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SAMPLING METHODS AND TRAPPING SUCCESS TRENDS FOR THE MOHAVE GROUND SQUIRREL, *SPERMOPHILUS MOHAVENSIS*

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The Mohave ground squirrel, *Spermophilus mohavensis*, is listed as threatened by the California Fish and Game Commission. Challenges to this listing have focused on the general lack of information on this species, which prompted this review of sampling data. We found that current datasets, while a rich source of data on squirrel occurrences, are of limited use for developing Mohave ground squirrel habitat models because survey methods varied in reliability, surveys that did not find squirrels are rarely reported, and many important environmental variables were inconsistently reported. To improve the utility of future datasets, we recommend that reports attempt to include 40 variables related to trap characteristics, trapping protocol, demographic features, health information, weather parameters, and site descriptions. We also found that trapping success decreased significantly between 1980 and 2000 across most of the Mohave ground squirrel range, and this decline was not correlated with winter rainfall which generally increased between 1984 and 1998. We recommend that the results of project surveys and trapping studies should be maintained by the CDFG, allowing for future population trend analyses and development of habitat models. We also recommend that studies be initiated to determine if the decline in trapping success continues into the near future and to identify the causes of this trend.

INTRODUCTION

The Mohave ground squirrel, *Spermophilus mohavensis*, is endemic to approximately 2.0 million ha in the western Mojave Desert (Gustafson 1993[1]), constituting the smallest geographic range of the seven *Spermophilus* ground squirrels in California (based on maps in Hall 1981). The California Fish and Game Commission

[1] Gustafson, J. R. 1993. Report to the Fish and Game Commission: a status review of the Mohave ground squirrel (*Spermophilus mohavensis*). California Department of Fish and Game, Sacramento, California, USA.

designated this species as "rare" in 1971 under authority of the State Endangered Species Act of 1970, and reclassified it as "threatened" in 1985 as stipulated by the California Endangered Species Act of 1984. These designations resulted from concerns that it could become threatened with extinction if special protections were not established.

In 1991, the California Fish and Game Commission received a petition from the Kern County Department of Planning and Development Services requesting that the Mohave ground squirrel be delisted (Gustafson 1993), based in part upon the general lack of information on this species, especially its habitat requirements (SWCA 1993[2]). Most data on the Mohave ground squirrel, especially trapping data, remain relatively inaccessible in unpublished databases and reports. These unpublished data are a potentially important source of information that have not been systematically analyzed.

Because there have been no published reviews on Mohave ground squirrel studies, we feel land managers and scientists dealing with this species would benefit from a synthesis of past study methodologies and results. In this paper we 1) summarize existing data sources, focusing on sampling and reporting methodologies; 2) evaluate the utility of current datasets for developing habitat models and propose new reporting protocols that would facilitate future modeling efforts; and 3) analyze past trends in trapping success. Current data on the Mojave ground squirrel came from two sources: the California Natural Diversity Database and trapping studies. Trapping studies included both land development project surveys mandated by the California Department of Fish and Game (CDFG), and a limited number of independent biological studies. We reviewed each source of data, focusing on study methodologies, results, and utility of using the data for habitat modeling.

EXISTING SOURCES OF DATA

California Natural Diversity Database

The California Natural Diversity Database (CNDDB) is a statewide inventory of the locations and condition of California's rare and endangered plants, animals, and vegetation communities (Bittman 2001). It is a positive-sighting database, meaning that only sites were a species occurs are recorded, but not locations were a species was searched for and not found. Entries into the database are submitted to the CDFG from diverse sources, such as state and federal land management agencies, private conservation organizations, and CDFG-mandated project surveys.

The CNDDB records for the Mohave ground squirrel as of 13 February 2001 consisted of 1,353 individual detections at 264 sites between 1886 and 2000. Detection methods varied, depending on whether animals were in hand and could be closely examined or were observed from a distance. Most of these detections were of individuals that could be examined closely after collection by trapping (72%), roadkill

[2] SWCA, Incorporated. 1993. Status evaluation of the Mohave ground squirrel. SWCA, Incorporated, Flagstaff, Arizona, USA.

(0.8%), or shooting (0.3%) (Fig. 1a). Other less reliable detections occurred by visual (10%), auditory (0.1%), or unreported methods (16.9%).

Although most individuals were detected by trapping (Fig. 1a), most sites with Mohave ground squirrels present were identified using less reliable methods such as visual, auditory, or unreported methods (55%; Fig. 1b). Only 45% of Mohave ground squirrel sites were identified using highly reliable methods (e.g., trapping, roadkill, or shooting) alone or with other methods. Sites with the most detections were those where intensive trapping studies produced multiple detections per sampling period distributed over two or more periods. In addition, 49% of Mohave ground squirrel sites were

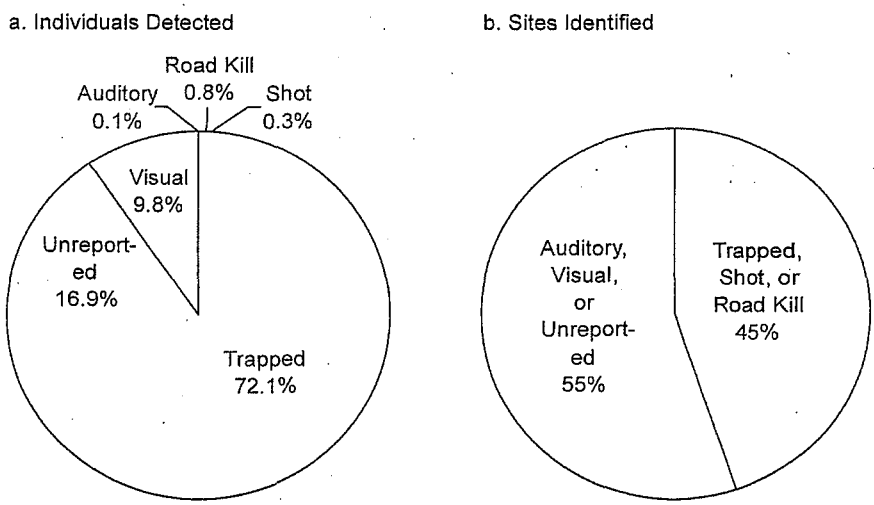

Fig. 1. Methods used to detect individual Mohave ground squirrels (a) and identify sites occupied by Mohave ground squirrels (b), from records between 1886 and 2000 in the California Natural Diversity Database.

identified from single detections.

Trapping Studies

The Mohave ground squirrel has statutory protection as a threatened species in California. Legislation requires the CDFG to ensure that land conversion actions do not adversely affect the species within its historical range . Such actions include residential and commercial development and the construction and maintenance of highways and utility infrastructure. Surveys are required to determine the presence or absence of Mohave ground squirrels on affected sites and mitigation is required if individuals are detected. Standard guidelines specify that a visual survey be conducted initially and, if no squirrels are detected, that a 5-day trapping survey be conducted between 21 March and 31 May, using a standard 4 × 25 grid of Sherman live traps (

23 cm long) spaced 25 m apart (more details on the survey protocol are available from the CDFG). The CDFG requires any person conducting these surveys to obtain a Memorandum of Understanding (MOU) authorizing the work. As conditions of the MOU, surveyors must submit a description of the project site to the CNDDB and report information about capture results when Mohave ground squirrels are found. Surveyors are not required to report variables such as habitat quality or demographic data.

We summarized the variables reported in 19 Mohave ground squirrel trapping studies (Grinnell and Dixon 1918[3], Hoyt 1972[4], Recht 1977[5], Wessman 1977[6], Zembal

[3] Grinnell, J., and J. Dixon. 1918. Natural history of the ground squirrels of California. Monthly Bulletin of the State Commission on Horticulture 7:597-708.

[4] Hoyt, D. F. 1972. Mohave ground squirrel survey, 1972. California Department of Fish and Game, Los Angeles, California, USA.

[5] Recht, M. A. 1977. The biology of the Mohave ground squirrel, *Spermophilus mohavensis*; home range, daily activity, foraging and weight gain and thermoregulatory behavior. Dissertation, University of California, Los Angeles, California, USA.

[6] Wessman, E. V. 1977. The distribution and habitat preferences of the Mohave ground squirrel in the southeastern portion of its range. California Department of Fish and Game, Sacramento, California, USA.

[7] Zembal, R., C. Gall, D. Kruska, and P. Lobnitz. 1979. An inventory of the vascular plants and small mammals of the Coso Hot Springs Area of Inyo County, California. China Naval Weapons Center, China Lake, California, USA.

[8] Leitner, P. 1980. Report IV - survey of small mammals and carnivores in the Coso Geothermal Study Area. Pages 17-46 *in* unknown editors. Field ecology technical report of the Coso Geothermal Study Area, in support of Coso Geothermal Development Environmental Statement. Rockwell International, Newbury Park, California, USA.

[9] Aardahl, J. B., and P. Roush. 1985. Distribution, relative density, habitat preference, and seasonal activity levels of the Mohave ground squirrel (*Spermophilus mohavensis*) and antelope ground squirrel (*Ammospermophilus leucurus*) in the western Mojave Desert, California. U.S. Department of Interior, Bureau of Land Management, USA.

[10] ERT. 1987. Biological baseline information for the Mohave ground squirrel and other wildlife at the Luz Solar Electric Generating Systems, Kramer Junction, California. ERT, Newbury Park, California, USA.

[11] Michael Brandman Associates, Incorporated. 1988. Phase one: China Lake Naval Weapons Center Mohave ground squirrel survey and management plan. Michael Brandman Associates, Incorporated, Santa Ana, California, USA.

[12] ERC Environmental and Energy Services Company. 1989. Biological survey report of the Gravity Wave Observatory Site, Edwards Air Force Base. ERC, San Diego, California, USA.

et al. 1979[7], Leitner 1980[8], Aardahl and Roush 1985[9], ERT 1987[10], Michael Brandman Associates 1988[11], ERC Environmental and Energy Services Co. 1989[12], Laabs and Allaback 1991[13], Rempel and Clark 1991[14], Recht 1994[15], Recht 1995a[16], Recht 1995b[17], Scarry et al. 1996[18], Leitner 1998[19], Leitner and Leitner 1998[20], Leitner 2001[21]). These reports were identified after an extensive survey of land managers, researchers, and environmental consultants familiar with the Mohave ground squirrel. Most of these studies were project surveys required by the CDFG, while a few were independent biological studies. Only two of these studies were published in widely available scientific periodicals: Grinnell and Dixon (1918) and the Zembal et al. (1979) report summarized in Zembal and Gall (1980). The other 17 studies were described in unpublished reports that were difficult to identify and obtain because they did not show up in standard literature searches.

We identified 40 variables that are important to consider when synthesizing the results of Mohave ground squirrel trapping studies. These variables relate to trap characteristics, trapping protocols, demographic information, health information, weather parameters, and site descriptions. The reporting frequencies varied widely

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[13] Laabs, D., and M. Allaback. 1991. Mohave ground squirrel study, El Mirage Cooperative Management Area, San Bernardino County, California. Biosearch Wildlife Surveys, Santa Cruz, California, USA.

[14] Rempel, R. D., and D. J. Clark. 1991. 1990 Indian Wells Valley Mohave ground squirrel survey, interim report. California Department of Fish and Game, Fresno, California, USA.

[15] Recht, M. A. 1994. Final report: small mammal surveys of selected sites at the National Training Center, Fort Irwin, California. The Nature Conservancy, San Francisco, California, USA.

[16] Recht, M. A. 1995a. Final report: 1994 small mammal surveys of selected sites at the National Training Center, Fort Irwin, California. Robert D. Niehaus, Incorporated, Santa Barbara, California, USA.

[17] Recht, M. A. 1995b. 1995 small mammal surveys of selected sites at the National Training Center, Fort Irwin, California. Pages 1-31 *in* unknown editors. Unknown report title. Dominguez Hills Corporation, Carson, California, USA.

[18] Scarry, P. L., P. Leitner, and B. M. Leitner. 1996. Mohave ground squirrel study in the West Mojave Coordinated Management Plan Core Reserves, Kern and San Bernardino Counties, May-June 1994 and April-May 1995. Cal Poly Pomona Foundation, Incorporated, Pomona, California, USA.

[19] Leitner, P. 1998. High desert power plant natural gas supply pipeline: Mohave ground squirrel survey. Phillip Leitner, Orinda, California, USA.

[20] Leitner, P., and B. M. Leitner. 1998. Coso grazing exclosure monitoring study: Mohave ground squirrel study, Coso Known Geothermal Resource Area, major findings, 1988-1996, final report. Phillip Leitner, Orinda, California, USA.

[21] Leitner, P. 2001. California Energy Commission and Desert Tortoise Preserve Committee, Mohave ground squirrel study, final report for 1998-1999. Phillip Leitner, Orinda, California, USA.

Table 1. Important variables to consider when synthesizing results of Mohave ground squirrel trapping studies, and their frequency of reporting among the 19 studies analyzed.

	Count	%[a]		Count	%
Trap characteristics			Demographic information		
Type	19	100	Sex	15	79
Cleaning	0	0	Age class	13	68
History of use	0	0	Reproductive status	8	42
Trapping protocol			Body mass	11	58
Shelter	15	79	Health indicators		
Trapping dates	19	100	Pelage condition	0	0
Time opened	15	79	Condition of eyes	0	0
Time closed	15	79	Condition of nose	0	0
Time checked	16	84	Trauma	0	0
Days trapped	17	89	Behavior condition	0	0
Trapping intervals	17	89	Weather parameters		
Bait type	18	95	Temperature	2	11
Bait amount	0	0	Wind	1	5
Pre-baiting	6	32	Cloud cover	1	5
Years trapped	17	89	Rainfall	1	5
Time caught	6	32	Site description		
Array dimensions	18	95	Location	13	68
Array number	18	95	Topography	7	37
Trap spacing	17	89	Elevation	10	53
Traps per array	17	89	Slope/aspect	6	32
			Soil type	9	47
			Vegetation cover	7	35
			Vegetation species	9	47
			Land-use history	4	21

[a]percentage of 19 trapping studies

among these variables, and 20% were not reported in any of the 19 trapping studies we analyzed (Table 1).

Many of these variables are easy to quantify and should be included in future reports to facilitate efforts to synthesize the results of multiple trapping studies. For example, potentially important information on the animal species previously collected in the traps and on the history of trap cleaning was never reported. Mammals rely strongly on olfactory communication (Vaughan 1986) and individuals may leave pheromones in urine and feces voided while inside traps. This could possibly affect the behavior of others subsequently approaching the traps. Extensive descriptions of trapping protocol were included in most reports. However, the times of day at which animals were caught and the amount of bait used were, respectively, rarely or never reported. Demographic information, which was reported for most studies, should be included in all reports, considering the ease with which it can be recorded and its importance in population viability analyses. Indicators of general health were not

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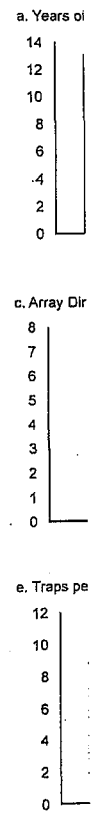

Fig. 2. I
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reported for any of the past studies, but basic health variables should be noted in the future because disease may be a significant threat to uncommon species with limited ranges. Weather conditions were not documented for most of the studies, even though animal activity levels and the frequency of trap encounters may vary widely due to weather. Site descriptions were lacking in several categories, most notably physical characteristics of the landscape, soils, and vegetation. Although human impact is a primary reason for this species being protected, only 21% of the reports described land-use history at trapping sites.

Most trapping studies were conducted for only 1 year (Fig. 2a), which provides relatively little information for a small mammal species that can fluctuate greatly in numbers among years. Multi-year studies spanning periods of contrasting rainfall are

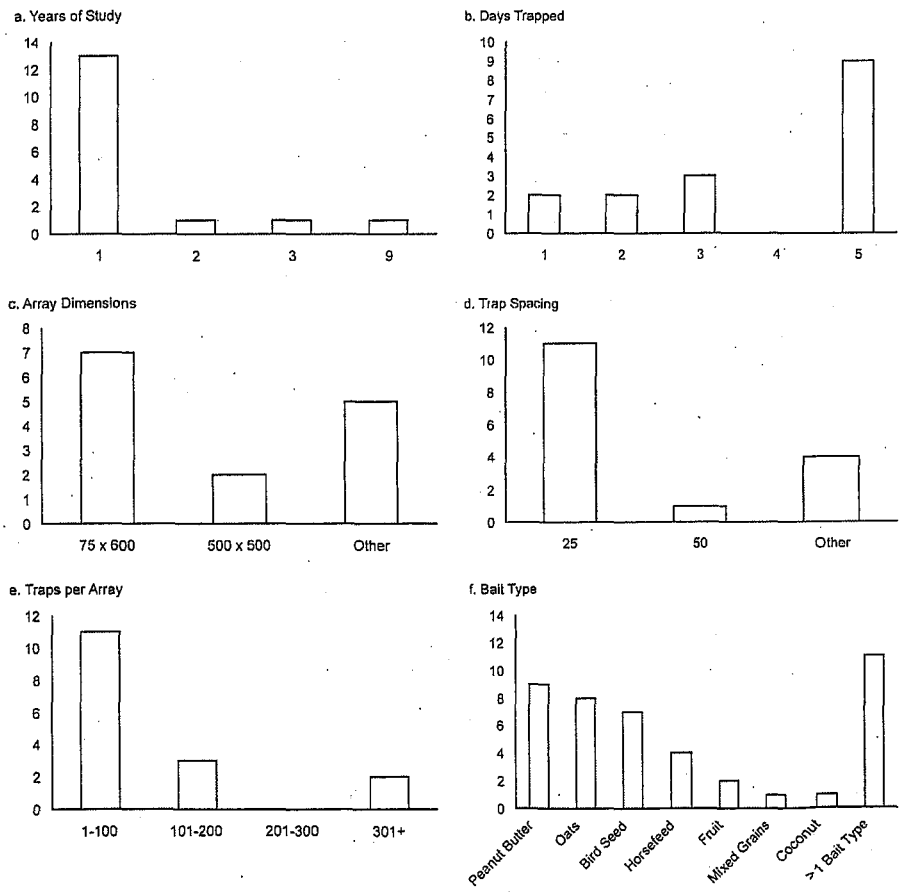

Fig. 2. Reporting frequency of selected trapping variables among 19 Mohave ground squirrel trapping studies. Sample size varied among variables and was always <19 because none of the variables were reported in all of the studies.

needed for many reasons, not the least of which is to identify possible core areas or refuge habitats where populations may persist during drought years. Most trapping was done for multiple days (Fig. 2b), which is appropriate protocol for small mammal studies (Thompson et al. 1998). Trapping array dimensions varied considerably among these studies (Fig. 2c), although the trap spacing (Fig. 2d) and the number of traps per array (Fig. 2e) were relatively consistent. The types of bait used also varied widely (Fig. 2f), and in many cases baits were a mixture of many types.

DEVELOPING HABITAT MODELS

The CNDDB is a rich source of occurrence data for the Mohave ground squirrel. Reported occurrences are spatially referenced within the database, so sites could be readily cross-referenced with other spatially-explicit environmental databases, such as vegetation, soils, topography, and climate. Moreover, site records, especially more recent ones, do list various environmental attributes associated with the site, which would facilitate habitat modeling. However, because the CNDDB is only a positive-sighting database, valid habitat modeling could not be accomplished by using this data alone. Because areas where squirrels were searched for but not found are not recorded in the database, a CNDDB-based habitat model could not conclusively rule out the environmental ranges where the squirrel does not occur. Supplementing the CNDDB database with past or present trapping studies that document no squirrels could be used to overcome this problem.

Trapping studies are also an important data source for habitat modeling, but inconsistent reporting makes valid modeling difficult. Ecological characteristics of the sites were either unreported or were incompletely or inconsistently reported, and all were of unknown accuracy. These sites could be revisited to collect more detailed environmental data, but inconsistent precision in reporting site locations and potential changes in habitat and Mohave ground squirrel populations since the original study limit the feasibility and validity of this approach. Other limitations include non-random selection of survey sites (which are biased toward roads and project locations), infrequent documentation of sites where individuals were not found, and frequent absence of information on life history characteristics and population densities at the detection sites. Future surveys must be more thorough if the data is to be used for habitat modeling.

TRAPPING SUCCESS TRENDS

While presently available data cannot readily be used for habitat modeling, changes in trapping success over time can be used to infer general population trends. Trapping success rates were calculated as the number of individuals captured per 100 trap-days using data reported in the 19 trapping studies mentioned previously. These studies contained trapping data from multiple sites and years. Some studies had several sites within close proximity of each other (1-2 miles). During some years these

clustered sites comprised the majority of sites sampled, resulting in a regional bias in the sampling intensity for that year. To minimize this bias, we combined these clustered sites prior to analyses. This pooling condensed 220 raw data points (sites within year) into 178. Most of the pooled data came from three studies: 31 trapping sites combined into 4 sampling points for data reported in Rempel and Clark (1991), 22 sites into 18 points in data from Aardahl and Rousch (1985), and 15 sites into 8 points from data in Zembal et al. (1979). Three other studies (Wessman 1977, ERT 1987, and Labs and Allaback 1991) had between one and two sites combined each. We performed analyses on both pooled and unpooled data and found no differences in the statistical significance of the results, so we only report statistics from the pooled data. Some studies also reported data from multiple trapping intervals at each site within a given year, which we averaged over the intervals to generate a single data point for that year. Trends in trapping success were evaluated using Spearman rank-order (r_s) correlations, and correlations were only reported if $P \leq 0.05$. We did not attempt to apply parametric statistical models because trapping success data were strongly skewed toward zero values and not normally distributed (Shapiro-Wilk test, $W = 0.71$, $P < 0.0001$).

A total of 178 trapping success values was generated for individual sites during separate years between 1972 and 2000. Samples were clustered in the Coso geothermal region in the northwest part of the range ($n = 54$), and the rest were spread out mostly south of Inyo County, California ($n = 124$; Fig. 3). Overall trapping success averaged 0.82 individuals/100 trap-days, but 35% of the values were 0 and only 13% were >2.

Trends in trapping success differed between sites in the Coso region and sites scattered throughout the rest of the range. At Coso, overall trapping success was 1.15 ± 1.30 SD individuals/100 trap-days. The averages were similar in 1978-1979 (1.50 ± 1.44) and 1987-2000 (1.01 ± 1.23), and trapping success was not significantly correlated with year (Fig. 4). At the non-Coso sites, trapping success averaged 0.67 individuals/100 trap-days, but the rates of success differed between 1972-1977 (0.42 ± 0.89), 1980 (2.04 ± 1.84), and 1987-2000 (0.46 ± 0.72). Although the overall correlation between trapping success and year at non-Coso sites was not significant, success was correlated with year when the 19 sampling sites that were located outside of the Mohave ground squirrel range (Fig. 3) were excluded from analysis ($r_s = -0.25$, $n = 105$). These 19 sites were sampled in 1977 in an attempt to delineate the southeastern boundary of the species range (Wessman 1977), so it is not surprising that Mohave ground squirrels were not found at any of them.

There was an especially strong decline in trapping success from 1980 through 2000 ($r_s = -0.60$, $n = 75$) at the non-Coso sites. Of the variables listed in Table 1, only trap spacing ($r_s = 0.49$, $n = 29$) and the number of days trapped per trapping period ($r_s = 0.48$, $n = 29$) were also significantly correlated with year. However, these variables were not correlated directly with trapping success, and there is no apparent reason why increased trap spacing or number of days trapped should cause a decline in trapping success. Thus, the recent decline in trapping success does not seem to have been associated with systematic changes in the trapping methods that we analyzed.

Fluctuations in rainfall can have significant effects on the abundance of small

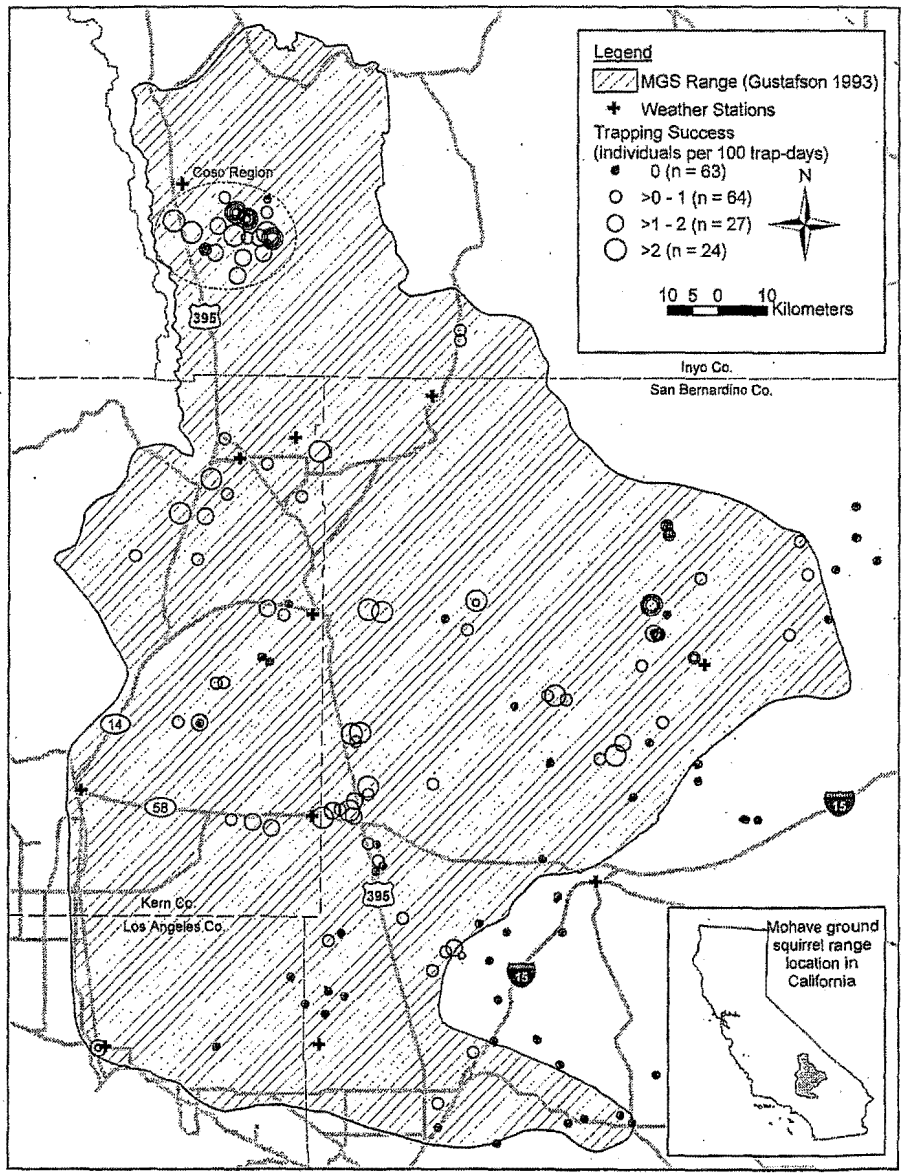

Fig. 3. Locations for 178 trapping success measurements calculated from 19 trapping studies and the 11 NOAA weather stations reported in Fig. 4.

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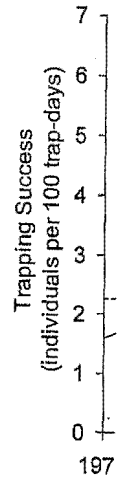
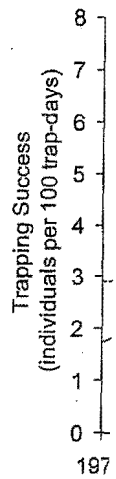


b. Non-Cos



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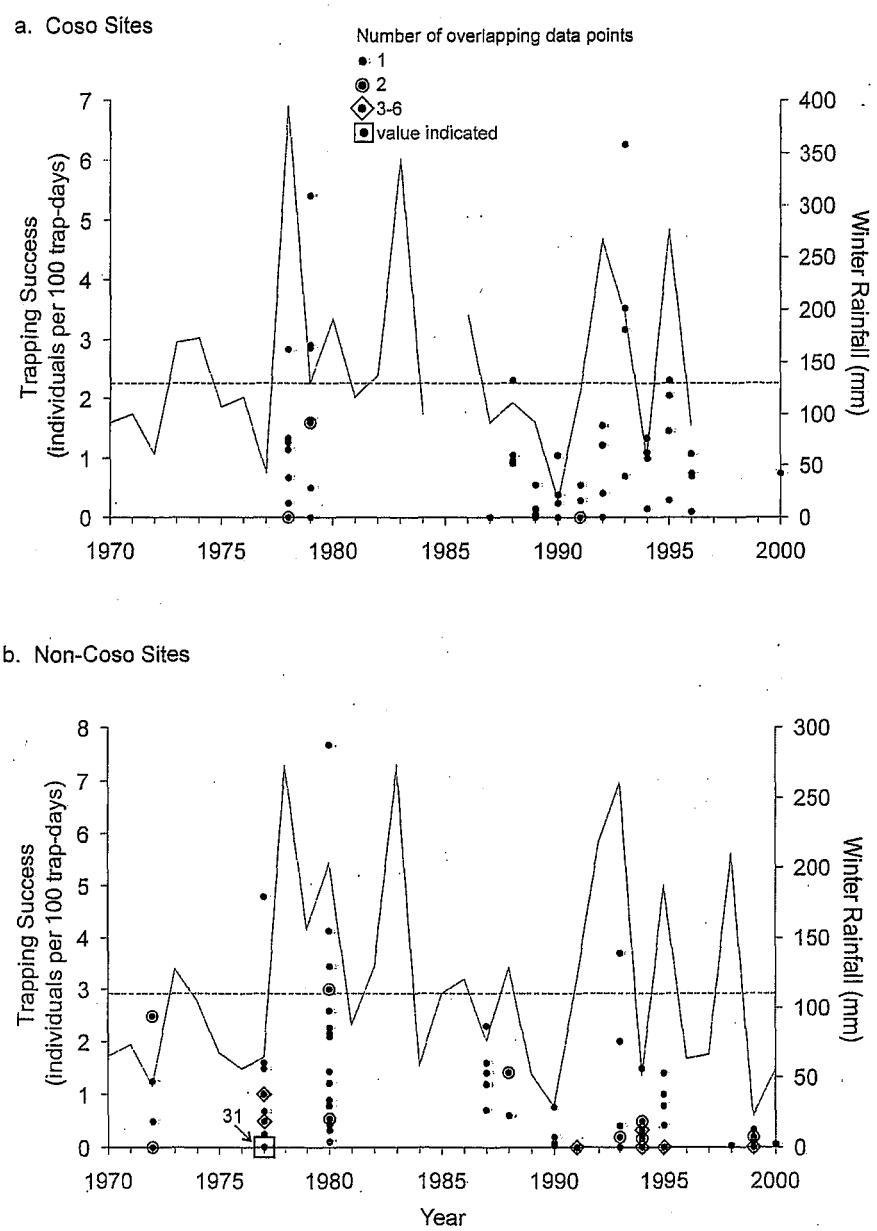

Fig. 4. Trapping success (scatter plot) and total winter rainfall from October through March (line plot) between 1970 and 2000 for the Coso region (a) and sites located in rest of the Mohave ground squirrel range (b). Winter rainfall estimated using data from 1 NOAA weather station for Coso data (Haiwee, 1985 data missing) and 10 additional stations for non-Coso data (Barstow, Boron, China Lake NAF, El Mirage, Goldstone Echo No 2, Inyokern, Mojave, Palmdale, Randsburg, and Trona; http://www.ncdc.noaa.gov). Long-term average winter rainfall is identified on each graph as a horizontal dashed line.

mammals such as the Mohave ground squirrel (Gustafson 1993), and trapping success was positively correlated with winter rainfall (October-March) from the current (r_s = 0.38, n = 178) and previous (r_s = 0.29, n = 178) year. However, multi-year trends between trapping success and winter rainfall varied between the first and last decades of our data set. The period from 1970-1977 had particularly low rainfall, and 1978 marked the end of a 36-year period of relatively low rainfall in the Mojave Desert (Hereford 2000[22]), so is it not surprising that trapping success in 1972 and 1977 was relatively low. Similarly, it is not surprising that increased rainfall beginning in 1978 was followed by increased trapping success during 1980, and decreased rainfall beginning from 1984-1991 was followed by decreased trapping success in 1987, 1988, 1990, and 1991. However, the cycle back from low rainfall in the mid-1980's to high rainfall in the 1990's was not followed by increased trapping success as would be expected. Thus, trapping success has declined across most of the Mohave ground squirrel range since the mid-1980's, and this decline was not associated with decreased rainfall.

Recent attempts to locate populations for new studies have been hampered by low trapping success, even during a period in which winter rainfall was adequate for reproduction and survival (Leitner 2001) and at sites where Mohave ground squirrels were previously abundant from the mid-1970's through the early-1980's. The results of others (Leitner 2001), coupled with the decreased trapping success since the mid-1980's that was summarized here, have heightened concerns that the Mohave ground squirrel may be undergoing a long-term decline in abundance.

MANAGEMENT RECOMMENDATIONS

Reporting to the CNDDB, and to the CDFG for project surveys, should include detailed descriptions of habitat and life history parameters of the Mohave ground squirrels. Trapping studies should include descriptions of trap characteristics, trapping protocol, demographic and health information for the animals captured, weather conditions, and site characteristics listed in Table 1. Results of project surveys and trapping studies should be maintained by CDFG in a database, separate from the CNDDB, for future population trend analyses and development of habitat models. New survey methods should be evaluated to search for study populations and, in the process of searching, generate additional data for a CDFG database. Studies should be initiated to verify that the observed decline in trapping success is due to an actual decline in the abundance of the Mohave ground squirrel, to determine if this trend continues into the future, and to identify the causes of this decline.

[22] Hereford, R. 2000. Past and future climate variation in the Mojave Desert, surface processes and land management issue. Oral presentation at the Desert Tortoise Council Symposium, Las Vegas, Nevada, USA.

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