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DISTRIBUTION AND ASPECTS OF THE NATURAL HISTORY OF STEPHENS' KANGAROO RAT (*DIPODOMYS STEPHENSI*) ON THE WARNER RANCH, SAN DIEGO CO., CALIFORNIA

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Abstract.—*Dipodomys stephensi* occupies 4,600 ha of grassland on the Warner Ranch near Lake Henshaw, San Diego Co., California. Distribution is restricted to Bull Trail and Mottsville series soils. Abundance is positively related to the proportion of annual forbs to grasses. Dispersion is patchy; each locus consists of a well-developed network of trails connecting burrow openings. A subterranean network of tunnels, 21 to 23 cm deep, mirrors the surface trail network, providing ready access to all portions of an individual's range without direct exposure to aerial predation. Surface activity appears concentrated along trails and cleared aprons around burrow entrances. Trap success is negatively influenced by heavy rainfall and subsequent high plant productivity. Trapping is an unreliable method of assessing presence or absence, which may significantly affect management considerations of this state-listed threatened species.

Introduction

Stephens' kangaroo rat (*Dipodomys stephensi* Merriam) currently is listed as threatened by the California Fish and Game Commission and occupies a restricted range in northern San Diego Co., western Riverside Co., and a small portion of southwestern San Bernardino Co. (Bleich, 1977; O'Farrell *et al.,* 1986). This species appears adapted for open grasslands or areas with sparse shrub cover. These latter areas generally represent narrow ecotones between dense chaparral or sage scrub and grassland and may represent marginal habitat for both *D. stephensi* and the shrubland adapted congener, *D. agilis.* Although various reports cite sympatry (Grinnell, 1923; Lackey, 1967; Thomas, 1975), Lackey documented that sympatry was uncommon and showed that distribution was primarily contiguously allopatric. The distribution within the known range consists of scattered, disjunct populations. Many locations appear suitable but harbor no *D. stephensi.* A lack of knowledge concerning habitat requirements may account for this discrepancy. Most of the potential past corridors between these populations have been significantly altered by urban and agricultural development. Similarly, many of the previously known population locations no longer support *D. stephensi* because of human encroachment (Thomas, 1975; O'Farrell and Uptain, unpublished data).

With the advent of stringent federal, state, and municipal legislation and the official categorization as "threatened," *D. stephensi* receives nominal protection. Activities within the known range containing potentially suitable habitat require a survey to assess presence or absence. If present, some type of mitigation is required to minimize adverse impacts to the species. Therefore it is critical to determine presence accurately.

Bleich (1977) summarized ecological and behavioral knowledge of *D. stephensi*. Published observations are virtually limited to statements verifying the propensity of this species for open grassland habitat. The most detailed accounts were unpublished theses that dealt with general rodent assemblages in relation to habitat type (Bleich, 1973; Bontrager, 1973) or ecological aspects of distribution and dispersion (Thomas, 1975). Recently, a major new population on the Warner Ranch, San Diego Co., was documented at the site of a proposed solar energy development (O'Farrell *et al.*, 1986). After documenting the presence of this species, a study was begun to determine valley-wide distribution and abundance. During the course of this investigation we discovered a variable response to traps that could seriously impair the successful completion of future studies on the species in general.

The purpose of this report is to document the distribution and to examine the mosaic of abundance of *D. stephensi* on the Warner Ranch. An attempt was made to establish the relationships between occurrence and abundance with vegetation and soil features. Certain noteworthy aspects of spatial use and behavioral response to traps are also reported.

Study Area

The study area was on the Warner Ranch, adjacent to Lake Henshaw, San Diego Co., California (T10S, T11S and R2E, R3E, SBBM). The area, a broad valley, consists of about 5,100 ha of rolling grassland from 823 to 975 m elevation. The higher elevations are occupied by chaparral, coastal sage scrub, and oak woodland habitats. Four drainages cross portions of the valley: Matagual Creek, Buena Vista Creek, Agua Caliente Creek, and the San Luis Rey River. Riparian and oak woodland habitats occur in the higher elevations along the drainages. The majority of the lowlands and the border surrounding Lake Henshaw contain saltgrass and rush vegetation. Cattle grazing predominates throughout the grassland although currently there are four areas in the lowlands containing clay bearing soils; areas used for agricultural crops. Within the grassland, dominant annual species are wild oat (*Avena fatua*), brome grasses (*Bromus diandrus, B. mollis, B. rubens*), fescues (*Festuca grayi, F. megalura*), barley (*Hordeum leporinum*), dove weed (*Eremocarpus setigerus*), filarees (*Erodium botrys, E. cicutarium*), and vinegar weed (*Trichostema lanceolatum*). Dominant perennials are triple-awned grass

Table 1. Monthly precipitation (cm) for the period of study, the preceding decade, and the 72-year mean for comparison. Data are from a weather station at Lake Henshaw Dam and provided by Vista Irrigation District.

Month	1973–1982 Mean	1983	1984	72-Year mean
Jan	18.2	11.2	0.5	12.7
Feb	16.9	21.0	0.5	13.7
Mar	27.8	35.3	0.5	12.5
Apr	4.4	12.6	3.7	6.3
May	2.0	0.5	0	2.1
Jun	0.1	0	0	0.2
Jul	1.3	0	5.6	0.6
Aug	1.7	7.1	6.4	1.2
Sep	2.5	1.5	2.8	1.1
Oct	2.3	3.7	1.9	2.5
Nov	5.9	11.8	6.7	5.5
Dec	7.4	15.5	25.9	10.9
Total	90.3	120.3	54.4	69.2

(*Aristida* sp.), and dropseed (*Sporobolus airoides*). (Nomenclature follows Munz, 1974).

The valley grassland occurs predominately on Bull Trail and Mottsville soil series with some scattered patches of Chino series (USDA, 1973). Bull Trail soils are the most abundant and are well-drained sandy loams with a sandy clay subsoil. Mottsville soils are excessively drained, very deep loamy coarse sands. Chino soils are found in low wet areas near drainages and are well-drained, fine sandy loams with a light clay loam subsoil. Drainages contain Tujunga series soils composed of very deep, excessively drained sands. Shallow soils of the Tollhouse and LaPosta series occur generally above 975 m elevation and contain chaparral and coastal sage scrub vegetation.

The climate on the Warner Ranch is mild with a distinct wet season. Mean maximum temperatures range from 34.2°C in summer to 13.5°C in winter. Mean minimum temperatures range from 12.7°C in summer to −2.3°C in winter. The wettest months extend from December through March and the arid months from June through September (Table 1). A significant wet cycle has predominated from 1973 through the first year of our investigations.

Materials and Methods

Topographic maps of the valley were delineated in 1.6 km sections and a preliminary field reconnaissance conducted to determine which sections contained potential habitat. The steep hillsides surrounding the valley containing dense chaparral and oak woodland as well as riparian drainages and active agriculture fields were excluded as potential habitat. A total of 12 sections were examined by transect. Each section contained two transects 1.6 km long and 0.2 km wide, yielding 20% coverage. One transect was situated randomly and the other was placed parallel to it at a distance of 0.8 km. Whenever possible, each pair of transects was alternated north–south and east–west to ensure an adequate sampling of topographic, vegetative, and soil features. In addition, a 100% walk-over was performed on a 100 ha proposed facility site in the southern portion of the valley, containing plant Transect 4, and a similar-sized pocket of grassland in the north near Puerta La Cruz.

Transects were walked from 14 through 18 November 1983 by four observers equally spaced along the corridor width. Field maps were constructed which included information on the presence of kangaroo rat burrows and runways, assignment of relative abundance (high, medium, low), and vegetation composition. Soil samples were randomly collected in each of the areas of relative abundance.

Within the grassland, six locations were selected for detailed quantification of habitat features and *D. stephensi* abundance. One plot was a high abundance area, two were medium, two were low, and one contained no sign of the species (see Fig. 1 for locations). A trapping configuration, modified from O'Farrell *et al.* (1977), of two 20-station long parallel lines placed 53 m apart and with 15 m trap spacing was established on each location. On each trapping plot, two 50 m plant transects were performed between 14 and 18 November 1983. A 2 by 3 dm frame was used at 2 m intervals to obtain a count of all identifiable plants. Cover was determined by the line intercept method (Canfield, 1941) for a 1 dm section at 2 m intervals. Height of standing litter was taken at 2 m intervals. A soil sample was taken randomly on each 50 m line. All soil samples were dried to constant weight, processed through a graduated nest of soil sieves for particle size distribution. Clay content was determined by the hydrometer method (Buoyoucos, 1936).

All active kangaroo rat burrows were counted within a 10 m swath along each side of the 50 m transects yielding 1,000 m^2. Holes free of detritus and spider webs were judged active. One medium abundance area, Plot 2, contained loose soil heavily worked by kangaroo rats and gophers. It was impossible to distinguish active burrows of the former species among such surface clutter.

Four burrow systems were excavated, accurately measured, and mapped in November and December 1983 while the ground was moist. In June 1984, a detailed map was prepared of surface artifacts including burrow entrances, runways, and dusting areas. A 50 by 50 m area, representing moderate *D.*

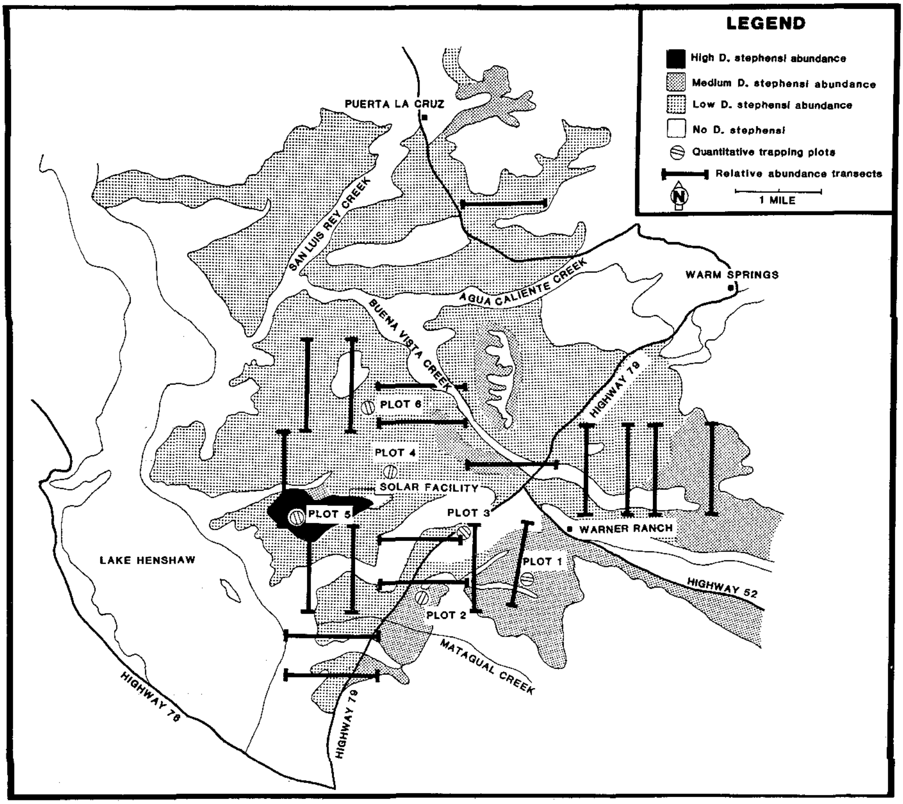

Figure 1. Distribution and abundance mosaic of *Dipodomys stephensi* on the Warner Ranch adjacent to Lake Henshaw, San Diego Co., California.

stephensi abundance based upon surface sign, was demarcated in 2-m squares using metal spikes and twine. The entire area was drawn to scale on metric graph paper.

Portions of the valley were sampled by live trapping from April 1983 to February 1985 at varying intervals but restricted to the new moon phase. Initially, the proposed 97-ha solar facility site was sampled by placing 300 live traps on inventory lines set ca. 300 m apart and with ca. 20 m between traps. A 12 by 12 station grid with 8 assessment lines (O'Farrell *et al.,* 1977), using 15 m trap spacing, was established on the proposed mirror field. A second identical grid was established 1.5 km north of the first and sampled for two trapping sets. It was replaced by two parallel line configurations, identical to the 6 plots described previously and each containing 4 assessment lines, situated contiguous to the western and northern borders of the mirror field. After initial poor trap success it became standard practice to monitor

Table 2. Select habitat measurements for different levels of *Dipodomys stephensi* relative abundance (RA) on the Warner Ranch. Density of grass and forbs = #/3 m^2; G/F = proportion of grass to forbs; Veg. ht. = mean vegetation height; Bare = percent bare ground; Holes = mean number of active burrows/1,000 m^2.

		Annuals			Perennials		Veg.		
Plot	RA	Grass	Forbs	G/F	G	F	ht.	Bare	Holes
3	None	182,930	935	195.6	11	5	8.9	22.9	0
4	Low	44,358	644	68.9	4	0	11.5	15.0	10.5
6	Low	42,996	2,218	19.4	57	0	11.7	5.5	9.5
2	Medium	151,029	1,921	78.6	0	0	16.7	2.1	NC*
1	Medium	699	2,548	0.3	0	0	20.5	7.8	64.0
5	High	3,628	1,780	2.0	4	0	3.3	41.7	80.5

* No hole count possible.

trap response by selectively placing 80 traps adjacent to active kangaroo rat burrows along a 1 km section of dirt road that crossed the northern portion of the project site. Sherman collapsible live traps baited with crimped oats were used throughout, although one experiment was tried using combinations of oats with bacon grease and oats with vanilla extract. Much of the trapping effort was devoted to detailing the effect of construction and initial operation of a solar power facility on *D. stephensi.* This study will be reported elsewhere but is summarized here for the purpose of describing a variable response to traps associated with season and vegetation conditions.

Results

Distribution.—Dipodomys stephensi was distributed throughout the grassland with areas of greatest relative abundance occurring in the southern portion of the valley and in a border strip on some foothills (Fig. 1). The areas of various relative abundance did not represent even distribution of the species, but rather a mosaic of patches of occurrence. These irregularly shaped patches ranged from 0.1 ha to over 20 ha of evenly distributed kangaroo rat burrows and trails. Interstices were equally variable in size. The species was not found in agriculture fields, salt grass and rush, or floodplains and active drainages.

The timing of microhabitat quantification in late November 1983 coincided with heavy rains (Table 1). Vegetation was responding to the rain, yielding high density counts (Table 2); it should be stressed that these numbers represent seedlings. Several trends are apparent with respect to certain habitat features and relative abundance categories. The proportion of annual grass to forbs is inversely related to relative abundance ($r = -.76, p < .10 > .05$). During the walking transects, we noted a trend in increasing numbers

Table 3. Soil particle size distribution from randomly selected sites and six specifically selected locations representing different relative abundances of *Dipodomys stephensi* on the Warner Ranch. Gravel = >2 mm; Sand = <2 >0.05 mm; Silt = <0.05 mm >2 μ; Clay = <2 μ.

Plot	Relative abundance	Gravel	Sand	Silt	Clay
—	None	11.3	84.5	4.2	0.5
3	None	11.0	84.5	3.6	0.5
—	Low	8.4	83.3	7.7	0.9
4	Low	12.5	84.0	3.3	0.3
6	Low	8.5	83.0	8.0	1.0
—	Medium	12.0	81.5	6.1	0.9
1	Medium	8.5	87.0	4.2	0.4
2	Medium	11.5	83.0	5.2	0.4
5	High	7.0	87.0	4.5	1.1

of perennial grasses in the northern portion of the valley (see Fig. 1 for plot placement). The percentage of bare ground is greatest on the high abundance area and consisted mainly of kangaroo rat trails and cleared aprons around burrow complexes. Bare ground was prominent on the plot where no kangaroo rat sign was found. Absence of kangaroo rats at this site may be misleading; bare ground consisted of mounds of dirt resulting from gopher activity.

The dispersion of *D. stephensi* on the Warner Ranch was superimposed on a detailed soil map. Occurrence was limited to Bull Trail and Mottsville series soils. Relative abundance was examined in relation to particle size distribution but no significant trends were identified (Table 3). Soil variability within the grassland was slight. The main descriptive characters are large sand content and minuscule clay content.

Within the valley portion of the Warner Ranch there is an estimated 5,100 ha of grassland. Approximately 4,600 ha of the grassland is currently occupied by *D. stephensi*; 75% of this area was rated as low abundance, 23.2% medium abundance, and 1.8% high abundance.

Burrows.—The patchiness in distribution of burrows has been described above. However, dirt roads throughout the grassland appeared to contain a significant concentration of burrows. This roadside distribution was also patchy although the number of active holes was greater next to the road. For example, the sample plot, 50 m on a side and used for burrow and runway mapping, contained 117 active burrows; 21% of these were within 4 m of the road edge (8% of the area surveyed). Extensive areas of *D. stephensi* occupation were found far removed from roadways. A dependence on roadways cannot be suggested. However, when *D. stephensi* are found along a road, burrowing activity is concentrated near the road edge.

The burrow mapping plot was chosen because it appeared representative of moderate abundance areas we encountered during the walking transects. Within this area burrows were generally solitary (>1 m from the nearest hole), although there was some clustering into burrow complexes. Of the 79 burrows or burrow complexes recorded, 81% were solitary, 10% contained 2 holes, and 5% contained 3 holes. Single complexes of 4, 6, and 9 holes also were found. Burrows and complexes tended to be situated close together (55% < 3 m), whereas 12% exceeded 10 m. Well-worn trails interconnect the various burrows and cleared aprons surround most burrows and all complexes. Cleared areas, many without holes, also occur at the intersection of major trails. These areas appear to be used as sand bathing loci.

Most of the surface activity of *D. stephensi* appears to be restricted to runways, burrow aprons and dusting areas. A total of 57 digging sites were found on the burrow mapping plot. These sites represented discernible surface activity besides trails and aprons. Only 5 sites were greater than 1 m from a runway or cleared apron; maximum distance was 2.5 m.

Each of the four burrow systems excavated appeared to be actively used, yet none contained a nest chamber. We could not reach the end of the system because there was always at least a single tunnel leading to another surface opening. Tunnel entrances descend almost vertically from the surface to a depth of ca. 21 cm; the tunnel maintains a relatively constant depth, 21 to 23 cm. All long, interconnecting surface runways had a corresponding tunnel directly beneath it, including runway irregularities such as shallow curves and sharp bends. Burrow complexes that contained multiple surface entrances demonstrated a subterranean connection between all holes and occasionally blind passages were found. Some of these side tunnels were filled loosely with soil and debris and one contained seeds and stems. Only one excavation contained multilevel tunnels. Beneath a cluster of holes a single tunnel descended to about 0.5 m; several short tunnels radiated out at this depth.

Trap response.—For the duration of the study, trapping was conducted for three different purposes: 1) to document presence of *D. stephensi* using inventory lines; 2) to obtain density and biomass estimations using grids and parallel line configurations; 3) to assess shifts in trap success using saturation trapping on monitor lines. Each trapping protocol differed somewhat in the intensity with which an area was sampled but the variations in trap success with respect to the effects of precipitation and associated seasonal changes in habitat features are instructive. The results presented below are only for *D. stephensi. Peromyscus maniculatus* was captured on the project site thoughout the study and were trappable when the kangaroo rat was not.

Table 4. Trapping results for *Dipodomys stephensi* (number of captures/trap night) on the Warner Ranch in 1983 and 1984. See text for a detailed description of the trapping protocols.

Date	#/Trap night	Trapping protocol
18–19 April 1983	3/600	Inventory lines
6–11 June 1983	2/1,728	Grids
26–27 July 1983	0/80	Monitor lines
30–31 August 1983	25/160	Monitor lines
7–12 September 1983	34/1,248	Grid—parallel lines
2–7 December 1983	6/1,440	Parallel lines
27 March 1984	0/80	Monitor lines
30 April 1984	0/80	Monitor lines
29 May 1984	8/80	Monitor lines
30 May–6 June 1984	73/1,472	Grid—parallel lines
23–28 February 1985	129/1,312	Grid—parallel lines

Trap success was below 1% during periods of great vegetative productivity (Table 4). In spring 1983, vegetation on the Warner Ranch was lush as a result of months of heavy precipitation (see Table 1). *Erodium* spp. were robust, covering large tracts of the study area with 100% ground cover and a profile of 30 to 40 cm in height. Cover was so dense that after three intensive walkover surveys and negative trap results, the eastern portion of the study site was judged uninhabited by *D. stephensi.* By mid-summer the annual forbs had disarticulated, resulting in large patches of bare ground. This loss of cover resulted in identifying occupation of the eastern portion by *D. stephensi* in moderate abundance.

In an attempt to compensate for the natural abundance of food resources in June, we felt that aromatic baits might attract kangaroo rats to the traps. Therefore, 10 separate clusters of burrows that showed fresh signs of activity were selected to test the efficacy of aromatic baits. Three live traps were placed at each cluster; one trap contained crimped oats, one crimped oats coated with bacon grease, and the third crimped oats coated with vanilla extract. These traps were checked for three consecutive nights but no animals were captured.

By the end of summer, vegetation was dried and forbs disintegrated, although discrete patches of dove weed and vinegar weed were scattered throughout the valley. Kangaroo rat surface activity was most apparent as evidenced by surface diggings, mounds of "worked" plant duff near burrow entrances, and by visual observations while driving the dirt roads at night. Trap success increased dramatically, 15.6%, at this time (Table 4).

Above-average precipitation in October, November, and December 1983 resulted in heavy germination and seedling growth (see Tables 1 and 2).

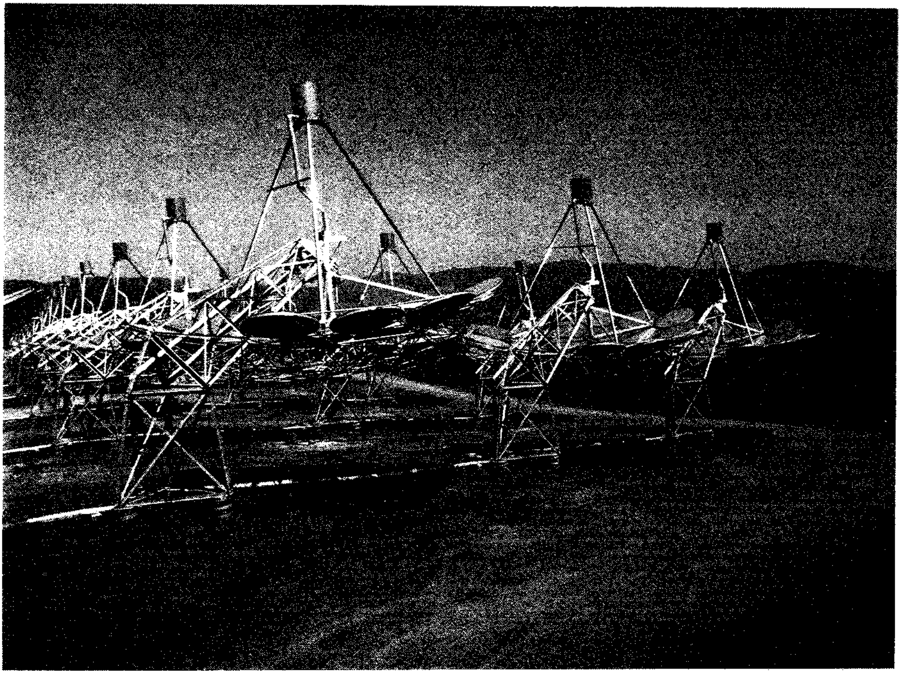

Figure 2. A corner of the solar mirror field illustrating the alternating rows of towers and cleared roadways. The adjacent grassland shows the lack of aerial cover.

Signs of surface activity were much reduced from those of late summer; trap success dropped below 1% again.

Drought conditions prevailed during the first half of 1984. Plant production was reduced from the previous year. Even with dry conditions trap success was negative. By May 1984 success was 10%. The remaining trapping effort was focused on the mirror field and adjacent control plots. In June 1984 and February 1985 trap success was good on the mirror field and poor in the open grassland. In the latter habitat only about half the traps near active burrows or runways yielded kangaroo rats. Assessment line trapping further illustrates the positive influence of the mirror field on trap response. About 80 of the 160 assessment line traps for the grid were situated outside the mirror field in open grassland. However, 25 *D. stephensi* were captured in the mirror field and 9 captures were recorded in the grassland.

The mirror field is ca. 12 ha of frame towers arranged in a grid (Fig. 2). Rows of towers are spaced 15 m apart and receive light vehicular traffic for maintenance purposes; each tower is 12 m apart along each row. The entire structure approximates 9 m in height. Heated fluids are transported through raised insulated pipes that lie along the rows. This arrangement has resulted in a 4 to 5 m belt of relatively undisturbed vegetation along rows as well as the establishment of considerable cover in the form of man-made vertical clutter. *D. stephensi* have established many burrows at the base of tower footings and pipelines, similar to burrow placement of other kangaroo rat species around the base of shrubs in desert scrub habitats.

Discussion

Kangaroo rats seem specifically adapted for open habitat with virtually no ground cover, presumably linked with the characteristic bipedal saltatory mode of locomotion (Bartholomew and Caswell, 1951). These authors proposed that this anatomical adaptation was of selective advantage in predator avoidance. Reichman and Oberstein (1977) demonstrated that rapid bipedal locomotion is also of advantage in obtaining sparse, clumped seed resources. If an individual can reduce surface foraging time by rapidly locating large seed clumps, it would follow that risk of predation is also reduced. This would be particularly important in sparsely covered habitats. The significance of bare ground to locomotion also is apparent from the results of Reynolds (1958), which showed an inverse relationship between kangaroo rat density and the density of perennial grasses.

Although most arid habitats display the "smooth-surfaced, sparsely vegetated" substrate necessary for kangaroo rats (Bartholomew and Caswell, 1951) there are still scattered shrubs providing aerial cover. This component may range from 5 to 40% (Beatley, 1974), thus providing substantial protection from predation. Although kangaroo rats are adapted for foraging in the open (Reichman and Oberstein, 1977), alertness and the ability to immediately achieve rapid, erratic motion would enable these animals to take advantage of existing aerial cover. They certainly use such cover in moonlight conditions (Price *et al.*, 1983). Thompson (1982) gives compelling evidence that although kangaroo rats frequently move across open spaces, more than 75% of the foraging effort is beneath shrub canopies.

The above generalizations hold for kangaroo rats throughout their geographic range with the notable exceptions of three chaparral adapted species (*D. agilis, D. venustus, D. elephantinus*), and *D. stephensi* and three species within the San Joaquin Valley of California (*D. ingens, D. californicus,* and *D. heermanni*). The latter four species inhabit annual grasslands with little or no permanent aerial cover. It would seem that specialized characteristics must be present in these species in order to compensate for lack of cover.

Although *D. stephensi* has been captured in certain coastal sage scrub situations, it is primarily associated with open grassland (see Bleich, 1977, for a review). The present study corroborates this finding and suggests that, based on burrow specializations, the species probably evolved in habitats devoid of shrubs. Within the grassland on the Warner Ranch, distribution was limited to Bull Trail and Mottsville series soils. Abundance was strongly related to a high proportion of annual forbs to grasses.

We estimate conservatively a valley-wide population of about 14,000 *D. stephensi*. This estimate reflects the following categorization of relative abundance: low < 5 individuals/ha; medium 5 to 10/ha; high > 10/ha. Density estimates obtained during impact assessment on solar facility construction were used to generate the categorization. We believe the Warner Ranch population represents the largest continuous stand of *D. stephensi* extant.

Our trapping results indicate that trap response in *D. stephensi* was profoundly affected by vegetative productivity and possibly time of the year. Grinnell (1932) found that *D. ingens* appeared to ignore grain baits when fresh green vegetation was available in late February. Trap success in the present study was virtually nonexistent during peak vegetative growth when total ground cover and a distinct vertical profile occurred. The productivity resulting from heavy precipitation in spring 1983 accounted for heavy ground cover and abundant food into early summer after most of the vegetation had dried. When most of the annual forbs had disintegrated and areas occupied by kangaroo rats were relatively bare, trap success increased dramatically. *D. stephensi* has difficulty in moving about when surface vegetation is thick and there would be little incentive to deviate from existing runways when food resources are abundant.

The lack of trap response in winter appeared to be associated with several factors. The quantity of the preceding season's growth was at a minimum and the availability of abundant seedlings was promoted by heavy rains. Increased exposure to predation due to lack of cover and readily-obtained food may account for the dearth of surface activity noted in December. This pattern of restricted surface movements was also evident at the end of March. By the end of April, trap response was nil but increased surface activity was evident; several months of drought conditions may have accelerated this behavior. Certainly, the greater trap success experienced in May–June 1984 than in the previous year was due to the ramifications of the drought. Trap-shyness would manifest itself by lack of captures, but some signs of exploratory behavior should be present. No signs of animals encountering and exploring open traps were evident at this time. Surface activity appeared to be confined to the entrance apron or to runways; movement along runways showed no signs of slow, exploratory movements. This would be expected with a paucity of aerial cover.

An examination of rainfall with respect to preceding studies of *D. stephensi* provides an interesting perspective. Although rainfall should differ somewhat from Lake Henshaw, regional patterns would be similar; therefore, we use annual precipitation values from Lake Henshaw below as an indicator of rainfall conditions during previous studies. Lackey (1967) obtained *D. stephensi* from December 1962 through March 1967 with most sampling occurring in summer months. All those years had below average rainfall except for 1965 (51.44, 57.25, 58.34, 94.18, 59.23, 67.41 cm respectively; see Table 1). He states that where practical, animals were collected using insect dip nets which proved to be more productive than live traps. The remaining studies occurred between October 1971 and October 1973 (Bleich, 1973; Bontrager, 1973; Thomas, 1975). All 3 years had below average precipitation which probably aided trap success (53.21, 37.13, 65.66 cm respectively; see Table 1). We submit that these studies would have been negatively biased with respect to *D. stephensi* had they taken place after the wet cycle beginning with 1978.

In marginal habitats containing shrubs, trap response may not be as adversely affected for much of the year simply because of aerial cover. The difference in trap response in May–June 1984 and February 1985 (Table 4) supports this notion. Half the assessment line traps were within the mirror field and the other half in undisturbed grassland, yet about three times more *D. stephensi* captures occurred within the mirror field. It was also obvious while walking the lines that we were not catching as many animals as were apparent from surface signs of activity.

Kangaroo rats using cleared trails in a grassland would have an advantage over predators by being able to move with maximum speed and agility to any one of several refuge holes. Trails would also be critical for movement when the spring vegetation is at a peak. The presence of a subterranean counterpart to the trail network suggests a mechanism for reducing surface exposure to aerial predation when forb cover has disappeared. Tappe (1941) indicated *D. heermanni* spent only 1 h above ground each day and that moonlight would curtail this activity; we speculate the same reduced surface activity for *D. stephensi*. Lack of aerial cover appears responsible for the restrictive behavior of grassland kangaroo rats. Increased trap response after the addition of considerable aerial cover (in the form of the mirror field) supports this contention. Schwartz and Bleich (1985) found that *D. stephensi* formed 13.9% of prey items in pellets of Common Barn-Owls (*Tyto alba*). Owls were abundant on the Warner Ranch. At times more owls than kangaroo rats were sighted on night drives, suggesting considerable pressure from aerial predators.

Many questions have been raised during the present investigation concerning above and below ground time budgets and intraspecific social structure. It is obvious that conventional trapping methods are not effective during some portions of the year, and are further affected by rainfall and subsequent vegetative productivity. One immediate concern relates to the threatened status of *D. stephensi* and its protection. Based on standard trapping inventories, many areas of potential habitat do not seem to support the species. In some instances, housing subdivisions and other forms of permanent habitat loss are allowed because one or two nights of sampling fail to yield captures. From a management standpoint, agencies and investigators need to exercise caution when designing and evaluating results of studies on this species. The broader view would indicate that the same caveat would apply to other grassland species of kangaroo rats. Comparative studies of these species to determine how the lack of cover is effectively handled are warranted.

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Literature Cited

Bartholomew, G. A., and H. H. Caswell. 1951. Locomotion in kangaroo rats and its adaptive significance. Journal of Mammalogy, 32:155–169.

Beatley, J. C. 1974. Effects of rainfall and temperature on the distribution and behavior of *Larrea tridentata* (creosote bush) in the Mojave Desert of Nevada. Ecology, 55:245–261.

Bleich, V. C. 1973. Ecology of rodents at the United States Naval Weapons Station Seal Beach, Fallbrook Annex, San Diego County, California. Unpublished M.A. thesis, California State Univ., Long Beach. 102 pp.

———. 1977. Dipodomys stephensi. Mammalian Species, 73:1–3

Bontrager, D. R. 1973. Rodent ecology of the Santa Rosa Plateau, Riverside County, California. Unpublished M.A. thesis, California State Univ., Long Beach. 115 pp.

Buoyoucos, G. J. 1936. Directions for making mechanical analysis of soils by the hydrometer method. Soil Science, 42:225–228.

Canfield, R. 1941. Application of the line interception method in sampling range vegetation. Journal of Forestry, 39:388–394.

Grinnell, J. 1923. The burrowing rodents of California as agents in soil formation. Journal of Mammalogy, 4:137–149.

———. 1932. Habitat relations of the giant kangaroo rat. Journal of Mammalogy, 13:305–320.

Lackey, J. A. 1967. Biosystematics of *Heermanni* group kangaroo rats in southern California. Transactions of the San Diego Society of Natural History, 14:313–344.

Munz, P. A. 1974. A flora of southern California. University of California Press, Berkeley. 1,086 pp.

O'Farrell, M. J., S. M. Juarez, and C. E. Uptain. 1986. A new addition to the known range of Stephens' kangaroo rat (*Dipodomys stephensi*) in San Diego County. California Fish and Game, 72:187–189.

O'Farrell, M. J., D. W. Kaufman, and D. W. Lundahl. 1977. Use of live trapping with the assessment line method for density estimation. Journal of Mammalogy, 58:575–582.

Price, M. V., N. M. Waser, and T. A. Bass. 1983. Effects of moonlight on microhabitat use by desert rodents. Journal of Mammalogy, 65:353–356.

Reichman, O. J., and D. Oberstein. 1977. Selection of seed distribution types by *Dipodomys merriami* and *Perognathus amplus*. Ecology, 58:636–643.

Reynolds, H. G. 1958. The ecology of the Merriam kangaroo rat (*Dipodomys merriami* Mearns) on the grazing lands of southern Arizona. Ecological Monographs, 28:111–127.

Schwartz, O. A., and V. C. Bleich. 1985. Optimal foraging in Barn Owls? Rodent frequencies in diet and fauna. Bulletin of the Southern California Academy of Science, 84:41–45.

Tappe, D. T. 1941. Natural history of the Tulare kangaroo rat. Journal of Mammalogy, 22: 117–148.

Thomas, J. R. 1975. Distribution, population densities, and home range requirements of the Stephens kangaroo rat (*Dipodomys stephensi*). Unpublished M.A. thesis, California State Polytechnic Univ., Pomona. 64 pp.

Thompson, S. D. 1982. Microhabitat utilization and foraging behavior of bipedal and quadrupedal heteromyid rodents. Ecology, 63:1303–1312.

U.S. Department of Agriculture (USDA). 1973. Soil survey, San Diego County, California. Soil Conservation Service and Forest Service. 2 volumes + maps.

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