STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF FISH AND GAME
WILDLIFE MANAGMENT DIVISION
NONGAME BIRD AND MAMMAL SECTION

POPULATION DENSITY, CENSUS METHODS, HABITAT RELATIONSHIPS, AND HOME RANGE OF THE SAN JOAQUIN ANTELOPE SQUIRREL, 1988-89

by

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1991

NONGAME BIRD AND MAMMAL SECTION REPORT 91-02

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ABSTRACT

The San Joaquin Antelope Squirrel *(Ammospermophilus nelsoni)* is designated as Threatened by the California Fish and Game Commission. The species was formerly found in the southern and western San Joaquin Valley, but has lost about 80% of its range. Although distribution and natural history have been studied, less is known regarding the population density, habitat relationships, interspecific relations, or home range of San Joaquin Antelope Squirrels. The purposes of this study were to conduct surveys in areas which had not been adequately covered in previous studies, determine the density of antelope squirrels in different habitats, develop effective census techniques, and determine the home range size of the species. The study was conducted during summer, 1988 and 1989.

Surveys resulted in very few new locations for San Joaquin Antelope Squirrels. Our surveys confirmed that the populations of San Joaquin Antelope Squirrels in the northern part of the species range and on the floor of the San Joaquin Valley are small, isolated, and in some cases exist in marginal habitat. The core of the species current distribution is in the southwestern part of the historical range and includes the area from the Elk Hills, in western Kern County, west through the Carrizo Plain, in eastern San Luis Obispo County.

Densities of San Joaquin Antelope Squirrels in open *Ephedra* scrub and shrubless study plots on the Elkhom Plain ranged from 0.8 to 8.0 antelope squirrels per hectare. All but two sites had densities less than or equal to 4.0 antelope squirrels per hectare, at the lower end of the range reported historically for prime habitat for this species (4-11 antelope squirrels per hectare). Densities on shrubless, grass-dominated sites were equal to or higher than those on sites with shrub cover. We found no consistent association of capture frequency with presence at trap stations under shrubs. Open shrubless areas with dense populations of antelope squirrels showed evidence of Giant Kangaroo Rat *(Dipodomys ingens)* activity.

The density of antelope squirrels on a study plot in the Panoche Hills area was 0.9 antelope squirrels per hectare in 1989. There were no recaptures during the 1988 study period. The study plot on The Nature Conservancy's Paine Preserve, on the floor of the San Joaquin Valley in northern Kern County, had a 'density of 2.0 antelope squirrels per hectare in 1988. There were no recaptures during the 1989 study period. At this site, which typifies the mixture of *Atriplex* - dominated hummocks and periodically flooded flat areas on the valley floor, antelope squirrels avoided flat areas and were usually captured on raised mounds, levees and roadsides.

We tested two techniques for censusing antelope squirrels without live-trapping: point centered counts and transect counts. Point-centered counts yielded too few observations to be useful as a census technique. Transect counts had a close relationship to density estimates based on live-trapping and thus appeared to be a practical method for estimating antelope squirrel density in an efficient manner. Transect counts should be conducted at consistent times of day and year by a small, experienced team of observers. Transect counts should be validated by live-trapping at sites with different habitat characteristics.

We studied the home range and movements of San Joaquin Antelope Squirrels at study plots on the Elkhorn Plain. Twenty antelope squirrels were equipped with radio transmitters at the Elkhorn 1 study plot and home range estimates were calculated based on mark-recapture data at study sites Elkhorn 1,2,4, and 5. The mean minimum convex polygon home range size was 3.63 hectares ±3.72 s.d.). A correction for sample size bias raises this mean to 10.81 hectares ±3.20 s.d.). The mean 95 percent ellipse home range was 14.41 hectares ±3.73 s.d.). Home ranges ranged from 0.74 to 16.1 hectares (minimum convex polygon), 2.43 to 53.49 hectares (minimum convex polygon corrected for sample size bias), and 2.53 to 59.4 hectares (95 percent ellipse). Means for juveniles were highest, followed by adult males and adult females, but these differences were not statistically significant.

We had the opportunity to observe interactions between California Ground Squirrels *(Spermophilus beecheyi)* and antelope squirrels. California Ground Squirrels displaced antelope squirrels from their burrow systems and surrounding caches. On small habitat fragments surrounded by disturbed or agricultural lands, the potential for California Ground Squirrels to have a negative impact on antelope squirrels may be significant.

1/ Nongame Bird and Mammal Section Report 91-02. Supported by funds from the California Endangered Species Income Tax Check-off Fund.

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This report should be cited as follows:

Harris, J.H., and D.M. Stearns. 1991. Population density and census methods, habitat relationships and home range of the San Joaquin Antelope Squirrel, 1988-89. California Department of Fish and Game, Nongame Bird and Mammal Sec. Rep. 91-02,37 pp.

RECOMMENDATIONS

1. Acquire or protect additional lands with San Joaquin Antelope Squirrel populations in the northern part of the species range and on the floor of the San Joaquin Valley, where populations are isolated and small.

2. Explore reintroduction as a primary recovery action and method of increasing the number of San Joaquin Antelope Squirrel populations, particularly in the northern part of the species' range. Possible locations for reintroduction include the Little Panoche Wildlife Area and BLM lands in the Kettleman Hills and Panoche Hills. Artificial burrow systems, similar to those used for reintroductions of Giant Kangaroo Rats, should be tested as a method for facilitating introduction of San Joaquin Antelope Squirrels.

3. Population studies using live-trapping methods should utilize a grid of a minimum of 13 hectares, corresponding to 100 traps spaced 40 meters apart, and should be conducted for five consecutive days. For populations of low density, this grid size may be too small to obtain a sufficient sample for population estimation.

4. A transect count index, the simplest, most repeatable method to census antelope squirrel populations in a cost-effective manner, should be the technique of choice for relative abundance studies.

5. Transect counts should be conducted during morning hours in late spring or early summer, with a consistent, experienced team of observers, and should be validated with live-trapping studies.

6. Variability between sites in our study suggests that further work on transect index methods should include trials with a strip census technique and more attempts to compare indices in different habitat types.

7. The relationships between San Joaquin Antelope Squirrels and Giant Kangaroo Rats, especially in open habitats, deserve further study.

8. The California Ground Squirrel may adversely affect San Joaquin Antelope Squirrels by displacing them from burrow systems, especially in fragmented habitats. Additional observations of interactions between the species would be informative, but an experimental approach involving removal of California Ground Squirrels from areas where the two species occur together would be more definitive.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

The San Joaquin Antelope Squirrel *(Ammospermophilus nelsoni)* is designated a Threatened mammal species in California (California Department of Fish and Game 1980). Habitat loss is responsible for the current status of the species and continues to be the primary problem facing San Joaquin Antelope Squirrels. Rodenticides and livestock overgrazing also may be important threats in some areas (Williams 1981). The historical distribution of antelope squirrels (Grinnell and Dixon 1918, Hawbecker 1953) included the southern and western portions of the San Joaquin Valley (south of the vicinity of Los Banos, Merced County) and adjoining upland habitats, Tulare Basin (Fresno and Kings counties), Buena Vista Basin (Kern County), upland habitats of the Carrizo Plain, Elkhom Plain, and Elk Hills (San Luis Obispo and Kern counties) and Cuyama Valley (Santa Barbara and San Luis Obispo counties). About 80% of the species native habitats had been lost to agricultural cultivation by 1979 (Williams 1981), and most that remains is not considered to be of prime quality. The core of the species' current distribution is the southwestern margin of the San Joaquin Valley and adjacent upland habitats, principally the Elk Hills and Elkhom Plain. Small, generally isolated populations are found on the San Joaquin Valley floor, in the Cuyama Valley, and in the Panoche and Kettleman Hills (San Benito and Fresno counties).

The life history and habitats of San Joaquin Antelope Squirrels and other ground squirrels were studied by Grinnell and Dixon (1918). This work provides some basis for comparison of current habitat use patterns and distribution. Much of our knowledge of the biology of San Joaquin Antelope Squirrels is based on the work of Hawbecker (1947,1951,1953,1958,1975). His work documented some aspects of the diet, habitat use, movements and annual cycle of the species in the northwestern portion of the historic range. The majority of Hawbecker's extensive fieldwork was conducted at a set of study plots on the eastern edge of Panoche Valley, San Benito County. Recent work has focused on determining the species' status in California. Williams (198 1) conducted a survey for the San Joaquin Antelope Squirrel, documenting its greatly reduced range. Recent surveys conducted by the California Energy Commission (Anderson et al. in prep.) will refine our knowledge of the species' current distribution.

Although the current distribution and habitat relationships of San Joaquin Antelope Squirrels are known generally, more information is needed in order to devise a conservation strategy for recovery of the species. There is little information on the density of antelope squirrels in different habitats in the remaining range, and there have been no studies comparing transect counts with density estimates derived from trapping. Even if densities are similar in various habitats, habitats may differ in productivity, and some habitats may be occupied by non-breeding dispersers (Van Home 1983). Information on density and habitat relationships is critical for planning the acquisition and management of habitat for preservation, for assessing habitat quality and for long term monitoring of the species' status. Furthermore, several areas within the historic range of antelope squirrels have not been recently surveyed for the presence of San Joaquin Antelope Squirrels. Williams (198 1) identified several areas in need of such surveys, including the Ortigalita Mountain region (Merced County), Kettleman Hills (Fresno and Kings counties) and portions of the Cuyama Valley (San Luis Obispo County). Some of these sites are in the northern parts of the species' range, where antelope squirrels are rare; their preservation may be critical to ensuring sufficient genetic variation in the species for long term viability.

The purposes of this study were to develop census methods for the San Joaquin Antelope Squirrel; determine population densities and home range sizes at different sites with a range of plant communities; and to locate additional populations of antelope squirrels. In this report we discuss some of the primary concerns for density estimation and censusing of San Joaquin Antelope Squirrels.

Densitv Estimates

Developing inexpensive and reliable census techniques was a high priority objective of this study. We sought to develop a census method or index and test it against density estimates derived by live-trapping. Both the census/index and the density estimate may be biased because of invalid assumptions and sampling errors that occur during population counts. However, many of these problems can be corrected or reduced with proper field methods.

Estimation of population size by live-trapping and marking individuals is a widely used technique with many possible approaches to estimating density from such data (see reviews of Otis et al. 1978, Davis and Winstead 1980, Seber 1982, White et al. 1982, Seber 1986). The most important problems (relevant to our study) with such methods were: determining whether the population was open or closed, accounting for variation in capture probabilities among individuals, accounting for responses to trapping, and determining the actual area sampled. By sampling for density during a restricted time period (five days), we could reasonably assume closure (Seber 1982, White et al. 1982). This implies that one would need to do separate density estimates for different trapping periods and seasons. By lumping trapping periods within a day into a single period, several potential sources of problems for population estimation may be overcome (White, et al. 1982, Seber 1986, Menkens and Anderson 1988). Time specific variation is reduced to that which occurs between days. By lumping several captures for “trap-happy” individuals, heterogeneity between individuals is reduced. If each trapping period were to be considered separately, the numbers of captures and recaptures would be very low, rendering population estimates variable and unstable.

Program CAPTURE (Otis et al. 1978, White et al., 1982) allows the investigator to choose a model for analysis of mark-recapture data which allows for one or more of the sources of variability mentioned above. Models are available for closed populations which do not assume that there is a lack of individual heterogeneity, behavioral response to capture, and/or variation due to time of day. The models evaluated by CAPTURE include the following:

M_o = Null model: assumes equal capture probabilities across individuals and times
M_h = Individual heterogeneity: assumes that capture probabilities differ between individuals
M_b = Behavioral response: assumes a general response to trapping, e.g. “trap-shy” response
M_{bh} = Individual heterogeneity and behavioral response: assumes both sources of variation
M_t = Time: assumes time specific variation in capture probability, e.g. time of day

Other combinations of effects are possible but do not have methods of analysis developed (White et al. 1982). Program CAPTURE includes a model evaluation procedure which performs a series of tests comparing each model to the null model. When sample sizes are small, it is unlikely that this procedure will detect differences between the null model and other models, even if the sources of variation are present. Thus the program is likely to select the null model even when it is inappropriate. Statisticians recommend using a population with a large sample size to evaluate possible models, then using that model for subsequent analyses (Menkens and Anderson 1988, Rosenberg pers. comm.).

Lincoln-Peterson estimates have often proved to be reliable population estimates (Davis and Winstead 1980, Menkens and Anderson 1988) when compared with other methods. By dividing a trapping study of several days into two periods, the effects of trap response and individual heterogeneity in capture probabilities can be reduced (Seber 1986, Menkens and Anderson 1988). This method performs well compared to CAPTURE when used with simulated data sets of small population size and when heterogeneity of capture probabilities among animals is low (Menkens and Anderson 1988). Schnabel estimates of population size are essentially weighted averages of successive Lincoln-Peterson estimates for multiple recapture occasions (Krebs 1989). The Schnabel estimate has the advantage, especially for small samples, of smoothing out some of the variations due to small numbers of recaptures. However, it should be remembered that both Lincoln-Peterson and Schnabel estimates are essentially null models, assuming no behavioral response, time variation or individual heterogeneity of capture probability.

Converting abundance estimates from live-trapping to density requires a knowledge of the area affected by trapping. Density estimates which simply divide the population size by the area of the study plot are undoubtedly over-estimates, because animals are attracted to the area by traps and animals with only a small portion of their range on the study plot are captured (White et al. 1982. Several methods have been developed to deal with this problem. These may involve calculating a boundary strip based on the size of the home range, use of assessment lines, and calculation of boundary strips using movement data from the live-trapping results (Johnson et al. 1987, Wilson and Anderson 1985).

Census procedures

The alternatives for estimating antelope squirrel density without trapping include censusing by visual and auditory detection of squirrels or by counting some indirect indicators of squirrel presence, such as burrows. We eliminated burrow counts as a census technique because we frequently observed use of the same burrow systems by both antelope squirrels and kangaroo rats (Hawbecker 1947, 1953). Thus visual and auditory observations of squirrels appeared to be the best alternative to live-trapping. A variety of general approaches to visual and auditory censusing have been used by avian ecologists (Ralph and Scott 1980, Vemer 1985). Most of these methods, which include variable circular plots, transect methods, and spot mapping, are intended to yield an estimate of density directly. For example, the variable circular plot method consists of censusing from a fixed point and using distances between the observed organism and the point to estimate density. Spot mapping involves the careful mapping of individual territorial singing birds. This method had no simple analog in the case of antelope squirrels. Transect methods involve traversing habitat along a straight line of a certain length and recording all individuals observed. It is possible to directly estimate density from transect counts if distances from the transect line are measured. However, there are a number of assumptions for calculating density directly from counts (Anderson et al. 1979, Burnham et al. 1980). These include:

1. Animals directly on the transect line are always seen.
2. Animals do not move before being seen or flushed (affects distance estimate).
3. Animals are not counted more than once.
4. The sighting of animals is independent (i.e. individuals do not alarm one another).
5. There is no error in measuring distances from a transect line.
6. Importance of defining and maintaining a straight line of travel (biases density estimate)
7. Transect lines are far enough apart to avoid overlap of observations

The last three assumptions involve measurement problems that, in principal, could be minimized or avoided by careful census procedures. The first four assumptions, however, were clearly a problem for censusing of antelope ground squirrels. Animals on the transect line which were in their burrows would not be observed, and there was likely to be a sizable fraction of the population which was underground at any given time, negatively biasing the estimate of density. While conducting transect counts in live-trapping grids, it was customary to observe a number of antelope squirrels which was only about one quarter of the number of marked animals in the study area. Secondly, squirrels in the vicinity of shrubs often observed the counter and moved to another shrub before being observed. The majority of observed squirrels during our transect counts were moving when initially sighted. Furthermore, some of these squirrels gave alarm calls, which violated the assumption that the sighting of animals was independent. During some seasons, squirrels were likely to be seen in clusters, probably corresponding to family groups. The activity, and likelihood of observation, of individuals in such groups was clearly not independent. Since most observed squirrels were moving, there was a possibility that the squirrel may have been counted again after making a long distance movement (squirrels frequently travelled more than 100 m while being observed). Given the densities of squirrels which we encountered, this did not seem like a major problem, but it might have been more important where a dense population occured in an area with a high percent cover of shrubs, such as the Buena Vista Valley and portions of the Elk Hills. The likelihood of violating these important assumptions rendered direct transect estimates of density based on distance measurements problematic at best.

Thus it seemed that the best course of action was to develop a reliable index to density. Indices have been constructed for a number of species, and have included observations of individuals, detection of their vocalizations (Bouffard and Hein 1978, Rotella and Ratti 1986) or indirect counts of sign such as burrows, or pellet groupings (Reid et al. 1966, Sarrazin and Bider 1973, Davis and Winstead 1980).

Unfortunately, even the most widely used indices have been rarely tested against other density estimates, e.g. mark-recapture studies (Eberhardt 1978, Dawson 1980, Seber 1982, 1986, Eberhardt 1987), thus they are only useful as indices of relative density. We might find that an index will have different relationships to density in different habitat types. A simple approach to censusing, with fewer assumptions, would be more meaningful and would likely be more repeatable with different observers.

Methods

Surveys

We conducted surveys to locate San Joaquin Antelope Squirrels in the Kettleman Hills (Fresno and Rings counties) and portions of the Cuyama Valley (San Luis Obispo County). We also surveyed areas in the Panoche Hills (San Benito and Fresno counties) and in the vicinity of The Nature Conservancy's Paine Preserve (Kern County). These latter areas were surveyed while in the process of searching for sites to establish live-trapping study plots.

To survey these areas, we examined the general region by car, choosing sites for surveys on foot based on presence of suitable habitat: open shrublands and grasslands lacking extreme disturbance (e.g. cultivation or flooding). While driving through survey areas, we frequently stopped to look and listen for San Joaquin Antelope Squirrels. Since our objective was simply to locate populations, rather than estimating abundance or density, we attempted to cover as much ground as possible on foot, without spending time to survey transect lines or live-trap. We looked for antelope squirrels, listened for calls, and noted any evidence of possible burrows of appropriate size. The general nature of the habitat was noted, especially where antelope squirrels were located.

Study Plots

We established live-trapping study plots based on information gathered from previous distributional surveys (California Natural Diversity Data Base, Williams 1981). We searched for sites with a range of habitat types within each of three general areas in the species range: northern upland, southern upland, and valley floor. Northern upland sites were located on Bureau of Land Management (BLM) lands in the Panoche Hills, Fresno County. These plots were on a bench at the northwestern end of the Panoche Hills (Table 1). The principal vegetation on this bench is open *Ephedra californica* shrublands, with an understory of grasses. Some plots that were trapped during efforts to locate suitable study plots in the Panoche Hills were Atriplex scrub, but these sites did not yield antelope squirrels. Southern upland sites were located in the Elkhom Plain area on lands administered by the BLM. These sites included two that. were open plains with virtually no shrub cover (sites 4,5) and three sites (sites 1,2,3) that were *Ephedra californica* scrub. Four of the sites were located near the Department of Fish and Game's Elkhom Plain Ecological Reserve. This reserve is fenced to exclude livestock and is surrounded by BLM lands. We arranged our study plots such that one *Ephedra* scrub site was located inside the fenced area (site 2) and one outside (site 1, Figure 1). The same arrangement was made for the two open shrubless sites such that site 4 was inside the fenced area and site 5 was outside. In addition to *Ephedra,* there was also significant cover of other shrubs, including *Eastwoodia elegans* and several *Eriogonum* species at the scrub habitat sites. Valley floor sites were located in the Semitropic Ridge region, on lands forming part of The Nature Conservancy's Paine Preserve (Figure 2). Shrub cover at these sites was primarily *Atriplex spinifera,* although *Suedu fruticosa* was also abundant, especially in alkaline microhabitats which appear to be frequently flooded. Two additional sites were trapped briefly in the Buena Vista Valley, on lands belonging to Chevron, IJSA. These were in an area transitional between valley floor and steeper terrain and had a shrub cover dominated by *Atriplex polycarpa.*

At our first site (Elkhom l), we established a grid with a spacing pattern of 40 meters between traps in a 10 x 10 trap array. This grid covered 13 hectares, and would have been too large for some of the study areas on smaller parcels of land, so some of our subsequent trapping grids had a 25 meter trap spacing and an area of 5.6 hectares. Grids which had an area of 13 hectares included Elkhom grids

Table 1. Locations of grids for live-trapping San Joaquin Antelope Squirrels. The months during which live-trapping was conducted are given, along with the total number of individuals marked and the distance between trap stations in meters. Each grid was a square with 100 trap sites.

Location	County	Legal Description	Dates	Animals Marked	Trap Spacing
Panoche Hills 1	Fresno	T14S, R11E, sec. 18, NW 1/4	6/88	0	25 m
Panoche Hills 2	Fresno	T14S, R11E, sec. 18, SW 1/4	6/88	0	25 m
Panoche Hills 3	Fresno	T14S, R11E, sec. 17, W 1/2 T14S, R11E, sec. 18, NE 1/4	6/88	0	25 m
Panoche Hills 4	Fresno	T14S, R11E, sec. 18, SE 1/4	6/88	1	25 m
Panoche Hills 5	Fresno	T14S, R11E, sec. 18, SE 1/4	6,7/88	2	25 m
Panoche Hills 5	Fresno	T14S, R11E, sec. 18, SE 1/4	6/89	7	25 m
Semitropic Ridge	Kern	T26S, R22E, sec. 36, NW 1/4	6/88	0	25 m
Paine Preserve 1	Kern	T26S, R22E, sec. 26, NW 1/4	6,7/88	23	25 m
Paine Preserve 1	Kern	T26S, R22E, sec. 26, NW 1/4	6/89	11	25 m
Paine Preserve 2	Kern	T26S, R22E, sec. 26, NE 1/4	7/88	0	25 m
Elkhorn 1	S.L.O.	T32S, R22E, sec. 20, NE 1/4 T32S, R22E, sec. 21, NW 1/4	5,6,7/88	47	40 m
Elkhom 1	S.L.O.	T32S, R22E, sec. 20, NE 1/4 T32S, R22E, sec. 21, NW 1/4	5,6/89	43	40 m
Elkhom 2	S.L.O.	T32S, R22E, sec. 20, NE 1/4	5,6/89	60	25 m
Elkhom 3	S.L.O.	T31S, R21E, sec. 27, SE 1/4	6/88	7	25 m
Elkhom 3	S.L.O.	T31S, R21E, sec. 27, SE 1/4	6/89	17	25 m
Elkhorn 4	S.L.O.	T32S, R22E, sec. 20, SE 1/4	6/89	75	40 m
Elkhorn 5	S.L.O.	T32S, R22E, sec. 20, SW 1/4	6/89	56	40 m
Buena Vista 1	Kern	T31S, R24E, sec. 19, SW 1/4	7/88	5	25 m
Buena Vista 2	Kern	T31S, R23E, sec. 23, NE 1/4	7/88	0	25 m

Figure 1. Elkhorn 1 study grid, San Luis Obispo County. The study grid is on grazed land south of the California Department of Fish and Game's Elkhorn Plain Ecological Reserve. The shrubs are *Ephedra californica*. Photograph by John H. Harris.

Figure 2. Paine Preserve 1 study grid, Kern County. The larger shrubs are *Atriplex lentiformis*, with some *Sueda fruticosa* visible in the foreground and in low spots throughout the photograph. Photograph taken by John H. Harris.

1,4, and 5. Grids of 5.6 hectares included the Paine Preserve, Semitropic Ridge and Panoche Hills grids. Elkhorn grids 2 and 3 were established with a 25 meter trap spacing in a 10 x 12 trap array; these grids had an area of 6.2 hectares. All study grids were trapped for 3-6 days as indicated in Table 3. Some exploratory trapping plots were used in the Paine Preserve and Panoche Hills areas. On these grids, which were established in order to attempt to locate antelope squirrel populations, we set out 40-100 live traps without surveying a grid In such a case, we spaced the traps by pacing, attempting to approximate a 25 meter spacing pattern in suitable habitat. Those exploratory grids that did not yield antelope squirrels were trapped for 2-3 days.

Trapping was conducted at various sites between late May and late July in 1988 and between late May and early July in 1989. The earlier termination of trapping in 1989 was due to high temperatures combined with the appearance of heat stress (licking of feet and face, panting) among animals captured during morning trapping periods. Traps were opened at 0600 hrs and were checked at 0900 hrs and 1130 hrs, at which time traps were closed. Traps were reopened at 1400 hrs and were checked at 1600 hrs and 1830 hrs. On days during which temperatures exceeded 35° C (95° F), we closed traps for 3-4 hours during the afternoon, then opened traps for a single late afternoon and early evening trapping period between 1600-l830 hrs. Generally the morning was a more productive trapping period during such days. Traps were placed in the shade of shrubs where possible. A burlap shade or shelter of dry cow manure was draped over traps which were in the open. Mixed bird seed was used to bait the traps.

Weight, sex, and any unusual marks were recorded for all captured animals. Individuals were classified as juveniles or adults based on size. Animals were individually marked with a numbered ear tag in 1988. In 1989, we marked the animals on the belly and a with a band on the tail using an indelible marker. Fading marks on recaptured animals were retraced. The location, date and approximate time of capture were recorded. No species other than San Joaquin Antelope Squirrels were captured during the study.

We determined the density of shrub species at each trapping grid using 50 point-quarter shrub counts (Cottam et al. 1953). We mapped the trap locations, recording slope (determined with a clinometer), topographic features (gullys, roads, large open areas, etc.) and microhabitat (classified as open or under a shrub). At the Paine Preserve site, we classified trap locations into two categories: mudflat and mound. We performed chi-square tests of capture frequencies with these habitat parameters.

We estimated the abundance of San Joaquin Antelope Squirrels by using Program CAPTURE and by calculating Lincoln-Peterson and Schnabel estimates. For all estimates, we lumped trapping periods within days into a single period. To estimate density, we calculated “naive” density estimates by dividing the population estimate by the area of the study grid. We also calculated densities using a boundary strip based on half the mean maximum distance moved between captures (Johnson et at. 1987). Program CAPTURE calculates the mean maximum distance moved between captures. We used an average of the mean maximum distance moved for Elkhorn sites 4 and 5, the two sites with the largest sample sizes, to calculate the boundary strip for sites with 40 meter trap spacing. For those sites with 25 meter trap spacing, we used the mean maximum distance for Elkhorn site 2, which had the largest sample size of the grids with 25 meter trap spacing.

We attempted two non-trapping census techniques which relied on visual and auditory detection of antelope squirrels. These two methods were 15 minute point counts and transect counts. For our initial efforts, we made no attempt to estimate distances to antelope squirrels from the point or transect line. Fifteen minute point counts were conducted by simply noting any squirrels seen or heard from a fixed point during a fifteen minute period. No point counts were conducted in 1989, because this method did not yield as many antelope squirrels per unit time as transect counts. Transect counts were conducted using the previously established grids as a reference system. We recorded all antelope squirrels we saw or heard while walking along the grid lines. We recorded the length and time of transect counts, and the number of antelope squirrels seen or heard on each transect. We attempted to avoid counting the same individual more than once during a transect count.

Home Range and Movements

The home range and movements of antelope squirrels were studied using radiotelemetry at the Elkhorn 1 site. Nineteen antelope squirrels (8 adults and 11 juveniles) were equipped with radio transmitter collars. We used a 3.0 gram, model BR collar (AVM instruments), which was slipped over the squirrel's neck and folded to fit the individual animal (Figure 3). Plastic heat shrink tubing was placed over the folded part of the collar and was heated with a hot knife, shrinking the tubing and holding the collar in place. The animals were located using the LA 12-DS receiver (AVM Instruments) and a hand-held Yagi antenna. Antelope squirrels were collared in the first two weeks of the study. Locations were determined as often as possible until mid-July. At this point, seven collars had been lost from their bearers. We attempted to recover the remaining collars by trapping the squirrels and removing their collars. For each determination of a squirrel's location, the distance and direction to the nearest trap site were measured using a compass and rolatape wheel or pacing. Locations were recorded and plotted on a grid. The home range analysis program McPaal (Stuwe and Blohowiak 1985) was used to calculate home range. In order to compare our results with previous studies of San Joaquin Antelope Squirrels (Hawbecker 1958) and White-tailed Antelope Squirrels *(A.leucurnus)* (Allred and Beck 1963, Bradley 1967), we also calculated home ranges using McPaal for antelope squirrels based on live-trapping data alone. Home ranges were calculated for all squirrels with five or more locations at three or more trap sites on four study plots: Elkhorn 1,2,4 and 5.

Two kinds of home range estimates were calculated for each animal. The minimum convex polygon (MCP) is the figure obtained by connecting the outermost locations such that no interior angle is greater than 180 degrees (Sander-son 1966). This estimate has the advantage of simplicity and historical use in the literature, and it should approach the true home range in homogenous habitat (Schoener 198 1). However, it includes unused' space, gives no indication of intensity of use, and is extremely sensitive to sample size and outliers. We used a sample size correction given by Jennrich and Turner (1969) as well as the uncorrected minimum convex polygons.

An alternative to the minimum convex polygon that is less sensitive to sample size is the 95% ellipse (Jennrich and Turner 1969). This method assumes a bivariate normal distribution to construct a 95% confidence ellipse. Since the bivariate normal is a continuously decreasing distribution, inclusion of a greater percentage of observations can increase the area of the ellipse substantially, while only including a few more observations, thus the widespread use of a 95% rather than 99% ellipse (White 1990). Because this method does not represent shape well, it is less useful for determination of range overlap between animals or patterns of microhabitat use. Most of our minimum convex polygon home ranges were roughly rectangular, suggesting that the 95% ellipse is an appropriate estimator.

Results and Discussion

Surveys

Our distributional surveys documented the presence of San Joaquin Antelope Squirrels in several locations (Table 2). The northern part of the species range, where there are a small number of recent locations and antelope squirrels are not common, is an area of particular concern. We located squirrels in the Panoche Hills and received reports of extant populations from the Kettleman Hills area (M. Wade, D. Williams, pers. comm.). Natural Diversity Data Base and BLM records indicated that antelope squirrels have been observed recently on a bench on the northwestern side of the Panoche Hills and in the northern Tumey Hills (south of the Panoche Hills). They also were known historically from the gently sloping terrain at the south end of the Panoche Hills adjacent to Panoche Creek (Hawbecker 1947,1951,1958). We found antelope squirrels on the northwestern bench and established study plots there. We also found a number of antelope squirrels scattered along a five mile stretch of Panoche Creek, mostly east of Panoche Pass, on the Silver Creek Ranch. This habitat has extensive *Atriplex* scrub and undoubtedly supports a larger number of antelope squirrels than the area

Figure 3. San Joaquin Antelope Squirrel equipped with a radio transmitter. Photograph of a radio-collared antelope squirrel taken on study grid Elkhorn 1, San Luis Obispo County. The radio collar is a model BR radio transmitter, AVM Insturment Company, Livermore, California. Photograph by John H. Harris.

Table 2. Survey locations and numbers of San Joaquin Antelope Squirrels observed. County abbreviations are as follows: S.B. = Santa Barbara, S.L.O. = San Luis Obispo. Squirrels seen are' the number of different individuals observed at each survey location. At the Panoche Creek locations, we surveyed by car following the Panoche Creek Road, hence only the portions of the listed sections visible from the road were surveyed. In the case of Cuyama Wash, we walked the length of the wash through the listed sections, but did not survey the entire area of these sections. Otherwise the portion of each section walked during surveys is indicated.

Location	**County**	**Legal Description**	**Date**	**Antelope Squirrels**
Panoche Hills	Fresno	T14S, R11E, sec. 17, W l/2	6/14-15/88	0
Panoche Hills	Fresno	T14S, R11E, sec. 19, NE l/4	6/14-15/88	0
Panoche Hills	Fresno	T14S, R11E, sec. 20, W 1/2	6/14-15/88	0
Panoche Hills	Fresno	T14S, R11E, sec. 28 and sec. 29	6/14-15/88	0
Panoche Creek	Fresno	T15S, R11E, secs. 27,28, and 29	6/16/88	0
Panoche Creek	Fresno	T15S, R11E, secs. 34,35, and 36	6/16/88	0
Panoche Creek	Fresno	T15S, R12E, secs. 16,20, and 21	6/16/88	0
Panoche Creek	Fresno	T15S, R12E, secs. 29,31, and 32	6/16/88	0
Little Panoche	Fresno	T13S, R11E, sec. 30, NW l/4	6/16/88	0
Little Panoche	Fresno	T13S, R10E, sec. 25, NE 1/4	6/16/88	0
Kamm Rd.	Fresno	T16S, R14E, sec.18, SW l/4	6/15/88	0
Panoche Hills	Fresno	T14S, R11E, sec.17, W l/2	6/17-18/89	0
Panoche Hills	Fresno	T14S, R11E, sec. 19, NE l/4	6/17-18/89	0
Panoche Hills	Fresno	T14S, R11E, sec. 20, W l/2	6/17-18/89	0
Panoche Creek	San Benito	T15S, R11E, sec. 27	6/17/89	2
Panoche Creek	San Benito	T15S, R11E, sec. 35, SE l/4	6/17/89	1
Panoche Creek	Fresno	T15S, R12E, sec. 29	6/17/89	1
Panoche Creek	Fresno	T15S, R12E, sec. 32, W l/2	6/18/89	2
Panoche Creek	Fresno	T15S, R12E, sec. 21, NW l/4	6/18/89	1
Tumey Hills	Fresno	T15S, R12E, secs. 14,23, and 24	6/18/89	0
Griswold Canyon	San Benito	T16S, R10E, sec. 1	6/18/89	0

Table 2, continued

Location	**County**	**Legal Description**	**Date**	**Antelope Squirrels**
Griswold Canyon	San Benito	T16S, Rl0E, sec. 12, W l/2	6/18/89	0
Griswold Canyon	San Benito	T16S, R11E, sec., NW l/4	6/18/89	0
Griswold Canyon	San Benito	T15S, R11E, sec. 30, SW l/4	6/18/89	0
Griswold Canyon	San Benito	T15S, R11E, sec. 31, W l/2	6/18/89	0
Sunflower Valley	Kings	T24S, R17E, sec. 23, E l/2	6/28/88	0
Kettleman Hills	Kings	T23S, R18E, sec. 2, SE l/4	6/29/88	0
Kettleman Hills	Kings	T23S, R18E, sec. 11, NE l/4	6/29/88	0
Kettleman Hills	Kings	T23S, R18E, sec. 12, W l/2	6/29/88	0
Kettleman Hills	Kings	T22S, R18E, sec. 36, NE l/4	6/29/88	0
Pyramid Hills	Kern	T25S, R18E, sec. 2, S l/2	6/29/88	0
Pyramid Hills	Kern	T25S, R18E, sec. 3, SE l/4	6/29/88	0
Sand Ridge, Hwy 5	Kings	T24S, R20E, sec. 27, E l/2	7/21/88	1
Paine Preserve	Kern	T26S, R22E, sec. 26, SE l/4	6/22/89	1
Paine Preserve	Kern	T26S, R22E, sec. 16, SW l/4	6/22/89	4
Paine Preserve	Kern	T26S, R22E, sec. 15, SW 1/4	6/22/89	0
Paine Preserve	Kern	T26S, R22E, sec. 16, SE l/4	6/22/89	0
Santa Barbara Cyn.	S. B.	T9N, R25W, sec. 14, SE l/4	6/30/88	0
Santa Barbara Cyn.	S. B.	T9N, R25W, sec. 22, SE l/4	6/30/88	0
Santa Barbara Cyn.	S. B.	T9N, R25W, sec. 23, NW l/4	6/30/88	0
Cuyama R. wash	S.L.O.	Tl0N, R25W, secs. 19,28,29,33,34	6/30/88	0
Cuyama Valley	S.L.O.	Tl0N, R25W, sec. 13, SE l/4	6/30/88	3
Cuyama Valley	S.L.O.	Tl0N, R25W, sec. 13, SW l/4	6/30/88	2
Cuyama Valley	S.L.O.	Tl0N, R25W, sec. 14, SE l/4	6/30/88	2
Cuyama Valley	S.L.O.	Tl0N, R25W, sec. 14, SW l/4	6/30/88	2
Cuyama Valley	S.L.O.	Tl0N, R25W, sec. 16, NW l/4	6/30/88	1

Table 2, continued

Location	County	Legal Description	Date	Antelope Squirrels
Cuyama Valley	S.L.O.	T10N, R26W, sec. 5, NE l/4	7/1/88	2
Cuyama Valley	S.L.O.	T10N, R26W, sec. 5, NW l/4	7/1/88	0
Cuyama Valley	S.L.O.	T10N, R26W, sec. 6, S 1/2	7/1/88	0
Cuyama Valley	S.L.O.	T10N, R26W, sec. 4, N l/2	7/1/88	0
Cuyama Valley	S.L.O.	T10N, R26W, sec. 3, S 1/2	7/1/88	2
Cuyama Valley	S.L.O.	T10N, R26W, sec. 2, SW l/4	7/1/88	2

where we located study plots in 1988. The areas in which Hawbecker (1947, 1951, 1953, 1958) conducted his studies on southern end of the Panoche Hills do not appear to have many antelope squirrels, and some of the areas appear to have had most of their shrub cover removed. We were unable to gain access to BLM lands on Ortigalita Peak, which may harbor antelope squirrels, although adjoining land of more suitable slope has been heavily grazed and has little shrub cover. Several sites in the Kettleman Hills appeared to have suitable habitat, though we did not locate any antelope squirrels during our surveys. The BLM lands and adjoining private lands in the two miles south of highway 41 along the crest and slopes of the Kettleman Hills appeared to be especially promising, but we found no antelope squirrels there. We received a report (M. Wade, pers. comm.) that antelope squirrels are found on lands belonging to Chevron U.S.A., Inc. and lands leased from BLM by Chevron in the North Dome Oil Field, on the north end of the Kettleman Hills. Williams (pers. comm.) reported observing antelope squirrels in the Avenal Gap, near the southern end of Kettleman Hills. Any squirrel population in the Kettleman Hills is significant, given the paucity of antelope squirrels to be found elsewhere in the northern part of the species range.

In the vicinity of the Paine Preserve, Kern Co., we located squirrels in two locations in 1989. One of these locations, where we observed a single antelope squirrel, was on land adjacent to Nature Conservancy holdings (and within the ultimate planned preserve boundary, R. Hewett, pers. comm.) in an area of *Atriplex spinifera* scrub. There was a large population of California Ground Squirrels *(Spermophilus beecheyi)* at this site. The other site, where four antelope squirrels were located, was on land under negotiation for purchase by The Nature Conservancy (R. Hewitt, pers. comm.). This parcel contained dry mud flats, hummocks with *Atriplex spinifera* (locations of sightings) as well as patches dominated by *Sueda fruticosa* and *Allenrolfea occidentalis.* While travelling on Interstate 5, a single antelope squirrel was seen in 1988 in a location not previously noted (Williams 1981, NDDB). This location, southwest of Sand Ridge, is within the species' historic range (Hawbecker 1953). There have apparently been other sighting reports from the Sand Ridge area (Williams, pers. comm.).

The Cuyama Valley is roughly the southern terminus of the antelope squirrel's range. Parts of the valley have not been surveyed (Williams 1981). We walked several miles of seemingly suitable habitat along the Cuyama River wash without observing any antelope squirrels. Probably the occasional flooding of this habitat is enough to eliminate any colonizing antelope squirrels and prevent the establishment of populations. We also briefly surveyed the mouth of Santa Barbara Canyon (Santa Barbara County). This canyon enters the Cuyama Valley opposite Ballinger Canyon (Ventura County), where a small population of antelope squirrels occupies the margin of the valley. We found no antelope squirrels in Santa Barbara Canyon, although it is possible that a low density population may exist in the area. The northern margin of Cuyama Valley, between the cultivated lands of the valley and the Caliente Range, contains extensive *Atriplex* scrub which appears suitable for antelope squirrels. We examined about 9 miles (13.4 km) of habitat along the northern edge of Cuyama Valley, locating 16 antelope squirrels at 8 locations (Table 2). There is probably a nearly continuous moderate to low density population of squirrels in this band of habitat. In some areas, the valley floor is cultivated up to the edge of steep terrain. Further expansion of cultivated areas, combined with the long term effects of heavy grazing seen in some locations, may reduce this population of antelope squirrels. We did not olbserve antelope squirrels while driving through dense *Atriplex* scrub on the Russell Ranch, north and west of New Cuyama.

To summarize, we documented the occurrence of antelope squirrels in two general areas of the Panoche Hills: the bench on the northwestern end of the hills and much of the length of Panoche Creek. The other location for antelope squirrels in the northern part of the range is in the Kettleman Hills, including the Avenal Gap area and the North Dome Oil Field (an area which has not been documented by recent surveys). These locations do not enlarge the historical range, but document the continued existence of antelope squirrels in areas where they have been infrequently observed. Survey results and live-trapping results in the Panoche Hills confirm the notion that the San Joaquin Antelope Squirrel is rare and localized in the northern part of its range. There may be locations on state or federal lands which would be suitable for reintroduction of the species in the northern portion of its range. For example, the Little Panoche Wildlife Area, administered by the Department of Fish and Game, has undergone a program of vegetation restoration resulting in habitat which should be suitable for antelope squirrels. This location is near a possible source population in the Panoche Hills. Habitat along Panoche Creek east of Panoche Pass represents another area where significant habitat should be preserved. Another possibility would be BLM lands in the Kettleman Hills.

On the floor of the San Joaquin Valley, there are few remaining populations of antelope squirrels, and those which remain are in marginal habitat (Williams 1981). We found antelope squirrels on lands adjacent to The Nature Conservancy's Paine Preserve which may eventually be acquired. Clearly the heart of the San Joaquin Antelope Squirrel's range is in the southwestern portion of its historical range: the Carrizo and Elkhorn Plains, Elk Hills, and Buena Vista Valley.

We examined a large area in the Cuyama Valley which has not previously been surveyed for antelope squirrels and found the species to be distributed in a narrow band along the northern edge of the valley between cultivated lands and steep, barren upland terrain. The BLM lands on the margin of the Caliente Range and Cuyama Valley are critical for maintenance of the species at the southwestern end of its range.

Density estimates

Table 3 provides a summary for each study plot of the number of animals marked, the total number of captures, the ratio of juveniles to adults captured, and the average probability of capturing an individual in a given trapping period (estimated by Program CAPTURE). The area of each study plot is given, as well as the width of the boundary strip and area of the study plot and boundary strip combined. Table 4 shows three estimates of abundance: the model of behavioral response (Model M_b) calculated by Program CAPTURE, the Lincoln-Peterson estimate and the Schnabel estimate. The model of behavioral response provided the best fit for the data from the two sites with the largest number of captures and animals marked (Elkhorn sites 4 and 5), so we used this model for all of the study sites.

Densities of antelope squirrels using the distance-based boundary strip method are used in all subsequent discussion. Densities on our study plots ranged from 0.7 to 8.0 animals per hectare (Model Mb estimates), 1.1 to 6.2 per hectare (Schnabel estimate), or 1.1 to 8.1 per hectare (Lincoln-Peterson estimate). Elkhom sites 1,2,4 and 5 had the highest densities; given the amount of variability they are probably not significantly different. Grinnell and Dixon (1918) suggested that density of this species in prime habitat was between 4 and 11 squirrels per hectare, and in the Elk Hills region they estimated density as about 2.3 per hectare. By these standards (probably not based on large samples), only the Elkhom 2 study area (fenced scrub habitat) and the Elkhorn 4 and 5 study areas (open habitat, Model M_b densities only) were in the range expected for good habitat. The high density on the Elkhorn 2 study plot could have been a result of the enclosure or the increased feeding and shade opportunities provided by the campsite on the southern edge of the trapping grid. The presence of the campsite also undoubtedly drew squirrels as habitual visitors from adjacent habitat. On the other hand, very large numbers of squirrels were observed using burrow systems throughout the fenced area. The Elkhorn 1 study area, in open shrublands outside the fenced enclosure, had a density slightly lower than the range for prime habitat reported by Grinnell and Dixon (1918). The two sites in open habitat, Elkhorn 4 and 5, had surprisingly high densities considering the lack of shrub cover. Elkhorn 4, inside the enclosed area, had a slightly higher density than Elkhorn 5, outside the fenced area. Both of these areas had large numbers of Giant Kangaroo Rat burrow systems, which were being shared by antelope squirrels. Perhaps the presence of other burrowing rodents compensated in some way for lack of shrub cover. Other areas on the Elkhorn Plain which lack shrubs and Giant Kangaroo Rats appeared to have far fewer squirrels, and areas which had been heavily overgrazed (such that grasses were essentially grazed to ground level, with mostly bare ground) generally lacked antelope squirrels altogether.

At several sites, antelope squirrels were so uncommon that the number of captures was very low. At these low density sites, both trapping and transect counts were likely to be variable, creating

Table 3. Summary data for study plots which yielded captures of San Joaquin Antelope Squirrels during the 1988 and 1989 seasons. Locations of study grids arc given in Table 1. The table includes the number of trap days (T) during census periods, the total number of animals marked (M), the total number of captures (N) including recaptures, the ratio of juveniles to adults captured (J/A), the estimated capture probability (p), the area of the study grid in hectares (A), width of boundary strip in meters (W) and the effective area trapped in hectares (A_w), equal to the area of the study grid plus the area of the boundary strip

Grid	**T**	**M**	**N**	**J/A**	**P**	**A**	**W**	A_w
Elkhorn 1-88	3	47	79	1.86	.33	13	50	21.2
Elkhorn 1-89	5	43	79	2.40	.20	13	50	21.2
Elkhorn 2-89	5	60	149	1.50	.35	5.6	38	9.1
Elkhorn 3-88	3	7	8	.75	.45	6.2	38	10.6
Elkhorn 3-89	5	17	48	.55	.51	6.2	38	10.6
Elkhorn 4-89	5	75	255	2.17	.49	13	50	21.2
Elkhorn 5-89	5	56	156	2.29	.40	13	50	21.2
Panoche 5-88 [1]	5	2	2	0.00		5.6	38	9.1
Panoche 5-89	3	7	15	.17	.48	5.6	38	9.1
Paine 1-88	4	17	37	2.83	.46	5.6	38	9.1
Paine 1-89 [1]	4	11	16	1.40		5.6	38	9.1

1. No recaptures between trapping periods

Table 4. Estimates of population size and density of San Joaquin Antelope Squirrels for mark recapture study plots during the 1988 and 1989 field seasons. Locations of study grids are described in Table 1. The estimates of population size include the behavioral response model (M_b) from program CAPTURE, a Lincoln-Peterson index (L) from data lumped into two periods, and Schnabel estimate (S). Density estimates include two "naive" density estimates, the behavioral response model estimate divided by study plot area (Mb/A), Lincoln Peterson index divided by study plot area (L/A), and Schnabel index divided by study plot area. All densities are given in units of animals per hectare. Finally, three density estimates based on movement are given. These are the behavioral response model, Lincoln-Peterson and Schnabel estimates divided by the effective trapping area: the study plot area in hectares plus a boundary strip equal to half the mean maximum distance moved in meters (M_b/A_w L/A_w S/A_w respectively). See Table 3 for the values of area (A) and effective area trapped (A_w) for each study area.

Grid	**M_b**	**L**	**S**	**M_d/A**	**L/A**	**S/A**	**M_b/A_w**	**L/A_w**	**S/A_w**
Elkhorn 1-88	73± 7.3	56± 8.9	64± 7.9	5.6	4.3	4.9	3.4	2.6	3.0
Elkhorn 1-89	60± 5.1	73± 8.6	60± 8.2	4.6	5.6	4.6	2.8	3.4	2.8
Elkhorn 2-89	73± 9.2	74± 3.7	67± 3.5	13.0	13.2	12.0	8.0	8.1	7.4
Elkhorn 3-88	8± 2.9	17± 1.5	14± 1.4	1.3	2.7	2.3	0.8	1.6	1.3
Elkhorn 3-89	20± 4.2	17± 0.8	16± 1.2	3.2	2.7	2.6	1.9	1.6	1.5
Elkhorn 4-89	114± 26.1	81± 1.8	69± 1.4	8.8	6.2	5.3	5.4	3.8	3.3
Elkhorn 5-89	85± 22.6	61± 2.7	54± 2.4	6.5	4.7	4.2	4.0	2.9	2.5
Panoche 5 -89	8± 2.9	14± 1.4	12± 0.8	1.4	2.5	2.1	0.9	1.5	1.3
Paine 1-88	18± 2.3	19± 3.5	18± 0.7	3.2	3.4	3.2	2.0	2.1	2.0

problems for establishing a relationship between the transect index and density. Habitat variation complicated this problem even further. For example, at the Elkhorn 3 site, shrubs were very dense but small, such that visibility at ground level was limited. At this site we observed only four antelope squirrels in 1988, mostly along the roadside, but captured seven individuals. In the Panoche Hills, on the other hand, shrubs were large but more widely scattered and grass cover was nearly continuous. Here we observed 15 antelope squirrels but captured only 2 in 1988. Reasons for the low capture success at this site were not clear, but 1989 provided an interesting contrast. The site was grazed to blare ground before we arrived in 1989. The number of antelope squirrel observations on transect counts was comparable, if not slightly lower, but our capture success was much higher, suggesting that food was in greater demand, or perhaps that traps were more obvious to the antelope squirrels under these conditions.

Two additional problems with live-trapping techniques for antelope squirrels were evident from this study. Ear tags were easily lost from these relatively small-eared squirrels. At the Elkhorn 1 study site, we captured eight animals during our second visit in 1988 which had evidently lost ear tags. This represented 19.5% of the animals marked during our first visit about one month earlier. Only one ear-tagged individual was recaptured the following year. During 1989, the final year of the study, we used indelible marking pens. A second problem related to live-trapping methods was the apparent violation of the equal catchability assumption (Seber 1982, White et al. 1982). Juveniles appeared to be more readily captured, and are also more likely to be recaptured. This represented not only heterogeneity in capture probability, but also response to trapping and an interaction between capture probability and trap response. A downward bias may have resulted from calculating density under these conditions (White et al. 1982, Menkens and Anderson 1988).

Antelope squirrel densities in good habitat in the Elkhorn Plain area were mostly in the range of 2-5 animals per hectare. This density is on the low end of the range suggested by Grinnell and Dixon (1918) for prime habitat. Exceptional sites may have higher densities, and there is much occupied habitat in this region which probably has densities less than 1 per hectare. Sites in the Central Valley are likely to have densities lower than 4 per hectare, as illustrated by our Paine Preserve site, considered to be one of the better sites for this species on the floor of the valley. Poor habitat quality and habitat fragmentation are significant concerns for the long-term persistance of this species on the valley floor. Densities at the Panoche Hills site were very low, and this isolated population may also be at risk in the long run.

<u>Census techniques</u>

We conducted 15 minute point counts at the Elkhorn 1 and Paine Preserve study areas in 1988 (Table 5). Transect counts were conducted at these study areas as well as the Elkhorn 3 and Panoche Hills study area in 1988 and at five Elkhorn Plain sites, Panoche Hills and Paine Preserve in 1989 (Table 6). Point counts were judged to be unsatisfactory after our early efforts for several reasons. Although the numbers seen varied in a manner expected based on trapping results at these two sites, the overall number of squirrels seen was low. This was due to the limited area observed while remaining in a fixed location, especially important where shrubs are dense and where the terrain is complex. Also, squirrels are less apt to be flushed by the observer during point counts. During transect counts, the time taken to travel one kilometer was roughly 15 minutes, thus one can compare the number of squirrels seen for the two methods by comparing point counts with squirrels seen per kilometer of transect counting. This reveals that 2-4 times as many squirrels were counted per unit time by using the transect method. Even if the two methods are equally accurate in detecting trends, the method which detects the most individuals per unit time is both more efficient and likely to be more precise (Burnham et al. 1980).

Transect methods yielded a greater number of detections per unit time because of the flushing of otherwise inconspicuous animals, increased rate of calling by disturbed squirrels, the ability to traverse over hilly terrain and the increased number of visual angles on the habitat when compared to observing

Table 5. Results of 15 minute point counts of San Joaquin Antelope Squirrels at the Elkhorn 1 and Paine Preserve 1 locations during 1988. Locations of study grids are given in Table 1. The number of 15 minute counts (N), the mean number of antelope squirrels per 15 minute count, and the standard deviation (S.D.) of point counts are given for each date and time. In addition, a mean for the total of all counts is given for the two sites.

Location	**Date**	**Time**	**N**	**Mean**	**S.D.**
Elkhorn 1	6/1	1000-1100	16	1.3	1.1
Elkhorn 1	6/2	0845-0915	2	1.0	1.4
Elkhorn 1	6/3	0930-1130	9	1.4	1.4
Elkhorn 1	7/9	0800-0900	8	1.1	1.0
Elkhorn 1	7/9	1900-2000	10	1.6	1.1
Elkhorn 1	Mean		45	1.36	1.1
Paine Preserve 1	6/10	0830-1000	6	0.5	1.2
Paine Preserve 1	6/10	1430-1530	4	0	0
Paine Preserve 1	6/10	1900-2000	7	0.7	0.9
Paine Preserve 1	6/11	0700-0830	5	0.6	0.6
Paine Preserve 1	7/14	0830-0930	6	0.2	0.4
Paine Preserve	Mean		28	0.43	0.8

Table 6. Summary of 250 m transect censuses of San Joaquin Antelope Squirrels during 1988 and 1989. Locations of study grids are given in Table 1. Means and standard deviations (S.D.) of transect counts of antelope squirrels per 250 m and the number of 250 m transects (N) are given. All transects were conducted by the same observer (JH), between 0730-1000, and in the period May 25-June 30 of the given year.

Location	**Year**	**N**	**Antelope Squirrels Per 250 m**	**S.D.**
Paine Preserve 1	1988	37	0.81	0.9
Paine Preserve 1	1989	9	0.89	1.2
Panoche Hills 5	1988	24	0.25	0.6
Panoche Hills 5	1989	16	0.19	0.6
Elkhorn 1	1988	33	1.38	1.0
Elkhorn 1	1989	12	1.30	0.9
Elkhorn 2	1989	9	12.00	3.8
Elkhorn 3	1988	16	0.00	0.0
Elkhorn 3	1989	16	0.73	0.6
Elkhorn 4	1989	5	9.00	0.7
Elkhorn 5	1989	6	7.81	1.7

from a fixed point. Based on transect counts and on general observations while live-trapping in 1988, we concluded that morning censuses were preferable. Observer differences are potentially a significant source of variation. As a result, we used only the transect counts for the single most experienced observer (JH). The means for morning transect counts are compared with the Model M_b estimates per hectare (Figure 4) and Schnabel estimates per hectare (Figure 5). There is a good relation between transect counts and both estimates (r^2 = .86, .66 respectively), suggesting that transect counts can be successfully used as a density index. However, the best fitting line achieves a value of zero for the y axis (transect count) at a density greater than zero, suggesting that transect counts might not be useful at very low densities.

Two sources of variation are likely to have adversely affected the relationship between transect counts and density. The site Elkhorn 2 included on its southern edge the campsite area occupied by researchers. This area attracted large numbers of squirrels during all daylight hours and probably affected transect counts near the camp. Two of the sites, Elkhorn 4 and 5, were in open shrubless areas where squirrels could be sighted at long distances relative to all other areas. These points are the two points conspicuously above the regression line in Figures 4 and 5. In order to use transects as a density index for such a habitat, it would be desirable to conduct further studies to develop a separate equation for open habitats. In particular, mark-release studies in open habitats with lower densities are needed. Alternatively, transect counts in open habitats could be conducted by using a strip census approach, with the width of the strip approximating the visibility distance for scrub habitats. This would require additional experience and practice on the part of observers.

Habitat and Microhabitat Use

The highest densities of antelope squirrels were obtained in two habitat types: open *Ephedra* scrub with fairly large, widely spaced shrubs (e.g. Elkhorn 1, Table 7), and open shrubless grassy habitats concurrently occupied by kangaroo rats. The high density of antelope squirrels in open habitat was not expected, as shrubs have been thought to be critical for thermal cover (Heller and Henderson 1976), and our own observations suggested that antelope squirrels center their activities around shrubs when available. In habitats with shrubs, we frequently observed squirrels at the base of shrubs, sitting in shade, eating or interacting with one another. The majority of burrows appear to be located at the base of shrubs in these habitats. The base of shrubs often has a denser cover of grass and herbs, and appears to provide more feeding opportunities. However, our density estimates suggest that shrub cover is not necessary to support populations of antelope squirrels, and therefore burrow systems can provide sufficient cover.

Another way to measure the importance of shrub cover is to examine the capture frequency at trap sites in the open as opposed to that of traps at the base of shrubs. Such results are subject to varying interpretations, since traps themselves provide visible shelter and can bias microhabitat use patterns. Nonetheless, we tested for differences in capture frequency at study plots which had trap sites in both situations (traps at Elkhorn 3 and Panoche Hills were all under shrubs, traps at Elkhorn 4 and 5 were all in the open). No difference was found for Elkhorn 1, 1989 (X^2 = .84), Elkhorn 2, 1989 (X^2 = 3.06), and the Paine Preserve, 1988 (X^2 = .65). In 1988, there was a slight but significantly higher proportion of captures near shrubs at the Elkhorn 1 site (X^2 = 4.06, $p < .05$).

A number of additional questions are raised by these results. It may be that squirrels in our open study plots were immigrants from nearby shrubby areas, and that these open areas are simply dispersal sinks. The presence of juveniles in apparent family groupings and the presence of adults in these open habitats suggests that these sites had breeding populations. The extent to which the presence of antelope squirrels in such open habitats depends on the presence of other small mammals is an interesting question worthy of further investigation. Although systematic surveys were not conducted with this question in mind, dense populations in open shrubless habitats on the Elkhorn Plain were only observed where kangaroo rat activity was evident, and our two study grids in open habitat had much evidence of Giant Kangaroo Rat burrow systems. Our results suggest that antelope squirrels might

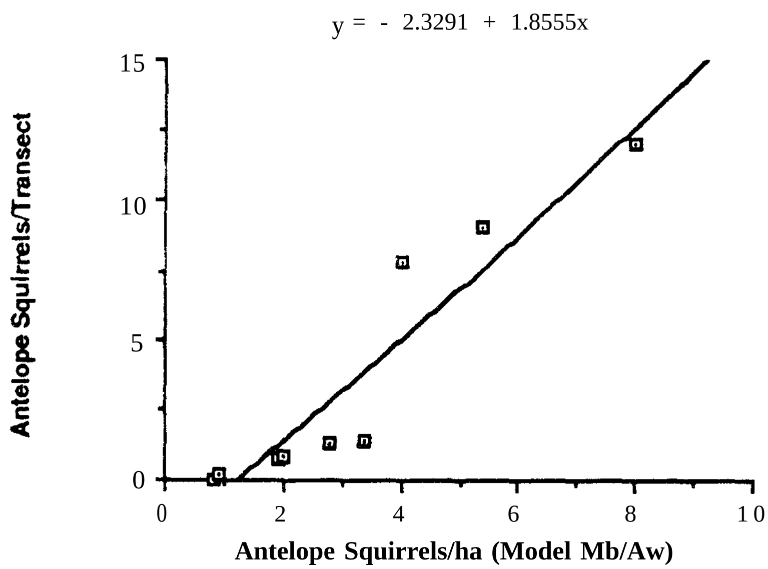

Figure 4. Relationship between population density of San Joaquin Antelope Squirrels in 1988 and 1989 and transect counts, expressed as antelope squirrels counted per kilometer of transect. For the equation shown, $r^2 = .86$. Population density is the Model M_b estimate divided by the study plot area plus the area of a boundary strip. The locations of study grids are given in Table 1, the population densities in Table 4, and the transect counts in Table 6.

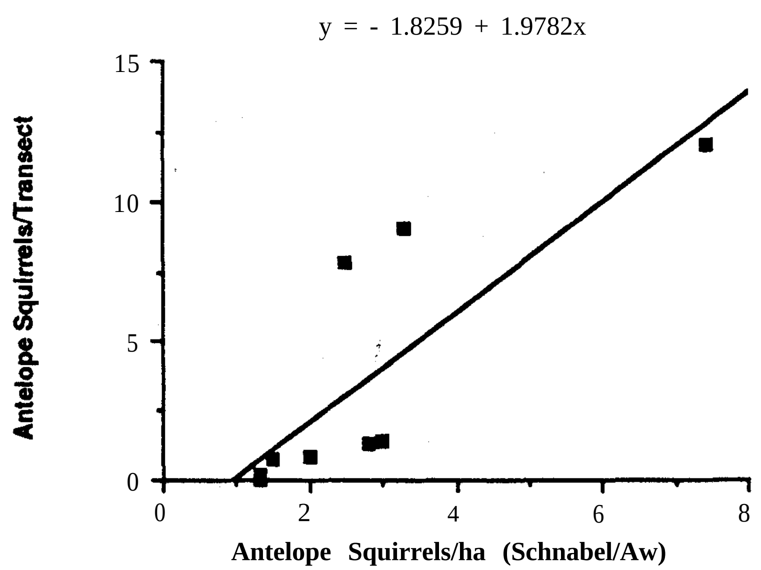

Figure 5. Relationship between population density of San Joaquin Antelope Squirrels in 1988 and 1989 and transect counts, expressed as antelope squirrels counted per kilometer of transect. For the equation shown, $r^2 = .66$. Population density is the Schnabel estimate divided by the study plot area plus the area of a boundary strip. The locations of study grids are given in Table 1, the population densities in Table 4, and the transect counts in Table 6.

have been common in perennial bunchgrass habitats without shrubs in the "pristine" Central Valley. It has also been suggested that topographic discontinuities, such as road cuts and gullys might provide alternative sources of thermal cover and opportunities for digging and burrow construction. Captures in our open study areas were not clustered around gullys, slope discontinuities or road cuts, though all were available in at least *one* of the sites. This does not preclude their use in other habitats, such as those where no kangaroo rats are present, and in fact antelope squirrels were seen along roadcuts and under water tanks in heavily grazed, barren habitats without kangaroo rat burrow systems south of our sites on the Elkhorn Plain.

Early studies of San Joaquin Antelope Squirrel habitat use (Grinnell and Dixon 1918, Hawbecker 1951, 1953, Williams 1981) pointed out that antelope squirrels tended to be found on flat to gently sloping terrain. Our experience during surveys and study site selection did not contradict these early observations. No preference for flatter areas over gentle slopes was detected within the range of slopes encountered at our study plots (slopes of 0-20 degrees). Most of the area of the plots, however, was gently sloping terrain within a range of 2-12 degrees. Steeper, rougher terrain east of the Elkhorn study plots did not appear to support many antelope squirrels. The extremely steep, highly eroded slopes surrounding the Panoche 5 study grid did not support antelope squirrels.

Valley floor sites (Paine Preserve and Semitropic Ridge) *were* more similar to each other in their overall character than to upland sites. Valley floor sites included flooded areas, as indicated by extensive low-lying regions with cracked mud and had a shrub cover of *Atriplex spinifera* and *Sueda fruticosa* (Table 7). Few antelope squirrels were found in the potentially flooded microhabitat, even in close proximity to raised mounds and levees. No antelope squirrels were seen or in nearby habitats dominated by *Allenrolfea occidentalis*, an indicator of very saline soils. At the Paine Preserve, the vast majority of captures and sightings were on raised mounds or roadside sites elevated above these periodically flooded microhabitats ($X^2 = 7.71$, $p < .01$). These results indicate that much of the *Atriplex /Sueda/Allenrolfea* scrub habitat remaining in the floor of the Central Valley may be unsuitable habitat for permanent occupation by antelope squirrels, since much of such habitat shows evidence of periodic flooding.

Interactions with California Ground Squirrels

Though not an objective of this study, we were presented with an opportunity to observe interactions between antelope squirrels and California Ground Squirrels *(Spermophilus beecheyi)*. It has been suggested that the larger, aggressive California Ground Squirrel might exclude antelope squirrels from suitable habitat (Taylor 1916). This could be an important problem for antelope squirrels, given the propensity for California Ground Squirrels to occupy habitats disturbed by human activities.

On June 3, 1989, a juvenile California Ground Squirrel was observed in our camp on the California Department of Fish and Game Elkhorn Plain Ecological Reserve, near study grid Elkhorn 2. Subsequently, another juvenile was observed in the vicinity and a third was captured south of the camp on the Elkhorn 1 study plot. These animals may have dispersed from populations located on steeper slopes east of the study region (Williams, pers. comm.). In subsequent weeks, the squirrel in camp was observed frequently. This animal occupied a burrow system within the camp area which had been occupied by a Giant Kangaroo Rat and by San Joaquin Antelope Squirrels. Both of these species were observed being displaced by California Ground Squirrels, that is, they moved away at the approach of the larger animal. Within a day of the occupation of this burrow, the California Ground Squirrel began to enlarge the burrow entrances. Later, it was seen to collect dry grass from the base of the shrubs at the burrow entrance and carry this material into the burrow system, presumably building a nest chamber underground. Antelope squirrels which had been using the area returned, dug up caches, and transported the material to other locations. In the meantime, the California Ground Squirrel located and pilfered some of this cached material. Antelope squirrels sometimes approached and sniffed the larger ground squirrel, but very little fighting or aggressive activity was observed. The typical behavior was a

Table 7. Densities of shrubs (number per 100 m^2) at selected grids at which San Joaquin Antelope Squirrels were live-trapped. Shrub counts were conducted in 1988 using the point-centered quarter method (Cottam et al., 1953). Locations of grids are given in Table 1.

Shrub Species	**Elkhorn 1**	**Elkhorn 3**	**Paine Preserve 1**	**Panoche Hills 5**
Ephedra californica	142.0	429.8		64.3
Atriplex lentiformis			119.1	
Juniper-us califomica				1.0
Eriogonum sp.	9.4	283.0		
Eastwoodia elegans	11.9	293.5		0.7
Sueda fruticosa			134.3	
Lycium andersonii	4.3			
Other	2.6	41.9		0.3
TOTAL	170.0	1,048.2	253.5	66.3

simple displacement by the larger California Ground Squirrel. By mid-July, both species were seen feeding in close proximity and lying side by side in the shade of vehicles parked at the campsite. The end result of this isolated incident seemed to be a spatial displacement from the burrow system followed by coexistence of the species without conflict. It is unlikely that the antelope squirrels, with their relatively large ranges, were adversely affected by this incident. However, the displaced Giant Kangaroo Rat, with its much smaller home range and extensive food caches, may have been severely affected. A second California Ground Squirrel was also observed within the reserve boundary. The situation with regard to California Ground Squirrels on the Elkhorn Plain Ecological Reserve obviously deserves to be followed closely in the future.

Populations of California Ground Squirrels were also observed on Nature Conservancy and private lands on and near the Paine Preserve. At the Paine Preserve itself, a small number of these squirrels occupied burrow systems along the roadside. Nearby, a larger colony was seen in an area where a single antelope squirrel was observed. For a very small antelope squirrel population occupying fragmented habitat, burrow displacement by California Ground Squirrels could be a highly significant problem. The areas occupied by antelope squirrels in the Paine Preserve area are limited in extent and are surrounded by agricultural fields and periodically flooded alkali flats. The agricultural fields were used by California Ground Squirrels for feeding, and these ground squirrels were frequently seen rushing from the fields to their burrow systems. In isolated habitat fragments such as those on the Paine Preserve, a small colony of San Joaquin Antelope Squirrels could simply be displaced out of existence by California Ground Squirrels. The population sizes for antelope squirrels are such that loss of even a few individuals to displacement by a colony of California Ground Squirrels might be critical.

Home Range and Movements

We equipped 19 San Joaquin Antelope Squirrels with radio transmitter collars. The collared squirrels included six juvenile females, five juvenile males, five adult females and three adult males. Of this group, four (all juvenile females) disappeared or lost their collars after having been located three or fewer times. These were excluded from further analysis. The home ranges and number of locations for radio-collared antelope squirrels are given in Table 8. Figures 6-8 show the minimum convex polygon home ranges of radio-collared antelope squirrels with five or more locations. Table 9 gives the home range sizes of antelope squirrels based on live-trapping alone at Elkhorn sites 1,2,4 and 5. These were based on smaller numbers of locations on average, but there was some overlap in sample size between the two methods.

The two methods used for estimating the size of an antelope squirrel's home range were the minimum convex polygon (corrected for sample size bias) and 95% ellipse. The estimates for home range of the San Joaquin Antelope Squirrel were 10.8 and 14.4 hectares, respectively. These ranges were over twice the size reported by Hawbecker (1958) of 4.46 hectares. They are also larger than our estimates based on trapping results only (see Tables 8 and 9), which compare closely to Hawbecker's estimate. Hawbecker's figure was derived on minimum convex polygon estimates, probably uncorrected for sample sizes. Unfortunately he did not give sample sizes for each antelope squirrel, but it is likely that sample size corrections would have led to a higher estimate. Our telemetry-based estimates were on the high end of the range of home range sizes reported for White-tailed Antelope Squirrels). This species' home range was reported to range from 1.4 to 9.4 hectares (Allred and Beck 1963, Bradley 1967) with an average in one study of 6.7 hectares (Allred and Beck 1963). Radiotelemetry usually results in larger estimates and better detection of exploratory movements (Kenward 1987), since the investigator can follow an animal out of a trapping grid into surrounding h.abitat.

Adult males had larger ranges (9.01 (MCP) or 13.32 (95% ellipse) hectares) than adult females (6.03 or 7.62 hectares), a typical pattern for most ground squirrels and chipmunks (Holekamp 1984). In ground-dwelling sciurids, females occupy a smaller area around the burrow system, while males tend to wander more widely, especially when searching for mates. Juveniles (Figure 8) had the largest home ranges (14.99 or 19.72 hectares), and some individuals had ranges several times greater than the

Table 8. Home ranges of San Joaquin Antelope Squirrels based on radio telemetry and mark-release trapping at Elkhorn grid 1 during the 1989 field season (location given in Table 1). Areas given are in hectares. Several home range estimates are given, with the following abbreviations: MCP = minimum convex polygon, MCPcor = minimum convex polygon corrected for sample size bias, 95% ellipse = 95% confidence ellipse. Ages are adult (A) or juvenile (J), sex is male (M) or female (F), and number of locations is N. Mean home range sizes ± one standard deviation are given for adult males, adult females and juveniles.

Animal	**Age**	**Sex**	**N**	**MCP**	**MCPcor**	**95% Ellipse**
M	A	M	27	2.87	5.33	7.11
A	A	M	6	1.36	7.95	15.76
H	A	M	24	6.95	13.76	17.10
Mean	A	M	3	3.73 ± 2.89	9.01 ± 4.31	13.32 ± 5.42
K	A	F	15	2.07	5.31	5.36
P	A	F	22	2.64	5.49	6.87
•J	A	F	21	4.74	10.13	13.10
•G	A	F	7	0.83	4.21	6.09
•L	A	F	8	1.16	5.02	6.67
Mean	A	F	5	2.29 ± 1.55	6.03 ± 2.34	7.62 ± 3.12
W	J	F	13	0.84	2.43	3.29
•R	J	F	12	4.07	12.52	19.50
•Q	J	M	11	0.74	2.45	2.53
•E	J	M	11	3.16	10.50	14.60
•W	J	M	10	4.72	16.62	30.00
••R	J	M	11	16.10	53.49	59.40
S	J	M	12	2.26	6.95	8.70
Mean	J	all	7	4.56 ± 5.31	14.99 ± 17.75	19.72 ± 19.97
Mean	all	all	15	3.63 ± 3.88	10.81 ± 12.53	14.41 ± 14.45

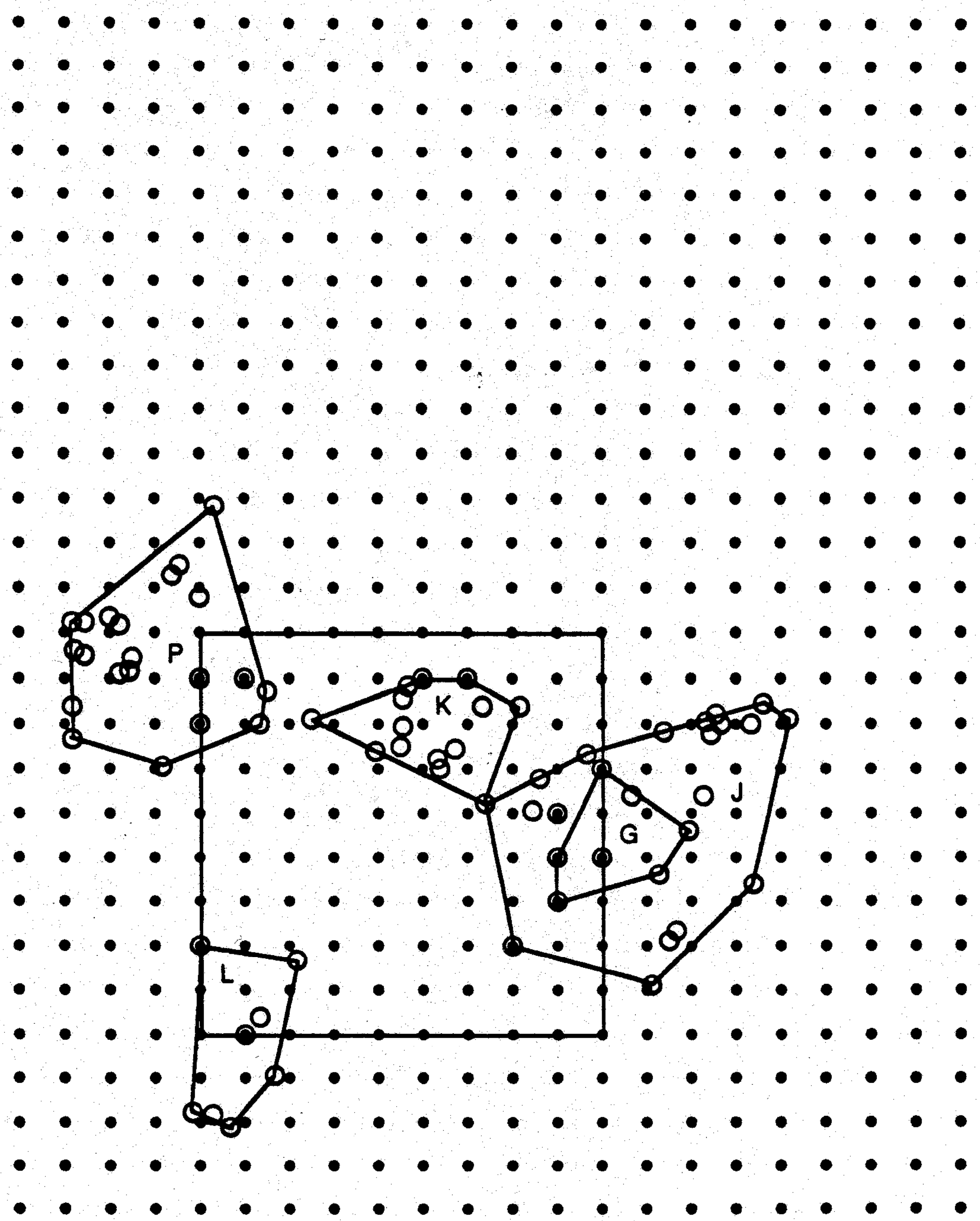

Figure 6. Minimum convex polygon home ranges of adult female San Joaquin Antelope Squirrels at the Elkhorn 1 study site. The outlined square is the boundary of the live-trapping grid. All dots are 40 meters apart, and dots on or in the study grid represent trap sites. Circles represent locations based on radio tracking or live trapping. Minimum convex polygon home range sizes are given in Table 8.

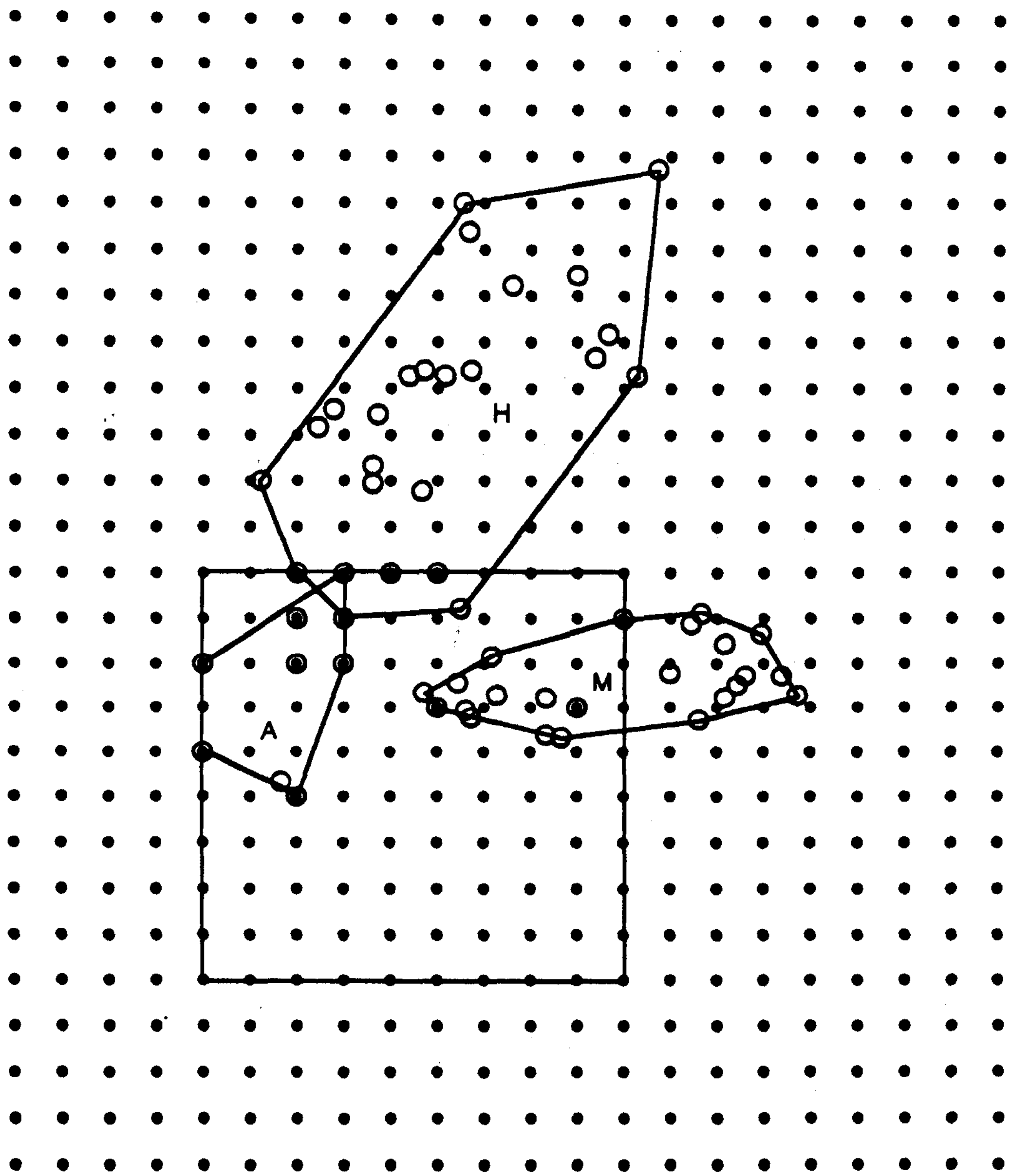

Figure 7. Minimum convex polygon home ranges of adult male San Joaquin Antelope Squirrels at the Elkhorn 1 study site. The outlined square is the boundary of the live-trapping grid. All dots are 40 meters apart, and dots on or in the study grid represent trap sites. Circles represent locations based on radio tracking or live trapping. Minimum convex polygon home range sizes are given in Table 8.

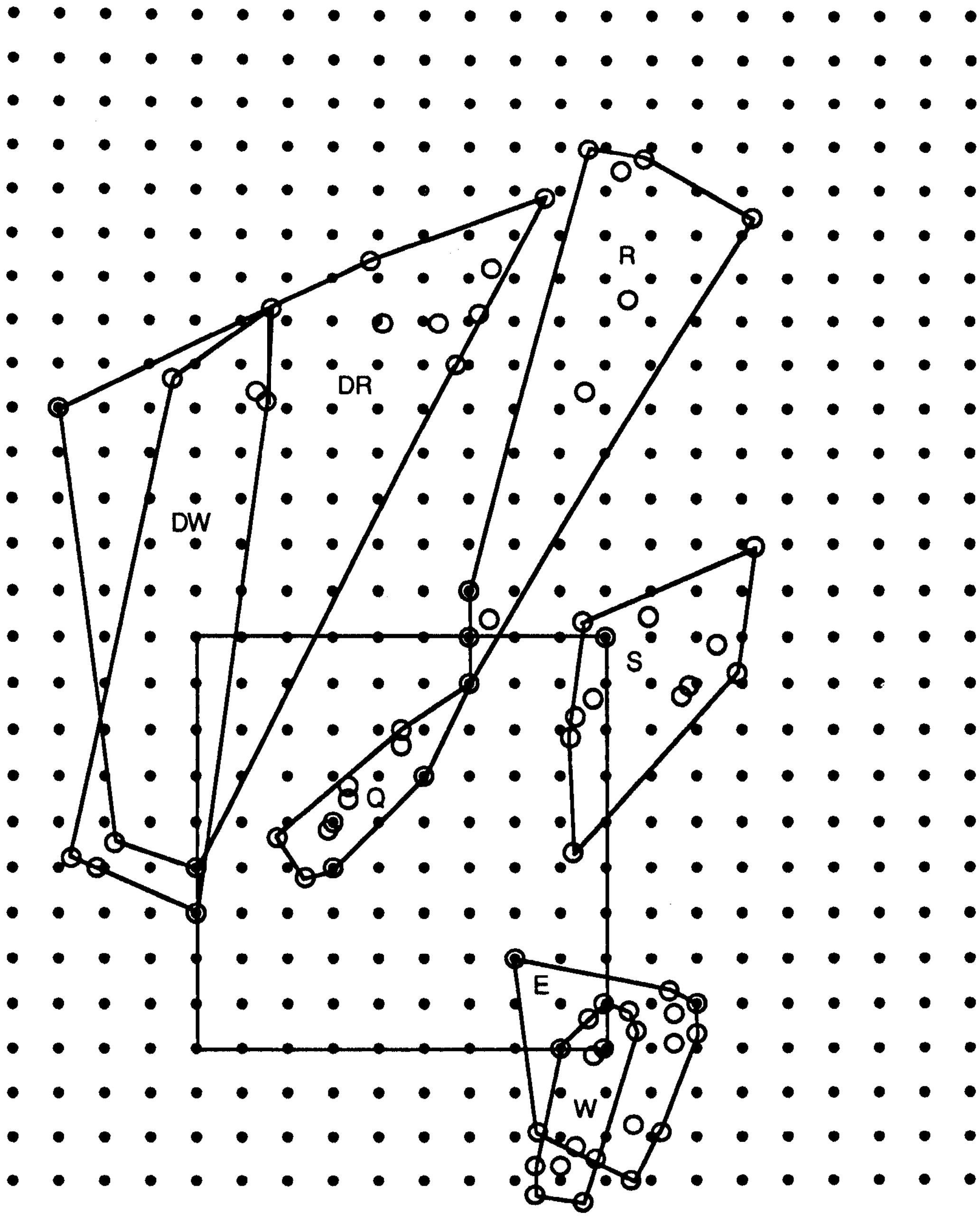

Figure 8. Minimum convex polygon home ranges of juvenile San Joaquin Antelope Squirrels at the Elkhorn 1 study site. The outlined square is the boundary of the live-trapping grid. All dots are 40 meters apart, and dots on or in the study grid represent trap sites. Circles represent locations based on radio tracking or live trapping. Minimum convex polygon home range sizes are given in Table 8.

Table 9. Home range estimates based on live-trapping data from four sites on the Elkhorn Plain. Animals included arc those trapped on Elkhorn grids number 1,2,4, and 5 (see Table 1 for legal description of locations) for which there were 5 or more trap locations and for which there were enough distinct trap locations to calculate a home range using the minimum convex polygon (MCP) or 95% ellipse models. The minimum convex polygon ranges arc also given with a correction for sample size bias (MCPcor, Jennrich and Turner 1969). Home ranges are given in hectares. The sex and age (adult or juvenile) are given as well as the number of trap locations (N). Mean home range sizes ± one standard deviation are given for each study grid.

Animal	Grid	Sex	Age	N	MCP	MCPcor	95% Ellipse
A	1	M	Ad	5	.72	5.33	11.51
C	1	F	Juv	7	.40	2.04	3.61
G	1	F	Ad	5	.24	1.78	4.68
I	1	F	Juv	6	.32	1.87	3.69
Mean	1	All	All	4	.42 ± .21	2.76 ± 1.72	5.87 ± 3.79
9	2	F	Ad	7	.66	3.37	5.51
10	2	M	Juv	7	.25	1.28	2.66
11	2	F	Juv	6	.13	.73	2.25
13	2	F	Juv	9	.50	1.95	3.34
18	2	M	Juv	5	.63	4.63	12.26
21	2	M	Juv	5	.03	.23	.73
Mean	2	All	All	6	.37 ± .27	2.03 ± 1.68	4.46 ± 4.13
2	4	M	Juv	7	.48	2.45	5.08
4	4	F	Juv	5	.16	1.19	3.04
5	4	F	Juv	10	.56	1.97	3.34
6	4	M	Juv	5	.48	3.56	10.68
9	4	F	Juv	7	.56	2.86	5.54
12	4	F	Ad	10	.32	1.13	2.03
14	4	M	Juv	11	.40	1.33	2.21
15	4	M	Juv	6	.32	1.87	4.83
18	4	F	Juv	6	.32	1.87	3.86
21	4	F	Juv	5	.24	1.78	4.80
27	4	F	Juv	7	.08	.41	1.04
33	4	M	Juv	7	.56	2.86	5.08
35	4	M	Juv	5	.48	3.56	9.36
42	4	M		7	.32	1.63	2.77
53	4	F	Ad	5	.08	.59	2.15
Mean	4	All	All	15	.36 ± .17	1.94 ± 0.97	4.39 ± 2.66
1	5	F	Ad	7	.56	2.86	4.97
4	5	M	Juv	5	.32	2.37	8.59
13	5	M	Juv	7	.48	2.45	4.21
21	5	M	Juv	7	1.12	5.71	9.40
38	5	M	Juv	6	.16	.94	1.80
45	5	M	Ad	8	.40	1.73	2.56
46	5	F	Juv	6	.24	1.40	3.12
Mean	5	All	All	7	.47 ± .32	2.49 ± 1.57	4.95 ± 2.96
Overall Mean				32	.39 ± .22	2.18 ± 1.32	4.71 ± 3.05

overall average. For example, juveniles W and DDR had 95% ellipse home ranges which were larger than the live-trapping grid on which they were captured (Table 8). Differences between age/sex classes were not significant, probably due to small sample sizes. An ANOVA of age sex classes revealed no significant differences between adult males, adult females and juveniles for minimum convex polygon ($F = 0.46$, $p = 0.64$, df = 2) or 95 percent ellipse ($F = 1.04$, $p = 0.38$, df = 2) home ranges.

Juvenile home ranges were more rectangular than those of adults (Figures 6-8); this resulted from the use of disjunct activity areas by several juveniles, particularly those with very large home ranges. Some juveniles had home ranges with a longest dimension approaching 500 m. Individuals occasionally were observed at opposite ends of their large ranges on consecutive days. Movements of individuals over distances of 100 meters while being observed were commonplace. These observations suggest exploratory movements away from the home burrow system, a pre-dispersal pattern reported for Belding Ground Squirrels, *S.beldingi* (Holekamp 1984). Antelope squirrel juveniles may move hundreds of meters in the course of pre-dispersal exploration, and it is likely that their final dispersal distance could be even longer. Antelope squirrels therefore should recolonize suitable habitat rapidly if source populations are available.

Hawbecker (1958) estimated dispersal distances for the few squirrels which he captured as juveniles, then recaptured in a later year. He found that of 18 young males, 14 were found on the same 5 hectare plot at the end of one year, but the maximum movement distances were 1281 meters for a young male and 915 meters for an adult female. The movement distances and large home ranges on our study area suggest that dispersal behavior might be different than that observed by Hawbecker. The studies are not strictly comparable, however, because of the difference in methods (trapping versus telemetry) and length of study period.

There was no indication of differences in home ranges based on live-trapping data between the oqen habitats (Elkhorn plots 4,5) and those dominated by Ephedra scrub (Elkhorn plots 1,2). An ANOVA of between-site differences revealed no significant differences between sites for minimum convex polygon ($F = 0.417$, $p = 0.742$, df = 3) or 95 percent ellipse home ranges ($F = 0.259$, $p = 0.854$, df = 3). There were insufficient numbers of frequently trapped animals to test for differences between age/sex classes at each of these sites.

Conclusions and Management Recommendations

We found that populations of San Joaquin Antelope Squirrels are isolated and have a low density on the floor of the San Joaquin Valley and in the northern part of the range, reinforcing the conclusions of Williams (198 1). Attempts should be made to acquire or protect additional lands in the northern part of the range of this species and on the valley floor. Reintroduction is a strategy for recovery of the species which would be worth attempting in areas of suitable habitat which do not currently support San Joaquin Antelope Squirrels. Reintroduction would be most valuable in the northern part of the species' range, where possible relocation sites might include the Little Panoche Wildlife Area and BLM lands in the Kettleman Hills and Panoche Hills. The Carrizo Plain macro-preserve is an ideal site for observing natural recolonization and for experimenting with reintroduction methods. Artificial burrow systems, such as those used for Giant Kangaroo Rat reintroductions (Williams, pers. comm.) would probably also be useful for San Joaquin Antelope Squirrel reintroductions.

Densities of antelope squirrels in the best remaining habitats of the southwestern portion of the range are within the limits reported for good habitat historically, although most sites are in the low end of this range: 2-5 squirrels per hectare compared to a range of 4-11 suggested by Grinnell and Dixon (1918) for prime habitat. Exceptional sites may have higher densities,but most of the area of suitable habitat within the current range of the species probably has densities lower than 1 antelope squirrel per hectare. Sites in the Central Valley are likely to have densities lower than 3 antelope squirrels per hectare, as illustrated by our Paine Preserve site, considered to be one of the better sites for this species on the floor of the valley. Poor habitat quality and habitat fragmentation are significant factors threatening the long-term persistance of this species on the valley floor. Densities at the Panoche Hills site were very low, at most about 1 antelope squirrel per hectare, and this isolated population may also be at risk in the long run.

Our largest study plots (Elkhorn 1,4 and 5 at 13 hectares each) and one of the smaller plots (Elkhorn 2 at 5.6 hectares) obtained a sufficient number of captures to obtain a reasonable estimate of abundance. Most of the smaller plots, however, were not large enough to obtain sufficient captures. Therefore we recommend that study grids of 13 hectares be considered a minimum. For very small, isolated populations, such as that at the Paine Preserve, it may not be possible to establish a large enough study grid; the populations may be too small to carry out population analyses. However, it may be possible to capture most antelope squirrels on these small plots. Comparison of the total number of animals marked for Elkhorn 3 in 1988 and 1989, Panoche 5 in 1989 and Paine 1 in 1988 (Table 3) with the estimated abundances for these plots (Table 4) reveals a close correspondence suggesting that most of the resident animals had been captured.

During a trapping period of several days, lumping captures within days for purposes of analysis significantly reduces variation due to time, individual differences in ease of trapping and behavioral responses to trapping, making a large improvement in the reliability of population estimates. Lumping captures within days is also necessary in order to achieve a minimally acceptable average capture probability (White et al. 1982 suggested that a probability of capture of at least 0.30 is minimal for reliable population estimates). Schnabel estimates are preferable to Lincoln-Peterson estimates, especially where samples are very small, because the Schnabel estimate is less likely to produce an unreasonably high population estimate when recapture rates are small (Krebs 1989). Even with large numbers of widely spaced traps, antelope squirrel densities are small enough that it will be difficult to obtain good density measures for most populations.

Transect counts are better than point-centered counts as a census technique when intensive mark-recapture efforts are not practical. Transect counts are linearly related to density measures. The following recommendations should be considered:

1. Transect censuses should be conducted within consistent times of day and year. Transect counts conducted during morning hours in late spring and early summer would be comparable to our results.
2. Observers must be careful to travel along a straight transect line, and to move at a constant rate of speed on all transect counts.
3. Attempts to refine transect censusing methods should experiment with a strip census method to reduce differences between habitats differing greatly in visibility.
4. Separate validation studies with mark-release trapping will be necessary for habitat types which differ greatly in amount of cover. Attention must be given to special habitat features (roadsides, gullies, campsites) which may affect transect counts.
5. Observer variability is a significant source of variability. Any effort expended in training or comparing observers on the same plots is worthwhile, and the number of different observers performing counts during a study should be limited.

Home ranges of antelope squirrels are larger than those previously reported for this species; adult antelope squirrels probably use an area of 10-14 hectares of habitat. Our minimum convex polygon estimated home range sizes are similar to Hawbecker's (1958) estimate of 4.46 hectares, but correcting these for sample size bias gives a larger result, as does the 95 percent ellipse method. Age/sex classes do not differ statistically in home range size, but juveniles had the largest home ranges and made more lengthy movements within their home range, probably correlated with exploratory pre-dispersal movements. Such movements could be significant in expansion of squirrels into newly restored or protected habitat.

The relations of San Joaquin antelope squirrels to other small mammal species deserve further study. Populations of Giant Kangaroo Rats may promote antelope squirrel habitat occupancy, especially in open habitats. Reintroductions at sites with and without kangaroo rats would be a valuable experiment. California Ground Squirrels may negatively affect San Joaquin Antelope Squirrels and Giant Kangaroo Rats by displacing them from burrow systems and seed caches. The effects of the California Ground Squirrel on small, fragmented populations should be investigated. A removal experiment might shed light on this relationship.

In summary, the status of the San Joaquin Antelope Squirrel in the northern portions of its range and on the floor of the San Joaquin Valley is a matter of critical concern. Remaining populations are very small and isolated, thus they may be subject to extinction due to population fluctuations due to a variety of causes, and they are vulnerable to factors which might be less severe in a larger population. Extant populations on the valley floor may be at risk due to the continued expansion of agricultural cultivation in this region. If the northern and valley floor populations of San Joaquin Antelope Squirrels were to be lost, there could be long term consequences due to the loss of genetic variation, a prospect which is impossible to evaluate at this point in time. Acquisition and protection of lands with extant populations of antelope squirrels in the Panoche and Kettleman Hills and on the San Joaquin Valley floor should be the highest priority for this species. Reintroductions of antelope squirrels could be attempted in selected sites and if successful would be a significant step toward ensuring the recovery and long term survival of the species.

The core of the remaining range of antelope squirrels contains populations with densities in the lower end of the range reported historically. The most extensive area of occupancy is the southwestern part of the species' range. The establishment of the Carrizo Plain Natural Heritage Reserve (administered jointly by the Bureau of Land Management, The Nature Conservancy, and the California Department of Fish and Game) may be important to the conservation of this Threatened species in the future. Reintroduction of antelope squirrels to restored lands on the Carrizo Plain may prove to be an important recovery strategy for the species.

Acknowledgements

Field assistants included the following students from Mills College: Lisa Christian, Miel Corbett, Ana Ferrus, Elizabeth Moore, Jeanette Moore, Marge Nelson, Kirsten Rinehart, Caroline Sidi, Heidi Struble and Danielle Stearns. Danielle Stearns and Lisa Christian assisted in data analysis and Ana Ferrus assisted in summarizing data. Advice and/or companionship in the field were provided by Dave Germano, Walter Tordoff, Ron Schlorff, Dan Williams and Sue Williams.

The manuscript was reviewed by Ron Schlorff, Dan Rosenberg and Thomas O'Farrell. Sightings of antelope squirrels or survey data were furnished by Richard Anderson and Linda Spiegel (California Energy Commission), Mark Wade (Chevron USA, Inc.), and Dennis Johnson (BLM, Hollister office). Permission to conduct surveys or trapping was provided by The Nature Conservancy, the Bureau of Land Management and Chevron USA, Inc. Support for this study was provided by the California Department of Fish and Game, Endangered Species State Income Tax Check-off Fund.

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