (Papouchis et al. 2001). Ewes also traveled significantly farther per day in April than February in Joshua Tree N. P., suggesting bighorn spent more time traveling than foraging and expended more energy during high recreation periods. Ewes in recreation areas bedded closer to permanent water in April than February, indicating open water is important for ewes during this time period. The fact that bighorn bedded closer to water, yet farther from trails, suggests animals are not completely abandoning habitat with a critical resource (water) but may be avoiding the waterhole approaches used by humans. Desert bighorn did not completely abandon habitat near a critical resource (mineral lick) in the San Gabriel Mountains of southern California due to human recreation activity, but used it when people were not present (Hamilton et al. 1982). Daytime human activity at watering sites forces bighorn to alter preferred watering times. These options lower the bighorns' ability to thermoregulate optimally, resulting in greater energy costs (Leslie and Douglas 1980, Campbell and Remington 1981).

Generally bighorn ewes occupy more rugged areas during the lambing season (late winter through early spring) (Bleich et al. 1997). In contrast, we found animals in areas more rugged and farther from trails in April than in February in the 49 Palms and Barker dam recreation areas. These areas receive high visitation, suggesting that recreation activities were influencing habitat use and movement patterns of bighorn. Collared bighorn in the remote (non-recreation) region followed the expected pattern by occupying less rugged areas in April than February, further supporting the hypothesis that habitat use in recreation areas was a consequence of human activity. Animals in these high use areas traveled over 450% farther per day, indicating both a greater expenditure of energy and that more time was spent traveling than foraging in April than February. Disturbance during spring may be particularly harmful to pregnant or lactating ewes in terms of energy costs (King and Workman 1986).

<u>Comparison of Habitat Use and Movement Patterns between recreation and non-recreation areas within February and April</u>

February is a peak lambing period for desert bighorn (Rubin et al. 2000), and also a time of low to moderate recreation use in Joshua Tree N. P. (Fig 7). Bighorn parturition sites are found in more rugged areas when compared to pre-parturition sites (Bangs et al. 2005), and our finding that ewes used more rugged terrain in the non-recreation than the 49 Palms and Pine City recreation areas during February may indicate ewes are selecting the more remote regions for lambing. Rugged terrain is available throughout the recreation areas as well, and we found bighorn use of more rugged terrain in the Barker Dam area than the non-recreation area during April. April is the time of greatest visitation, and the Barker dam area is very popular among tourists. Bighorn ewe use of rugged areas as escape terrain is well documented (Bangs et al. 2005, Sappington et al. *in press*), and ewes may be using more rugged areas to escape human encroachment during peak visitation periods. We observed no ewes with lambs within any recreation area during the study period. Rock climbing in rugged areas, an activity attracting thousands of visitors a year to the park and peaking during March-April (source: Joshua Tree N.P.), may be causing ewes to select more remote areas for lambing.

Other explanations for the observed distribution of ewes are likely separate from anthropogenic impacts. Our finding of ewes on steeper slopes in recreation than non-recreation areas in February was derived primarily from ewes inhabiting the steep terrain near the water sources at the 49 Palms Oasis area. Ewes traveling greater distances in the remote, non-recreation area than in the 49 Palms Oasis area in February may have been the result of differences in the distribution of vegetation, the attraction of the 49 Palms Oasis water sources, or other factors.

Behavior

Ewes spent more time observing, and less time moving, in recreation verses non-recreation areas during the high recreation season of both years. King and Workman (1986) also found desert bighorn increased the amount of time observing in areas of greater human activity. However, during this period we observed only two of nine groups in areas of high recreational use, and therefore, support for this interpretation is limited. Differences in percent time spent moving may also be explained by differences in forage plant distribution and/or availability (Warrick and Krausman 1987).

Historic and Present Day Water Sources

Historic mining and other forms of development have drastically reduced water availability for desert bighorn in the southwest (Monson and Sumner 1981). As a result, agencies responsible for bighorn sheep have spent significant resources providing artificial water sources as part of their management plans (Bleich et al. 1982, Werner 1984). Most authors agree that artificial water developments support desert bighorn populations (Campbell and Remington 1979, Douglas and White 1979, Allen 1980). However, some authors argue that sheep populations may not benefit from water developments (Broyles and Cutler 1999, Krausman and Etchberger 1995). Presently, man-made guzzlers and dams have approximately restored, in terms of quantity, the losses of natural water sources that have occurred since 1950 within Joshua Tree National Park, CA. However, the locations of working guzzlers do not mimic historic natural spring distribution in terms of proximity to each other (Fig. 3). The existence of over 63% of critical summer habitat in the park depends upon guzzlers that must be periodically maintained if this habitat is to remain viable. Man-made dams are another major source of restored water. However, bighorn access to water sources behind dams in recreation areas might be subject to the level of human disturbance (Leslie and Douglas 1980). Furthermore, water sources behind these dams were ephemeral during drought conditions (Lowrey, pers. observ.).

BIGHORN SHEEP MANAGEMENT

Because of the relatively low bighorn population size and potential for population fragmentation, long-term monitoring of both population size and environmental conditions within the Wonderland of Rocks/Queen Mountain region of Joshua Tree N.P. would provide valuable information for managing this population into the future. Bighorn populations may have natural variations in size in response to variance in rainfall and other factors. It is therefore important that estimates are made in the context of weather patterns and other environmental conditions to separate anthropogenic from naturally occurring effects on population size.

The long-term effects of human-induced changes upon this population are unknown. Continued monitoring of bighorn habitat use and recreation levels in and near recreation areas is needed to determine whether sheep continue to return to habitat within recreation areas during low-recreation time periods. Recreation activity should be monitored in as many geographical locations as feasible. Restrictions to recreation activities of visitors at and near water source areas, especially during the spring and summer months, would benefit bighorn sheep. The 49 Palms Oasis (UTM 582210E, 3773370N) is heavily used by bighorn sheep especially during summer months, and serves as the primary water source for the northeast region of the study area (Fig. 13). Furthermore, the constant presence of hikers at the nearby lower 49 Palms Oasis spring (UTM 582550E, 3774320N) may effectively eliminate the lower water source from use by sheep. The loss of the upper spring due to drought could be catastrophic unless mitigation measures are taken. Frequent monitoring of this spring and the closure of the lower 49 Palms Oasis spring would lessen impacts to sheep in the event the upper spring dries up. The Pine City guzzler (586660E, 3767452N) is also an especially important water source, serving the entire southeast region of the study area (Fig. 13). Ewes used this water source year round, and this area served as the departure point for travel between the Queen Mountain and Pinto Ranges to the east. Continuing maintenance of the Pine City guzzler and restricting access to the immediate area during spring and summer months would benefit sheep. Johnson Spring (577544E, 3771800N) serves the northwest region of the study area (Fig. 13). This spring was heavily overgrown with vegetation during the study period; however, there was standing water present during the summer months. Installation of a small cistern/tank able to exclude vegetation would provide bighorn access to this water source.

To maintain long-term survival and genetic diversity of bighorn sheep, the placement of any new guzzlers must support the ability of bighorn to maintain connectivity with other bighorns populations within and outside the park. Furthermore, any water supplies should mimic historic water availability of the area before their elimination by human activities. Maintaining probable routes between mountain ranges would help prevent isolation from other populations. The most likely source of immigration into the study area is from the Little San Bernardino Mountains, approximately 14 km to the southwest. Actual migration routes are unknown; however, probable major routes can be estimated from terrain and historic water source locations shown in Figure 14. Continued maintenance of the Stubbe Spring guzzler (UTM 570600E 3757990N), an historic water source located at the base of the Little San Bernardino Mountains, would support bighorn along a potential route into the Wonderland of Rocks/Queen Mountain region (Fig. 14). The distance between two permanent water sources, from Stubbe Springs along the easternmost probable route to Johnson Spring, is over 22 km. This distance may constrain or prohibit travel between areas (Douglas and White 1979). Historically, permanent water sources were available between these areas specifically at Quail Springs (UTM 568600E 3766380N) (Fig. 10) (source: Joshua Tree N.P. archives). Reestablishment of at least one historic permanent water source in the water establishment area shown in Figure 14 would promote connectivity between bighorn populations in Joshua Tree N.P.

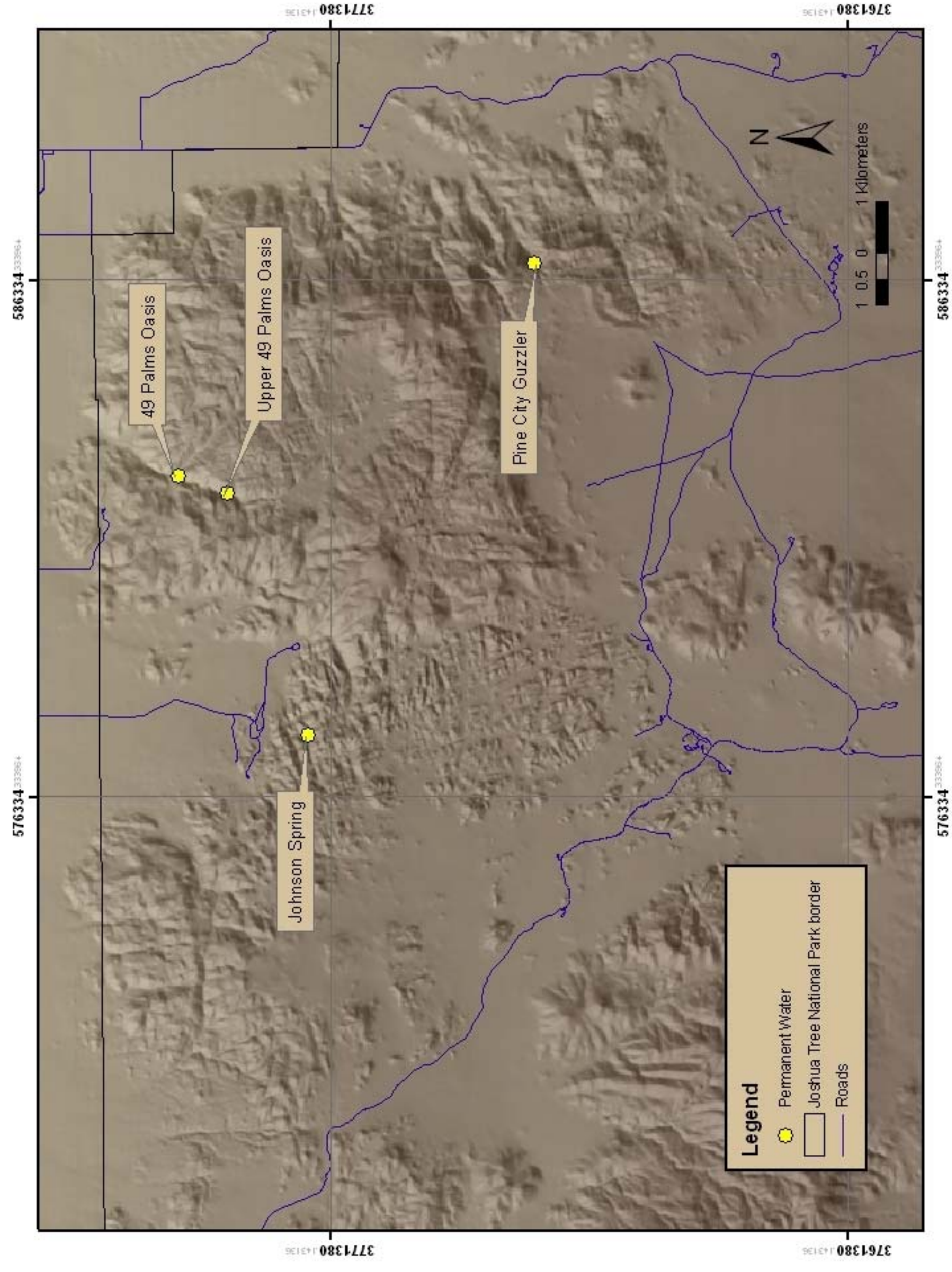

Figure 13. Locations of permanent water sources as of 2004 within the Wonderland of Rocks/Queen Mountain region of Joshua Tree National Park, California.

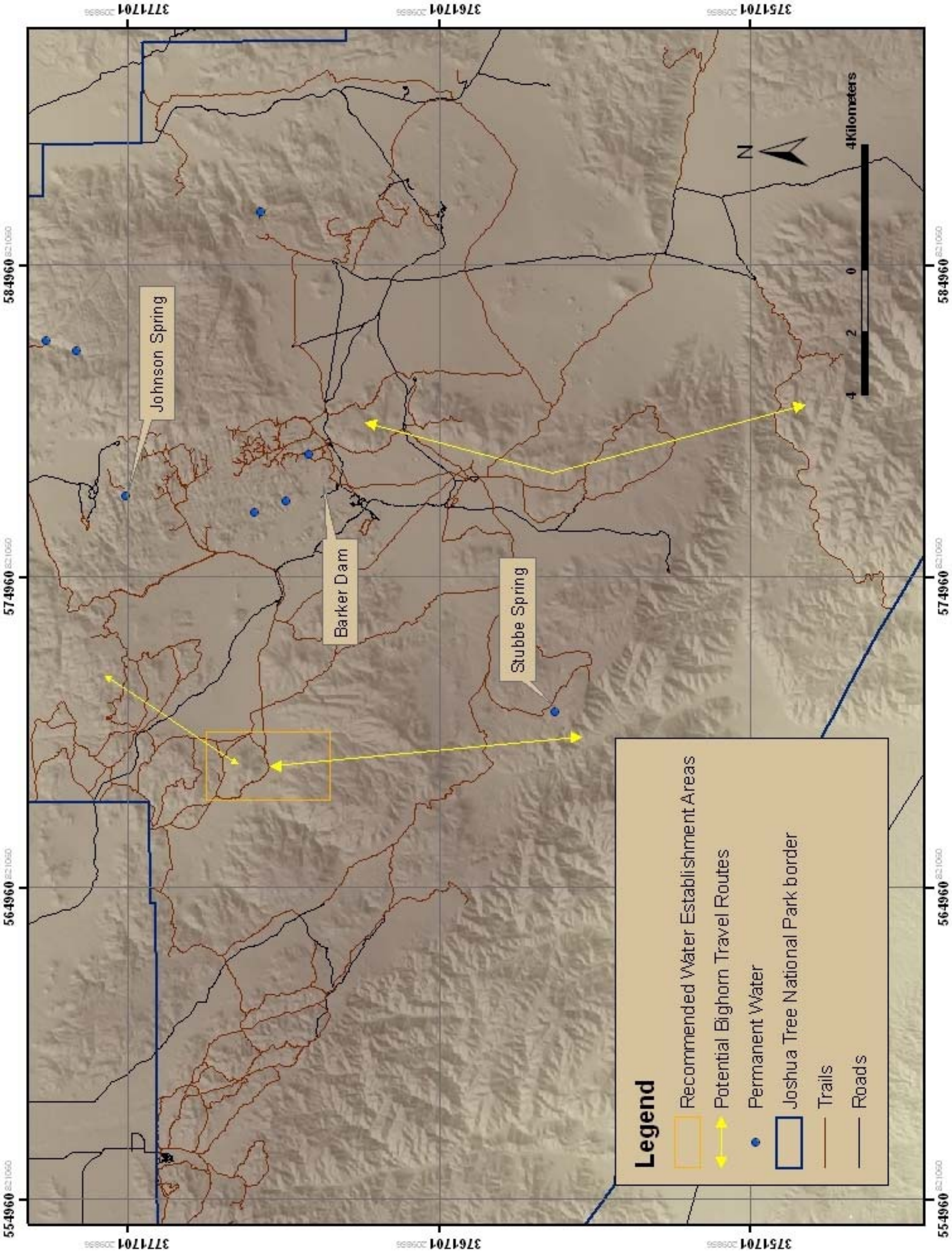

Figure 14. Probable routes of travel between the Queen Mountain and the Little San Bernardino Mountains and area for establishing a guzzler within Joshua Tree National Park, California.

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