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Studies of *Cordylanthus palmatus* at the Springtown Alkali Sink Livermore, California

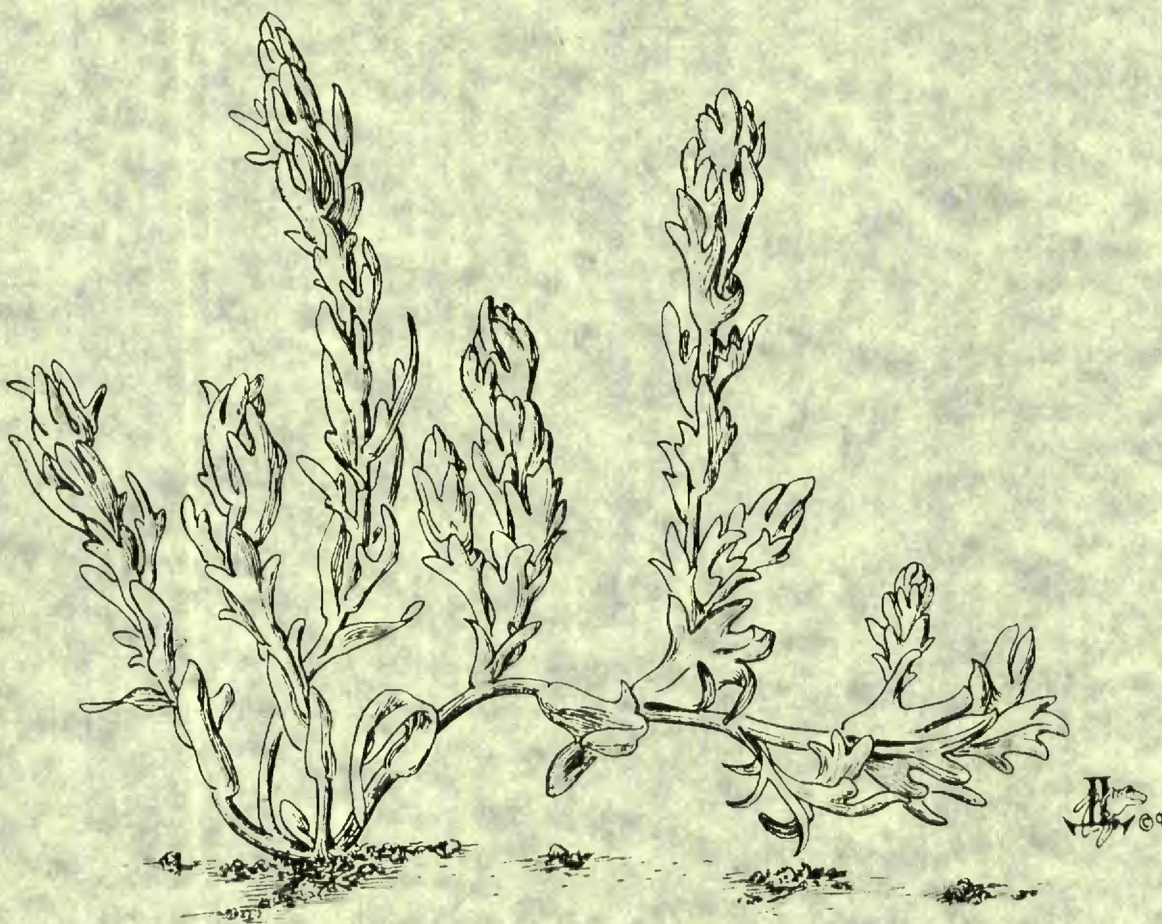

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Table of Contents

List of figures and tables

Introduction

In the summer of 1990, the Center for Conservation Biology began research on the Springtown Alkali Sink in Livermore, California toward the conservation and management of the federally- and state-listed endangered plant, palmate-bracted bird's beak (*Cordylanthus palmatus*). This work was done under contract with the California Department of Fish and Game's Endangered Plant Program.

This report summarizes the work conducted under this contract (including more than 70 site visits and 800 person-hours in the field), presents an interpretation of data and observations, and outlines further research toward the conservation of this species.

Importantly, these data provide the first quantitative measurements of *Cordylanthus palmatus* distribution. This information on the distribution and abundance of plants at Springtown, together with population monitoring data and life history information, form the basis of a study to identify and protect the species' alkali sink scrub habitat.

Study System

Life history of *Cordylanthus palmatus*

The palmate-bracted bird's beak is a federally- and state-listed endangered annual plant in the genus *Cordylanthus*, a small group of hemiparasitic plant species in the family Scrophulariaceae (the figwort family). Although members of the genus are found across much of the western United States and Mexico, the palmate-bracted bird's beak, *Cordylanthus palmatus* (Ferris 1918) MacBride (1919), is restricted to central California. The species is also known as Ferris' bird's beak (see Figure 1).

Figure 1. *Cordylanthus palmatus* in the field. Note the salt crystals on the leaves.

The plant was described by Ferris in 1918, who designated the species *Adenostegia palmata* (Ferris 1918). Following a 1919 revision of the genus by MacBride, the species was placed in the genus *Cordylanthus*. Divisions within this genus were debated for some time; *Cordylanthus mollis* and *C. palmatus* were lumped together by Mason (1957), who saw the group including these two species as an "exceedingly variable complex...in an active state of speciation, with minor habitat races becoming evident. Of these, *Cordylanthus palmatus* represents one extreme and *Cordylanthus mollis* another." Chuang and Heckard revised the genus again in 1973 and formally differentiated between *Cordylanthus palmatus* and *C. mollis* (Chuang and Heckard 1973).

Members of the *Cordylanthus* genus are characterized by yellow roots, alternate leaves, and inner floral bracts that are modified into calyx-like structures (Heckard 1977). At maturity, individuals of the species *C. palmatus* are 10 to 30 cm tall with several to many branches, which often spread from the base of the stem.

The leaves of *C. palmatus* are grey-green and are often suffused with purple anthocyanin (Chuang and Heckard 1986; Munz and Keck 1959). The leaves, 7-20 mm long and oblong to lanceolate, are entire on the lower stems, and above have one or two pairs of lobes (see Figure 2). The leaves are hirsute, with hairs up to 1 mm long. Individual plants are often covered by a saline solution or dry salt crystals.

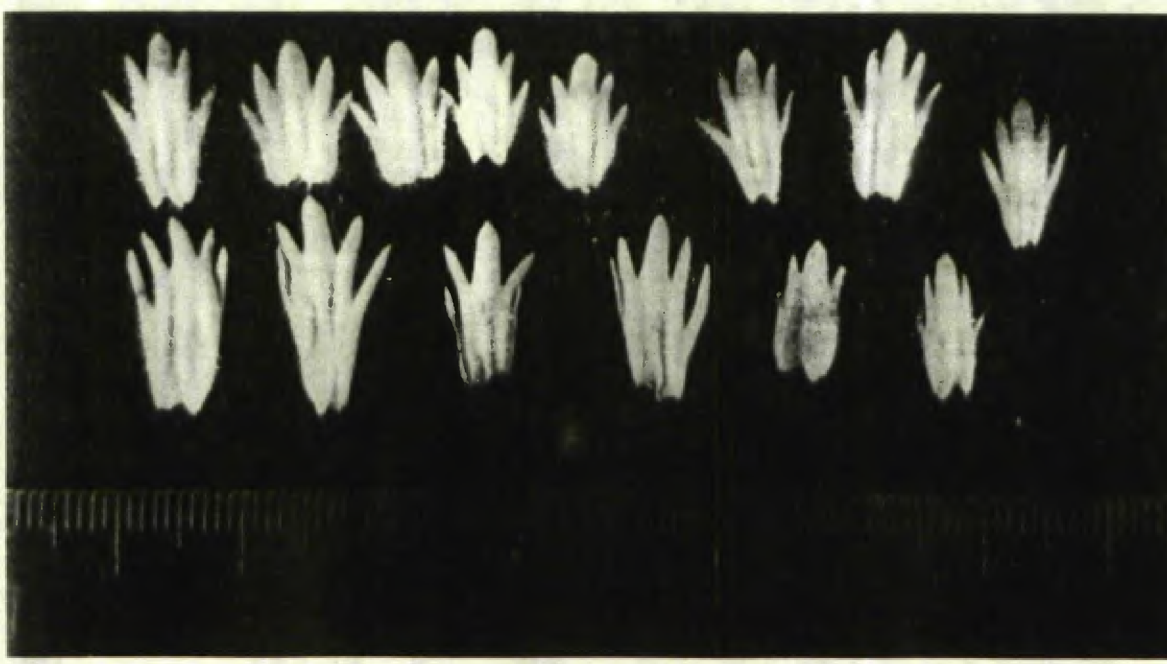


Figure 2. Upper leaves from *Cordylanthus palmatus*.

The small (1-2 cm long) flower of *C. palmatus* is white to pale lavender, sometimes with pale purple striations, and surrounded by a palm-shaped floral bract. The fruits of *C. palmatus* are 6-7 mm long; each typically contains 6-12 dark brown seeds that are characterized by deeply reticulate seed coats and prominent undulating crests (see Figure 3).

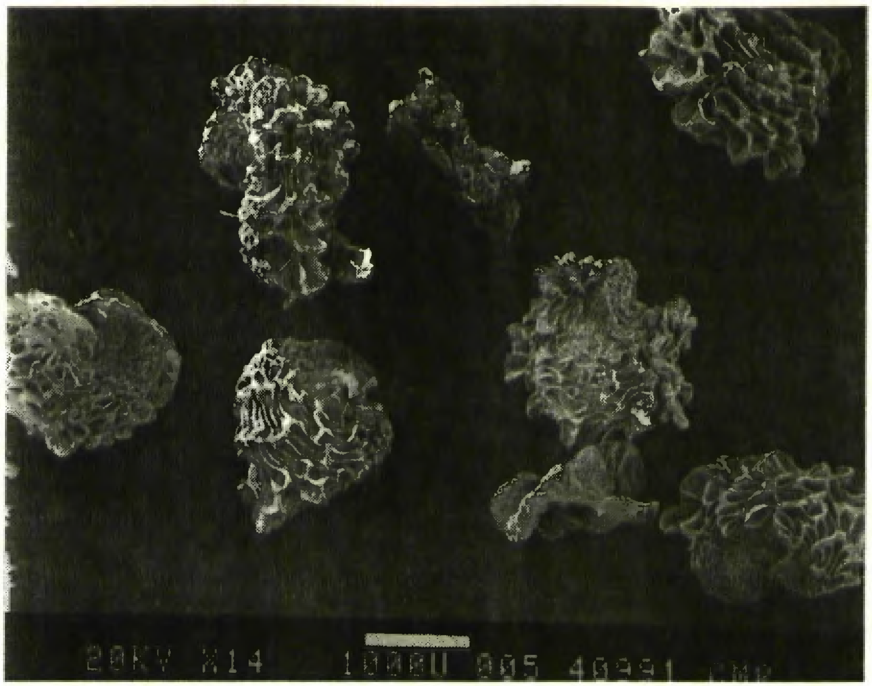


Figure 3. Scanning electron micrograph of *Cordylanthus palmatus* seeds collected at Springtown in fall 1990. Note the reticulate seed coat walls and the undulating crest of the seed coat. Photograph is 14x magnification; the white bar at the bottom of the photo represents 1 mm.

Cordylanthus palmatus and a morphologically similar congener, *Cordylanthus mollis*, comprise the section *Hemistegia* (Chuang and Heckard 1973). *C. mollis hispidus* (soft bird's beak), also recorded from Springtown, is distinguished from *C. palmatus* by a seed coat that lacks an undulating crest, by its coarsely hairy infloresences (on which the longest hairs are more than 1 mm long, in contrast to the shorter hairs of *C. palmatus*), and by its pale yellow to white flowers (white to pale lavender flowers in *C. palmatus*) (Coats *et al.* 1988; Munz 1968). *C. mollis hispidus* was noted at Springtown in 1983 and 1986 but was not found in subsequent surveys (Coats *et al.* 1988), including those conducted in the course of this study.

Cordylanthus palmatus flowers June through October by which time most other annual plant species have already senesced. The species is likely insect-pollinated (see the Results section of this report). Fruits develop in late summer and early fall; seeds germinate in mid-winter. At Springtown, *Cordylanthus palmatus* seedlings are easily identifiable by March or April.

Cordylanthus palmatus is found in lowlands characterized by seasonally flooded saline/alkaline soils. It frequently co-occurs with other lowland halophytes, including *Allenrolfea occidentalis* (iodine bush), *Cressa truxillensis* (alkali weed), *Distichlis spicata* (salt grass), *Suaeda fruiticosa* (seepweed), *Salicornia subterminalis* (pickleweed), and *Frankenia grandifolia* (alkali heath). Other vegetative associates of *C. palmatus* at Springtown include *Atriplex* spp. (saltbush), *Hemizonia pungens* (spikeweed), *Plantago bigelovii* (plantain), *Holocarpa obconica* (tarplant), and a variety of spring-flowering annuals (Coats 1986; authors' observations).

The species apparently is restricted to areas of highly saline/alkaline soils found in the sink scrub habitat, including areas of typical sink scrub vegetation, alkali grasslands, and alkali scalds. A non-specific facultative parasite, *C. palmatus* can produce haustoriae (modified root-like structures) which attach to the roots of host species and transport water and possibly nutrients or photosynthates to the *Cordylanthus*.

Historic and current distribution

The habitat of *Cordylanthus palmatus* was once widely scattered throughout the Central Valley and Livermore Valley of California, but it has been significantly reduced in extent due to agriculture, livestock grazing, channelization, and urbanization (Federal Register July 1, 1986). The species is known historically from at least ten locations in Alameda, Colusa, Fresno, Madera, San Joaquin, Yolo, and Kern Counties (Showers 1988, Mason 1957). The species has never been recorded outside of California.

The four known remaining populations of *Cordylanthus palmatus* are scattered throughout the central portion of the state in the Central and Livermore valleys (see Figure 4). Approximate population sizes over the last six years are indicated in Table 1.

Figure 4. Remaining populations of *Cordylanthus palmatus*. See Table 1 for details and citations.

POPULATION	1986	1987	1988	1989	1990	1991
Colusa *USFWS* *National Wildlife Refuge,* *Colusa County*		500[l]			~300[j]	5000[k]
Delevan *USFWS* *National Wildlife Refuge,* *Colusa County*			2500[b]	1000[b]		~10,000[k]
Mendota *California Dept. Fish and Game* *Alkali Sink Ecological Reserve,* *Fresno County*		800[g]	40[h]	40[j]	0[e]	0[e]
Springtown Alkali Sink *City of Livermore,* *Alameda County*			~10,000[c]		9000[a]	10,000[a]
Woodland *City of Woodland,* *Gray's Bend quad,* *Yolo County*	800[f]	400[f]	1500[f]	100[b]	850[d]	

Table 1. *Cordylanthus palmatus* population trends (approximate total number of plants). The Mendota population is thought to be extinct as plants have not been observed there since 1989. Sources: [a] This work. [b] California Natural Diversity Database. [c] Coats *et al.* 1988. [d] EIP Associates 1990. [e] Howard 1992. [f] Showers 1988. [g] Showers and Knudsen 1987. [h] Stebbins 1988. [j] Steeck 1991a. [k] Steeck 1991b. [l] Stone 1987.

Surveys in the late 1970's and early 1980's of likely habitats within the range of *Cordylanthus palmatus* did not locate additional populations of this species (Federal Register July 1, 1986). The small sizes of several of the remaining populations of this species and eminent threats to its habitat led in 1984 to its listing by the State of California as an endangered species. In 1986 the U.S. Fish and Wildlife Service followed suit by listing the species as endangered. *Cordylanthus palmatus* is also ranked by the California Natural Diversity Database as G1S1.1 ("less than six viable element occurrences or less than 1000 individuals or less than 2000 acres; very threatened"), that group's most severely threatened category (CA Dept. of Fish and Game August 1991). *Cordylanthus palmatus* is on the California Native Plant Society list in category 1B (3-3-3) ("rare or endangered in California; occurrence limited to one or a few highly restricted populations, or present in such small numbers that it is seldom reported; endangered throughout its range; endemic to California.") (Smith and Berg 1988).

Springtown Alkali Sink

Cordylanthus palmatus has been known since 1982 from the Springtown Alkali Sink in the northeast portion of the Livermore Valley, Livermore, California (Coats *et al.* 1988). The weather at Springtown is typical of central California. Virtually all precipitation occurs in the winter months; the summers are hot and dry. Patterns in temperature and precipitation by month for the past three years are presented in Appendix 4, Figure A4-1.

The Springtown Alkali Sink is located in the southern part of a ~7000 ha basin delineated by the Altamont uplands and a fault contact zone. Approximately 300 hectares of the sink proper contain a mosaic of iodine bush shrubland (alkali sink vegetation), alkali grassland (characterized by large stands of *Distichlis spicata*), annual grassland (dominated by non-native grasses), natural and channelized stream drainages, seasonal and year-round flowing streams, and vernal pools (see Figure 5). The upper portions of the basin are dominated by agricultural lands and annual grasslands.

This study was confined to ~180 ha in the south part of the basin (Figure 6). Although *Cordylanthus palmatus* is known only from this subset of the greater sink, it is clear that the entire 7000 ha basin is one hydrologic unit. These 180 ha receive much of the surface runoff and groundwater from the upland portions of the basin. A variety of habitat types typical of alkali sinks in general, and of the greater Springtown Alkali Sink in particular, are found on this site. For purposes of this report, this ~180 ha area is referred to as Springtown.

Figure 5. Aerial photograph of the greater Springtown Alkali Sink, Livermore, California. The study area for purposes of this report is outlined. Photograph is scale 1:16,000.

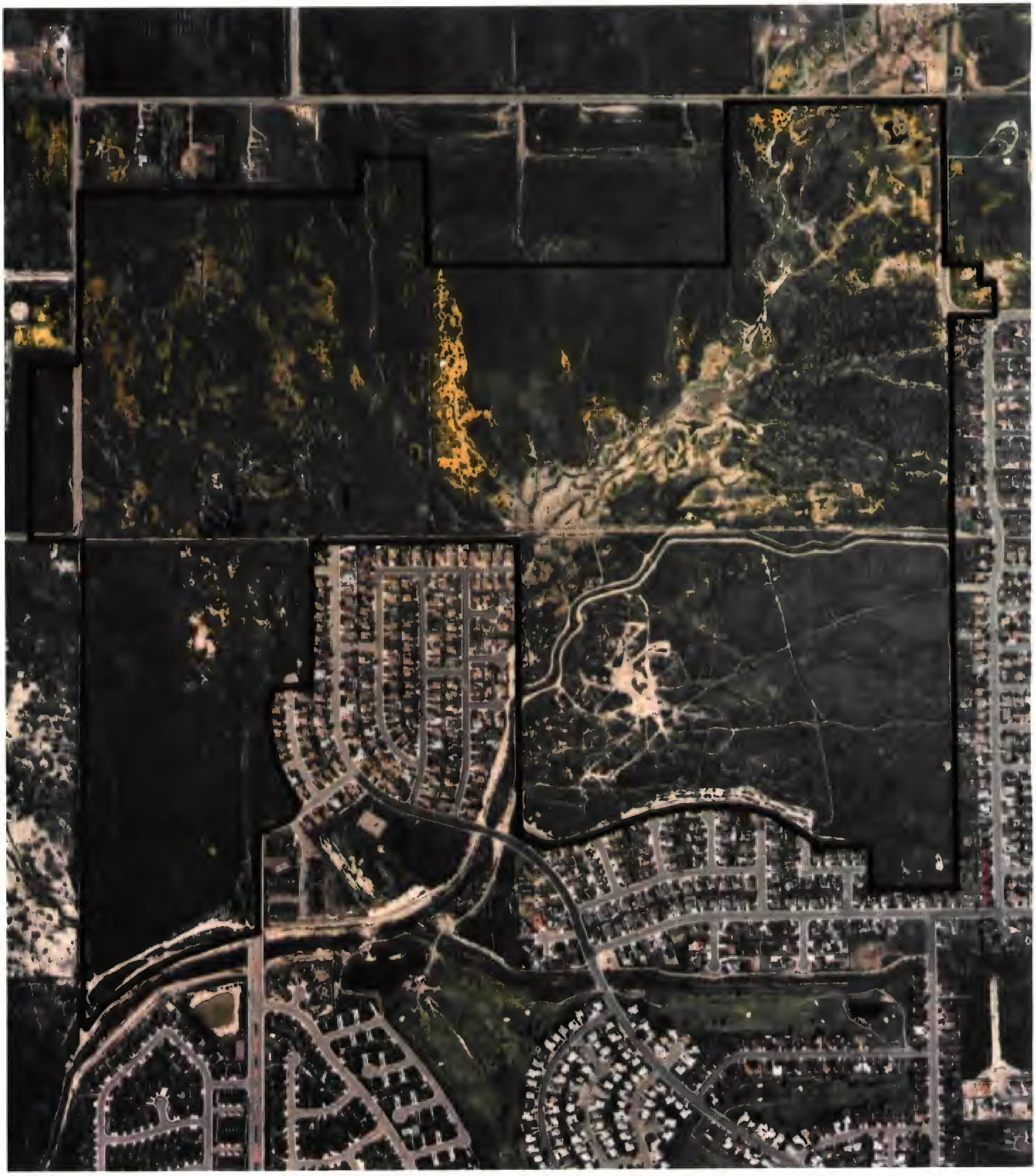


Figure 6. Aerial photograph, Springtown study site. Photograph is scale 1:1500.

Much of the Springtown site is defined as wetland by the U.S. Army Corps of Engineers (Coats *et al.* 1988). At Springtown, as is frequently the case in wetlands, several types of alluvial soils differing in composition and age are distributed in a complex fashion across the landscape. Fine-grained sediments and dissolved salts from marine deposits of the Altamont uplands have been deposited in the sink by surface flow. As water evaporates from the basin, the salts tend to concentrate in low-lying areas. Soils from "highland" areas, located between drainages in the central portion of the sink, in the "mima mound" areas (western portion of City owned property), and in the upslope portions of the sink (generally, the northern portion of the site), tend to accumulate fewer salts. Additionally, the generally high water table of the basin also allows for the capillary movement of water to the surface, transporting salts from deeper alluvial deposits (in general, groundwater levels at Springtown are from six inches to five feet below surface level; Alameda County 1991). This could further salinize surface soil (Coats *et al.* 1988, Alameda County 1991) (see Appendix 3).

Cordylanthus palmatus occurs in patches across a range of microenvironments at Springtown, including with *Distichlis spicata* in alkali grassland (see Figure 7), in sparsely vegetated areas of iodine bush scrub (see Figure 8), on sides of drainage channels, in barren alkali scalds (see Figure 9), and in heavily disturbed alkali grasslands, scrub, and scalds (see Figure 10). Although soils throughout the sink are alkaline and saline, conditions are especially extreme in the alkali scalds, nearly bare areas where soil conditions are apparently so harsh that only a few salt-tolerant species persist, including the bird's beak.

Saline/alkaline scalds are found through Springtown. Comparatively large scalds, tens of meters in diameter, are found in the southwest portion of the site; along several of the large drainage systems expansive patches of scald-like salt deposits are common. Smaller scald-like bare patches (from one to three meters wide) are scattered about the site. Additionally, at numerous locations across Springtown, soils apparently brought to the surface by burrowing mammals form broad mounds up to several meters in diameter.

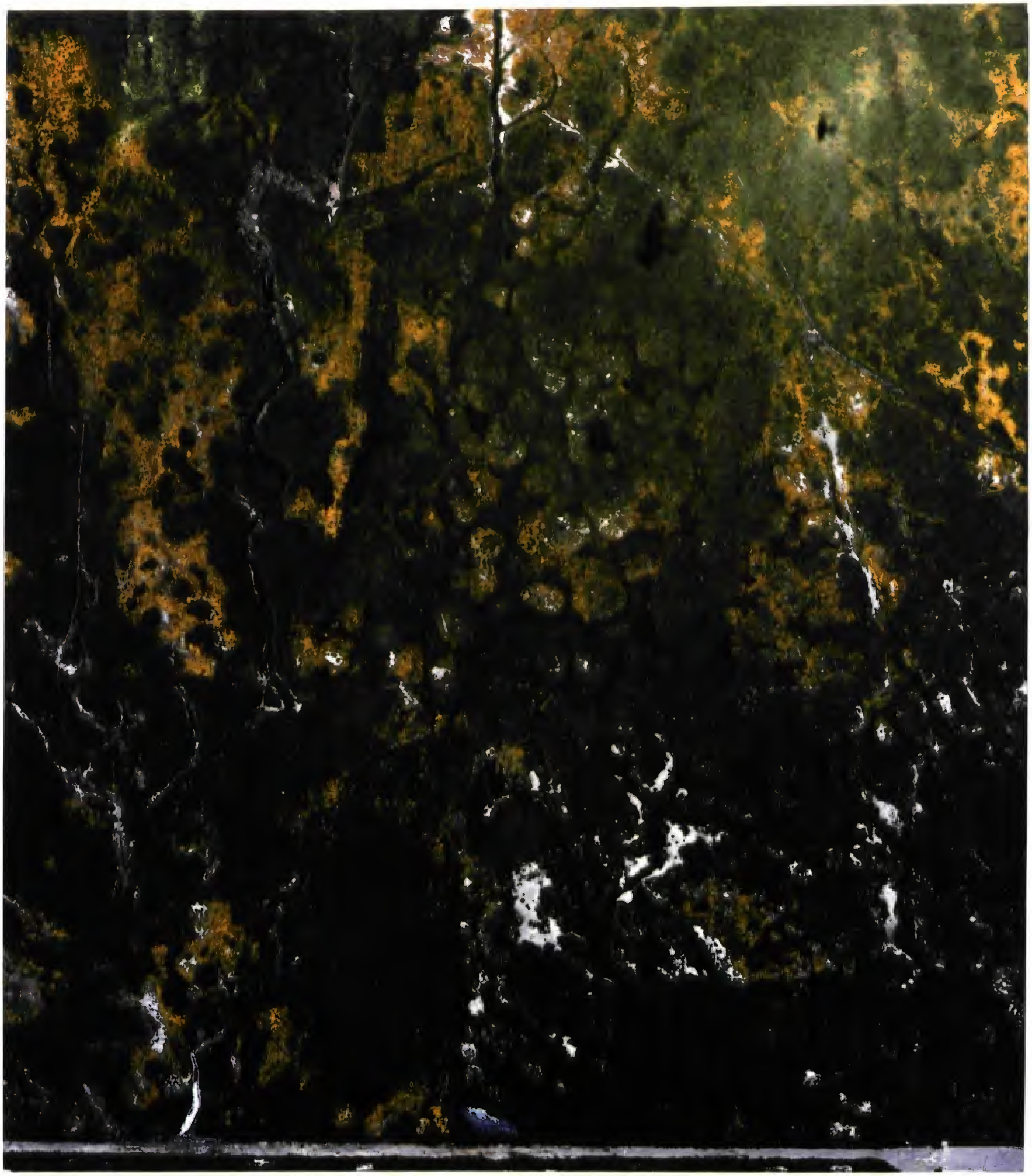


Figure 7. Aerial photograph, Springtown NW, *Distichlis spicata* and alkali grassland. Note the extensive drainage network. Photograph is scale 1:2500.

Figure 8. Aerial photograph, Springtown NE, iodine bush scrub (*Allenrolfea occidentalis*). Photograph is scale 1:2300.

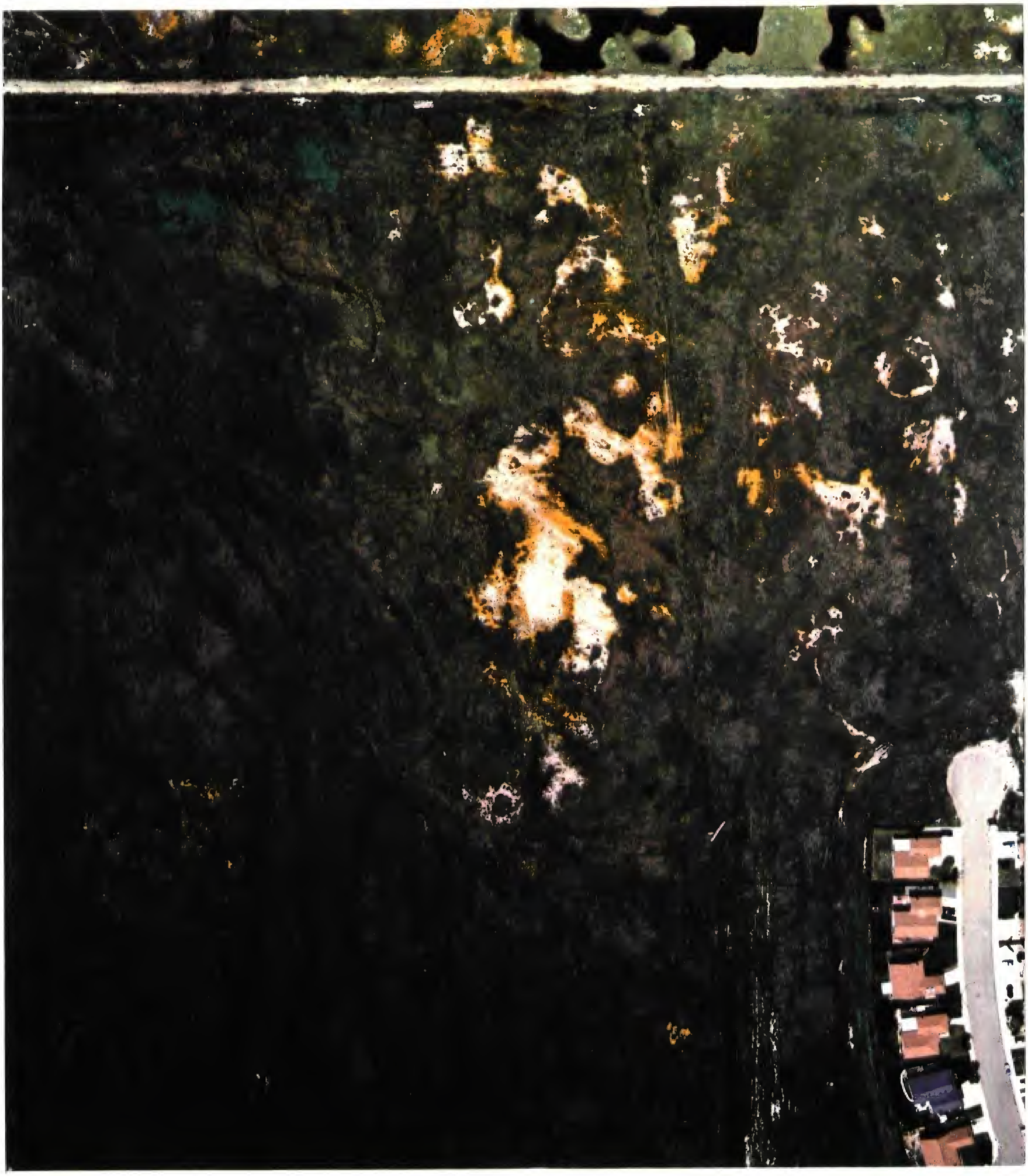


Figure 9. Aerial photograph, SW Springtown, alkali scalds. Photograph is scale 1:2100.

Figure 10. Aerial photograph, SE Springtown, heavily disturbed alkali grassland, iodine bush scrub, and alkali scalds. Photograph is scale 1:2100.

Modification of wetlands habitat at the Springtown Alkali Sink has been extensive. Major habitat disruptions have accompanied the construction of two large residential developments in the southeast and central portions of the sink (completed in the 1970's and early 1980's) and with the modification of Altamont Creek, which involved realignment and channelization (Coats *et al.* 1988). Portions of the sink have also suffered significant damage due to improper land use. The north section of the sink, owned by the City of Livermore, was heavily impacted by cattle for a number of years (ending in January 1990); cattle wore numerous trails into the site, directly damaged some of the perennial plants through either herbivory or trampling, and trampled and compacted some of the low-lying areas to the extent that they did not support plants of any type. Areas of the sink immediately to the west of the study site also apparently sustained an unacceptably high grazing intensity as recently as 1990. The southeast corner of the sink has been seriously damaged by off-road vehicles and bicycles, and is similarly heavily trespassed for other recreational purposes. Extensive areas of the sink (including the southwest portion) were disced in 1983 (Federal Register July 1, 1986), and smaller areas, particularly near the fence-lines of the large city owned parcel, were disced as recently as the late 1980's. To the west, prior to the establishment of the FCC station in 1946, wheat and volunteer grass were cultivated on that parcel, which was annually disced and burned for many years (Van Stavern 1991).

The Springtown Alkali Sink is dissected by roads and is partially surrounded by development: to the south and east are residential subdivisions, to the north is an inactive landfill, and the west is bounded by a Federal Communications Commission station. Development options threaten to completely encircle the sink and cover much of the upper portions of the basin within 20 years. Figure 11 indicates parcel ownership.

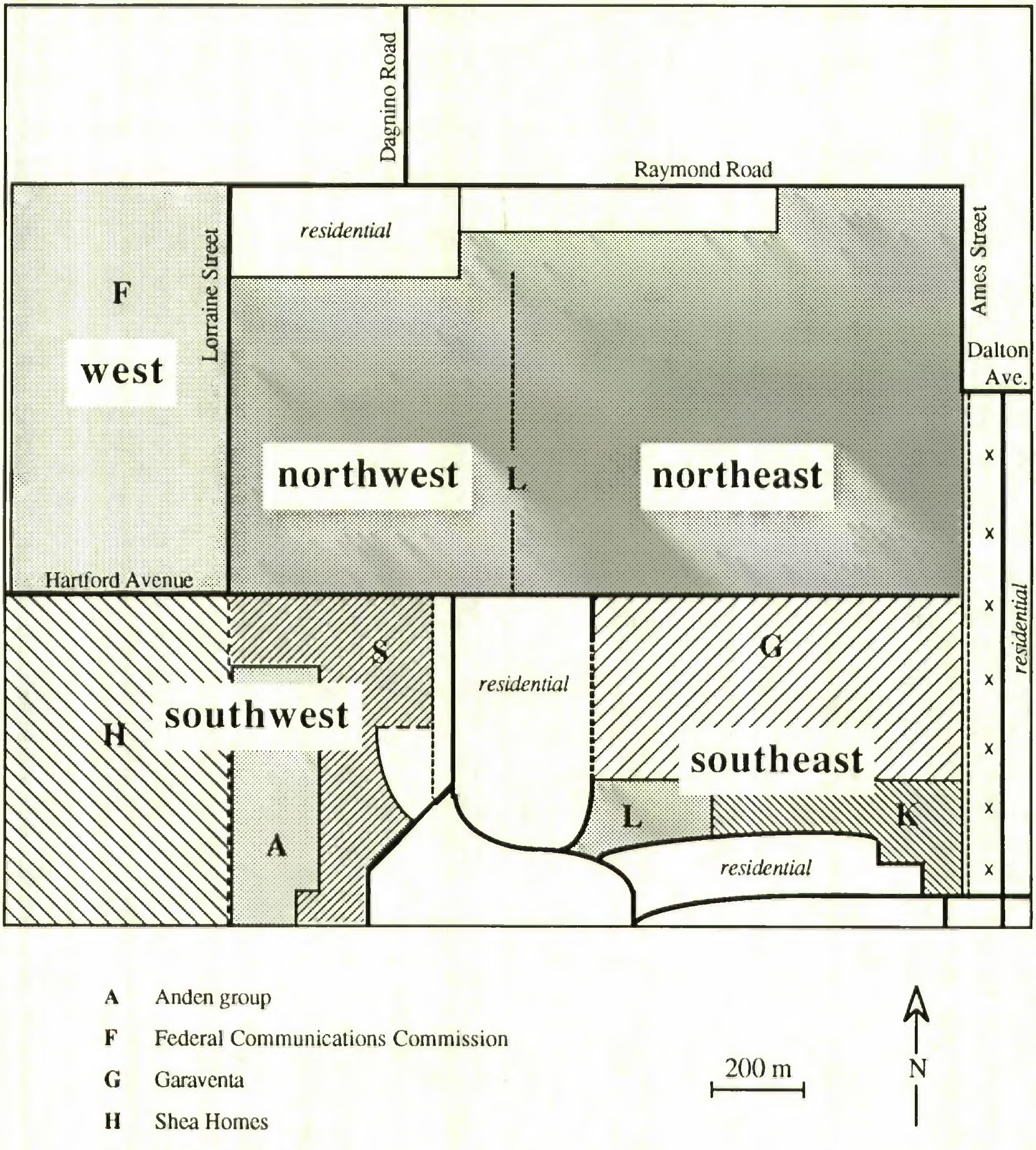


Figure 11. Areas and approximate parcel ownership at Springtown Alkali Sink, Livermore, California. Adapted from Coats *et al.* 1988.

The hydrologic character of the Springtown Alkali Sink has been significantly altered over the past 40 years (see Coats *et al.* 1988 for details). Surrounding development and agricultural activities have doubtless affected both the quantity and the quality of surface flow, and may affect groundwater levels (at least in localized areas). Data on nitrate, chloride, and total dissolved solids (TDS) from three monitored wells indicates significant variation in water quality, especially in chloride and TDS, in groundwater sampled just southwest of the sink and on City of Livermore lands (Alameda County 1991).

The effects of these disturbances of the local hydrology on the Springtown Alkali Sink are unclear. Records kept by the Alameda County Flood Control and Water Conservation District at their three monitored wells in Springtown (see Appendix 3) indicate that groundwater levels have varied by as much as eight feet (at the well just southwest of the sink) and as little as four feet (at the well on the north part of Springtown) over the past 14 years (Alameda County 1991). All three wells indicate somewhat of a rise in groundwater level during the mid-1980's, but since then no consistent site-wide trends are obvious. Unfortunately, long-term baseline information on groundwater fluctuations before the disturbances is lacking. Additionally, anecdotal evidence suggests that the groundwater level in and around Springtown has remained relatively constant in the past ten years (Killingstad 1991).

In 1987-88, in response to these and other changes in the land use and hydrology at Springtown, Philip Williams and Associates conducted a study of *Cordylanthus palmatus* funded in part by the U.S. Fish and Wildlife Service Endangered Species Grant-in-Aid and the California Endangered Species Tax Check-off Fund. This work allowed them to produce a proposed management plan for the Springtown wetlands and the endangered bird's beak (Coats *et al.* 1988).

The work presented in this report was designed to refine and expand that management plan, and to conduct additional biological studies needed for conservation planning for this rare plant. This work was funded by the California Department of Fish and Wildlife Endangered Plant Program and U.S. Fish and Wildlife Service Endangered Species Grant-in-aid.

Study plan

Surveys indicated that in 1988 the *Cordylanthus palmatus* population at the Springtown Alkali Sink in Livermore, California consisted of between 8,000 and 9,000 reproductive adults (Coats *et al.* 1988). Because little is known about historic population trends and distribution patterns in this species, a key part of this study was to gather baseline data on the population at the Springtown Alkali Sink, and to establish standardized, repeatable techniques for long-term monitoring of the population.

A second goal of this study was to identify which ecological characteristics and requirements of *Cordylanthus palmatus* are important to conservation planning. The distribution of *Cordylanthus palmatus* on saline/alkaline soils raises a number of questions regarding the species' viability on other soil types, competition between this native halophyte and other species, and the physical habitat requirements of *C. palmatus*. This study therefore was designed to investigate the ecological requirements of *Cordylanthus palmatus*, including relationships between patterns of *Cordylanthus palmatus* distribution and abundance, and physical features of the Springtown Alkali Sink, especially soil salinity and alkalinity.

The ultimate purpose of this study is to aid development of a preliminary management plan for this species at the Springtown Alkali Sink. Questions integral to this study include the following:

(1) How many *Cordylanthus palmatus* individuals are there at Springtown Alkali Sink?
(2) How are individual plants distributed across Springtown?
(3) Do the number or distribution of *Cordylanthus palmatus* individuals vary on a yearly basis?
(4) Is *Cordylanthus palmatus* restricted to saline/alkaline soils either physiologically or ecologically?
(5) Coats *et al.* (1988) suggests that seedling/plant mortality in late spring/early summer may be significant. Are pre-reproductive plants dying? Why?
(6) How many *Cordylanthus palmatus* seeds are produced annually?
(7) How are *Cordylanthus palmatus* seeds dispersed? Are large numbers of seeds carried to areas with unsuitable germination conditions?
(8) What is the germination rate of *Cordylanthus palmatus* seeds in various environments? If the germination rate is low in the alkali sink, do seeds remain in the soil until conditions are acceptable for germination?
(9) How do the salinity and alkalinity of sink soils vary, across time and space?
(10) Is *Cordylanthus palmatus* pollinator limited?

With the goal of answering these questions, and with special consideration of those for which answers would significantly contribute to development of a management plan for Springtown, we used existing literature on *Cordylanthus palmatus* and preliminary field observations to develop a study plan focused on the plants' distribution and abundance at three scales, seed production and viability, germination in various environments, variation in the physical environment at Springtown, and ecological relationships.

Methods

Distribution and abundance of *Cordylanthus palmatus*

The investigation of relationships between patterns of *C. palmatus* distribution and abundance and physical features of the site included establishment of a monitoring regime at three scales: coarse-scale (a population-wide survey of the entire population), mid-scale (local distribution and density) and fine-scale (survivorship of individual plants).

Coarse-scale population monitoring

To survey the entire *Cordylanthus palmatus* population at Springtown and identify site-wide patterns in distribution and abundance, a monitoring grid of 733 50 m x 50 m quadrats (each 0.25 ha) that encompassed the study area was constructed. Grid lines were established with 50 m and 100 m tapes and a compass. Steel rebar was used to permanently mark corners of quadrats along the border of the study area; interior corners of quadrats were temporarily marked with wire surveyor's flags.

In both 1990 and 1991, each quadrat was systematically examined between July and September by one or more persons. The primary purpose of these surveys was to note the number of *Cordylanthus palmatus* in each quadrat. In 1990, notes were also made of general habitat types/physical features, intensity of grazing and other habitat disturbance (e.g. ORV tracks, refuse), and the presence of plant species other than *C. palmatus*. All surveys were conducted just before or during flowering season, when *Cordylanthus palmatus* is most visible and easily identified. This schedule allowed the population to be surveyed after the potentially confounding early season mortality had occurred, and at a time when the majority of observed plants were reproducing. The monitoring activities at this coarse level were designed to provide baseline information on patterns of distribution and abundance of *Cordylanthus palmatus* at the Springtown Alkali Sink.

Mid-scale monitoring

A second monitoring effort targeted three microhabitat types: a large channel, an intermediate channel with seasonally standing water, and a small, shallow side channel. In each of these microhabitat types transects of 1 m quadrats were designated in areas known to support *Cordylanthus palmatus*. As these transects followed physical features of the site, the length and width of each varied; the total area examined in each microhabitat was 2400 square meters along the large channel (divided into 20 subdivisions), 880 square meters along the intermediate channel (three subdivisions), and 215 square meters in the shallow side channel (three subdivisions). Within these transects data were recorded on the number of *C. palmatus* individuals and the number of *C. palmatus* stalks (defined as branches at least 4 cm long) per individual. These data were collected for each quadrat in the summers of 1990 and 1991. For comparisons of mean number of stalks per plant, 100 individuals from each microhabitat were analyzed each year.

Data from this mid-scale monitoring provide information on the patterns of distribution and abundance along known physical features of the site. Monitoring at this level also allows for the identification of very localized changes in *Cordylanthus palmatus* distribution and abundance. Spatial and temporal changes in individual plant size is addressed by this effort.

Fine-scale monitoring

In the spring and summer of 1991, demographic monitoring studies were carried out in four areas occupied by *Cordylanthus palmatus*. Nine transects, each five to eleven meters in length and two meters wide, were established in five nominally distinct microhabitats (see Figure 12): a small, relatively flat basin (northwest Springtown, transect NW-1); a main drainage channel (northwest Springtown, transects NW-2 and NW-3); an open wash (northeast Springtown, transects NE-1 and NE-2); a large scald (southwest Springtown, transects SW-1 and SW-2); and a disturbed scald/grassland channel (southeast Springtown, transects SE-1 and SE-2).

Each transect traversed a microenvironmental gradient; these gradients included grassy patches, channels free of vegetation, scalds, bicycle trails, and ground sheltered by *Allenrolfea*. Each transect included areas of high *Cordylanthus palmatus* density as well as areas of low density. The end points of the transects were permanently marked with 12 inch metal stakes sunk flush into the ground. The stakes were relocated visually or with the aid of a metal detector.

The position and condition of all *C. palmatus* individuals rooted within each transect was recorded on a scaled map (see Appendix 1 for sample data sheet). The transects were monitored every two to four weeks for a period of 17 weeks, until all remaining live plants had set seed. Changes in population composition were noted on reproductions of the scaled maps from the previous monitoring session.

This study allowed us to identify patterns of initial abundance and mortality of *C. palmatus* across time and space and in different habitat types. Across all nine transects, 1850 individual plants were monitored from late spring through reproduction in late summer and early autumn. Data collected at this fine scale includes that on temporal and spatial variation in mortality, and helps identify relationships between local density, mortality, and reproductive success.

Figure 12. Aerial photograph of Springtown Alkali Sink, with 1991 fine-scale monitoring transects marked. Photograph is scale 1:9000.

Seed production and viability

Reproductive data were gathered from fifty stalks from a total of twenty-seven pre- and post-senescent plants collected randomly from the Springtown site on a single day in late August 1990. The length of each stalk was measured, the number of fruits per stalk was recorded, and the number of seeds in each reproductive fruit was counted. The number of seeds in each of 97 fruits from several randomly collected plants was counted.

The potential for seed dispersal was investigated qualitatively. To predict how *Cordylanthus palmatus* seeds in the field might travel in water-filled channels, observations on seed behavior in water were made under laboratory conditions. Field observations also were taken on the distribution of individuals in areas known to have had wintertime surface flow or standing water, and on the apparent distance dispersed from parent.

In summer of 1990, prior to seed set, soil samples were collected from areas of the Springtown Alkali Sink where *C. palmatus* was present as well as from apparently suitable but unoccupied habitat. These samples were used to determine the presence or absence of dormant, viable *C. palmatus* seeds which originated prior to 1990.

In January 1991 one liter of soil from each sample was spread atop a 1:1 mixture of potting soil and sterile sand in each of ten flats. In addition, three control flats were prepared with a base of potting soil/sand. Atop this was spread 1 liter of Springtown soil taken far from occupied habitat; 50 *C. palmatus* seeds (collected randomly from Springtown in fall 1990) were set on this mixture in each of these three flats.

All flats were maintained in greenhouses at Stanford University, and watered with tap water. They were examined regularly for the presence of *C. palmatus* seedlings, which were marked with toothpicks. This protocol is nearly identical to that of Chuang and Heckard (1971).

Germination in various environments

In summer 1990, soil and water samples were taken from various occupied and unoccupied habitat at Springtown. Analyses of these samples indicated a wide range of chemical parameters in the Springtown environment (see Appendix 2). Soil analyses indicated that the electrical conductivity (EC) of soils in the Springtown *Cordylanthus palmatus* habitat varies from 800 - 110,00 µmho/cm, and that Springtown soil alkalinity ranges from 6.0 to 8.8.

The results of these tests were used to develop a matrix of 24 nutrient solution environments approximating different combinations of salinity and alkalinity found in the Springtown environment. These solutions were used to test the germination rates of *Cordylanthus palmatus* in various environments.

Test nutrient solutions were developed with conductivities of 700 µmhos (an unmodified nutrient solution), 5,000 µmhos, 10,000 µmhos, 20,000 µmhos, 40,000 µmhos and 80,000 µmhos (the latter solution is 1.25 times as saline as sea water), and pH values of 6.0, 7.0, 8.0, and 9.0 (see Table 2).

Solutions were prepared around a base of a weak General Hydroponics nutrient solution consisting of 3.0 liters deionized water, 2.5 ml General Hydroponics FloraGro (4.0 - 1.0 - 7.0), and 1.25 ml FloraMicro (2.0 - 0.0 - 2.0). Salinity (as measured by electrical conductivity) was adjusted with the addition of table salt; alkalinity was adjusted by the addition of a potassium carbonate/potassium hydroxide solution.

pH	**6.0**	**7.0**	**8.0**	**9.0**
Electrical conductivity (in μmhos)				
700	sol'n 6N	sol'n 7N	sol'n 8N	sol'n 9N
5,000	sol'n 6-5K	sol'n 7-5K	sol'n 8-5K	sol'n 9-5K
10,000	sol'n 6-10K	sol'n 7-10K	sol'n 8-10K	sol'n 9-10K
20,000	sol'n 6-20K	sol'n 7-20K	sol'n 8-20K	sol'n 9-20K
40,000	sol'n 6-40K	sol'n 7-40K	sol'n 8-40K	sol'n 9-40K
80,000	sol'n 6-80K	sol'n 7-80K	sol'n 8-80K	sol'n 9-80K

Table 2. Conductivity (salinity) and pH of nutrient solutions used in germination experiments. Twenty-four nutrient solutions were developed to encompass the natural range of environmental variation available to *Cordylanthus palmatus* at the Springtown Alkali Sink near Livermore California. Five replicates of 20 seeds were tested in each solution for a total of 2,400 seeds.

Seeds were collected from plants throughout the Springtown population in late summer of 1990 and stored in a dark, low-temperature refrigerator until the experiment was initiated. In February 1991, 2400 seeds were placed in groups of 20 per petri dish; five replicates were prepared for each solution. In accordance with Chuang and Heckard 1971, each group was soaked in solution for 24 hours, then placed in a 5.5 cm dish lined with #22 Whatman filter paper that was saturated with solution. The dishes were covered and sealed with Lubriseal to prevent evaporation, and housed in Sherer Plant Growth Chambers under a 12-hour 70° day-50° night regime. Pans of water were placed on the bottoms of the chambers to keep relative humidity high. Each petri dish was resaturated weekly with nutrient solution. Deionized water was added to dishes as necessary between these weekly solution waterings.

Each seed was examined weekly for the emergence of a recognizable plumule or root; that date was designated as the date of germination for that seed. Once both a sturdy plumule and a root were noted, the seedling was planted in a 2" pot of sterilized sand and watered with the same solution in which it germinated. Seedling pots were placed in 8 x 10" Pyrex pans that were filled with solution and flushed weekly; as with the petri dishes, deionized water was added mid-week as necessary to keep the sand saturated.

After three consecutive weeks in which no seedlings germinated in a given dish, that dish was dried and stored in a low-temperature refrigerator for later study. The experiment was run for 18 weeks, after which time all dishes had shown no new germination within the previous three weeks. All seeds that did not germinate in this experiment were dried and put into cold storage for later tests on germination of older seeds. All seedlings were moved into a greenhouse at the conclusion of the experiment and used for other experiments.

Variation in soil environments

Samples of soil and standing water were taken across various occupied and unoccupied habitats at Springtown during January 1991 (to coincide with the germination of *Cordylanthus palmatus*), and analyzed chemically.

Ecological relationships at Springtown

During both field seasons, several insects were observed to visit *Cordylanthus palmatus* flowers. Scanning electron micrographs were taken of the pollen removed from the legs of these insects, and compared to those made of *Cordylanthus palmatus* pollen collected from greenhouse specimens. The micrographs were examined in particular for morphological characteristics of pollen.

Among the most important ecological relationships involving *Cordylanthus* species are those between host plants and the hemiparasitic bird's beak. Effort was taken during the three monitoring activities to identify other plant species which *Cordylanthus* individuals may have been parasitizing.

Throughout the field season, gross patterns of herbivory were noted, including some searches for herbivore damage.

Results and discussion

Distribution and abundance of *Cordylanthus palmatus*

At all three levels of monitoring, results indicate moderate to slight spatial and temporal variation in the distribution and abundance of *Cordylanthus palmatus*. The *Cordylanthus palmatus* population at Springtown did not change greatly in size or distribution between 1990 and 1991.

Coarse-scale population monitoring

Results of the coarse-scale monitoring indicate that large concentrations of *Cordylanthus palmatus* were patchily scattered throughout the Springtown Alkali Sink (Figures 12 and 13). In 1990, surveys indicated a population of 8,994 individual plants at Springtown, and in the following year 10,439 individual plants were counted. Given the patches of extremely high density of *Cordylanthus*, and the frequent ground-level branching of individual plants, an estimate of the accuracy of these numbers was difficult to precisely ascertain. The maximum estimate of error, based on the comparison of field counts by multiple observers, was 10%. The observed 16% change in population size might be an artifact of sampling error, but when population level changes on a subregion level are considered, the data appear to reflect a real site-wide increase (Table 3).

	No. of *C. palmatus*			No. 50 m quadrats occupied/total		% of Springtown population	
	1990	*1991*	*% change*	*1990*	*1991*	*1990*	*1991*
West (FCC)	**172**	**360**	**+109%**	**4/16**	**6/16**	**1.9%**	**3.4%**
North (City of Livermore)	**1,049**	**1,940**	**+85%**	**37/442**	**40/442**	**11.7%**	**18.6%**
Northwest	698	1007	+44%	17/172	23/172	7.8%	9.6%
Northeast	351	933	+166%	20/270	17/270	3.9%	8.9%
Southwest	**1,538**	**2,198**	**+43%**	**19/105**	**22/105**	**17.1%**	**21.1%**
Anden Group	623	1,074	+72%	7/46	8/46	6.9%	10.3%
S&L Investments	915	1,124	+23%	12/59	14/59	10.2%	10.8%
Southeast	**6,235**	**5,941**	**-5%**	**40/170**	**40/170**	**69.3%**	**56.9%**
Garaventa	6,140	5,619	-8%	35/128	35/128	68.3%	53.8%
Kaufman & Broad	70	15	-79%	3/32	2/32	0.8%	0.1%
City of Livermore	25	307	+1128%	2/10	3/10	0.3%	2.9%
TOTAL	**8,994**	**10,439**	**+16%**	**159/733**	**170/733**	**100.0%**	**100.0%**

Table 3. *Cordylanthus palmatus* surveys, 1990 and 1991, by region and by parcel at Springtown. Regions and rough parcels are indicated in Figure 11. Because quadrat boundaries did not always coincide with parcel boundaries, the numbers of plants per parcel are estimates.

The general pattern of *C. palmatus* distribution observed in this study is consistent with distributions mapped in previous studies, as presented in Coats *et al.* 1988, but for two exceptions. In 1988, Showers observed a small concentration of *Cordylanthus palmatus* north of the bike trail in the southeast corner of the City of Livermore property. Two years later, no plants were found within at least 200 m of that area. Second, in both 1990 and 1991, more than 600 plants were found near the fence along the west edge of the southwest portion of Springtown, an area in which Showers noted no plants in her 1988 survey work. At the present time it is impossible to precisely identify the reasons behind these apparent slight shifts in distribution. Figures 13 and 14 display the distribution of the *Cordylanthus palmatus* population in 1990 and 1991.

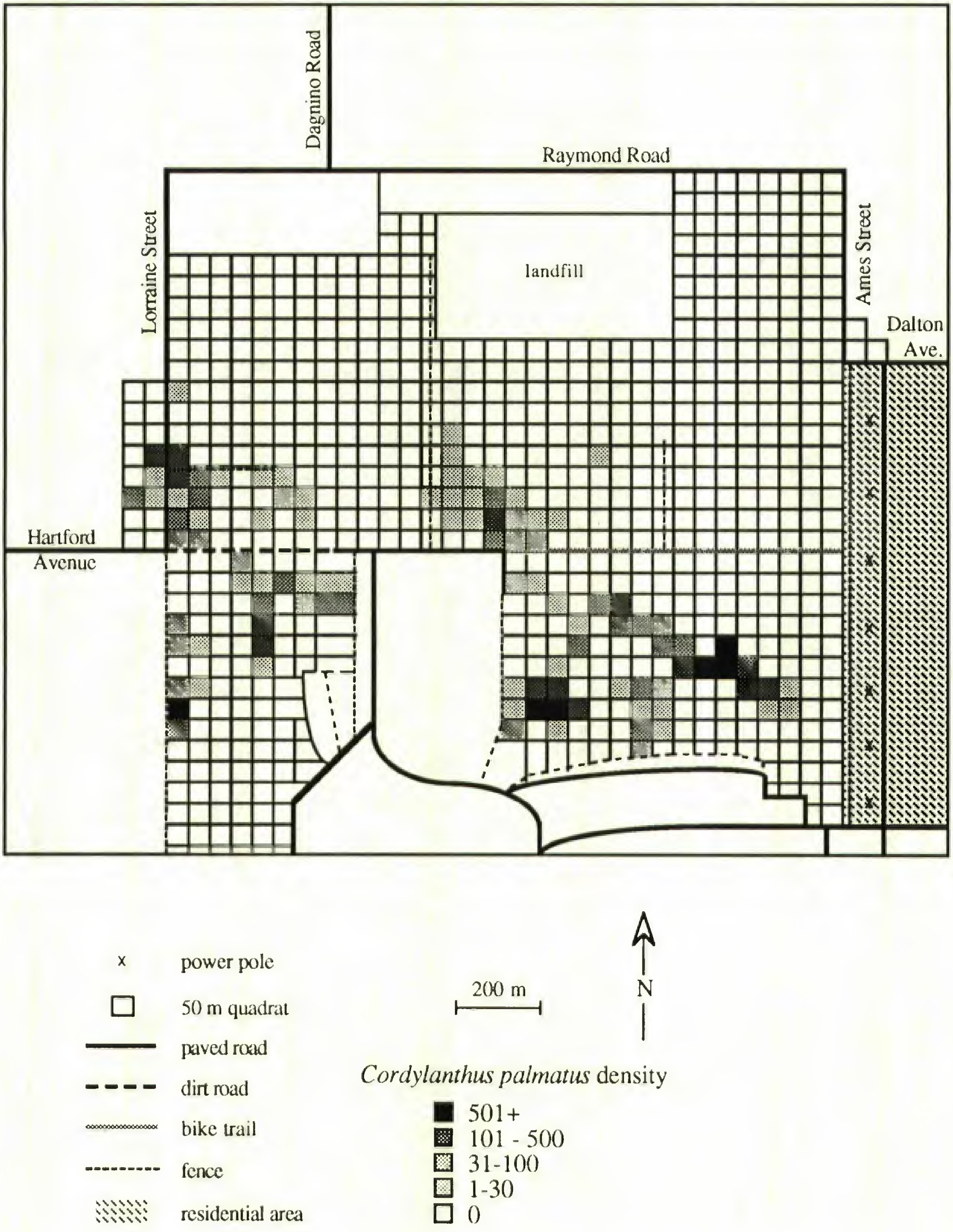


Figure 13. *Cordylanthus palmatus* population at Springtown Alkali Sink, 1990. Density is indicated for each 50 m quadrat. Scale is 1:13,500.

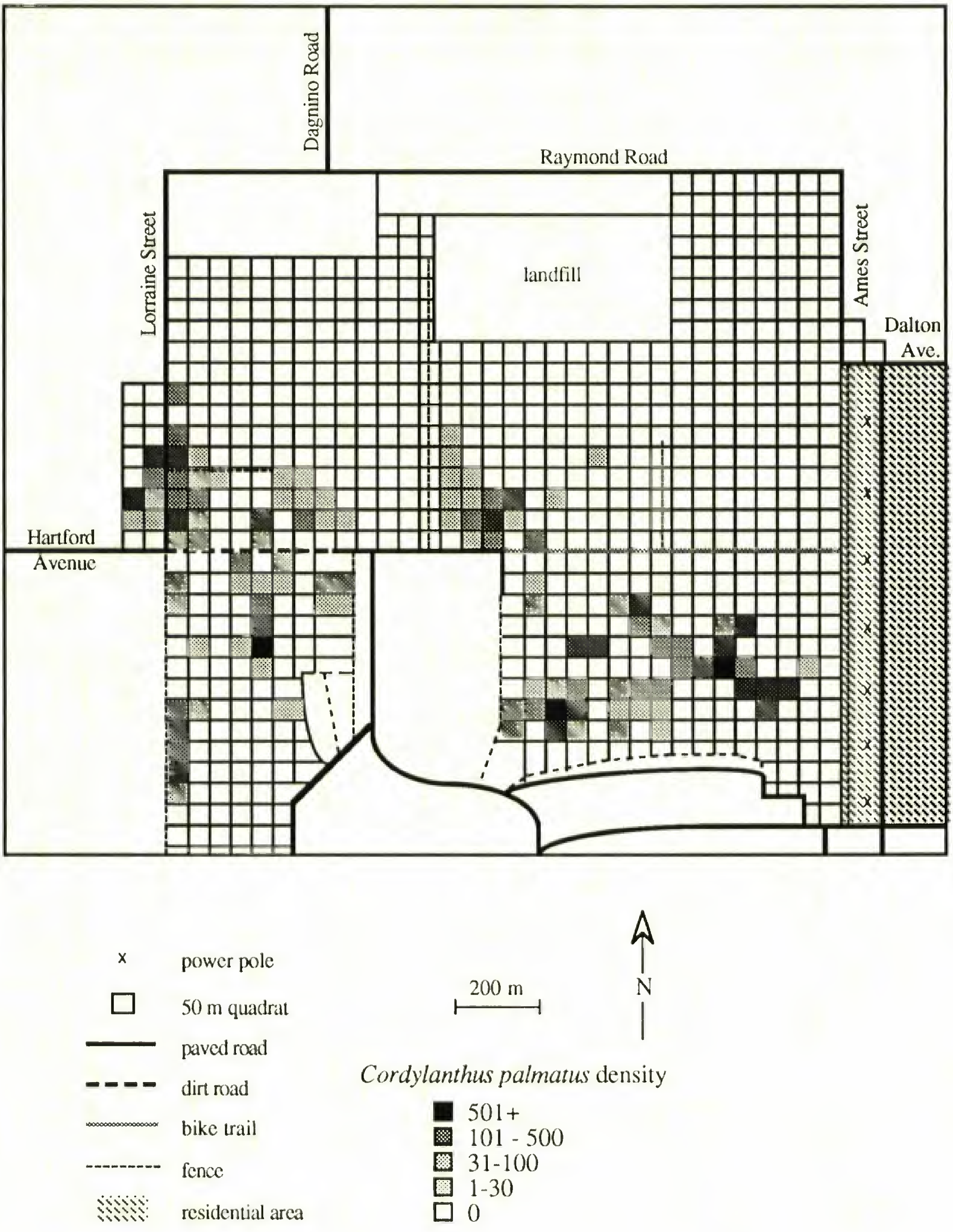


Figure 14. *Cordylanthus palmatus* population at Springtown Alkali Sink, 1991. Density is indicated for each 50 m quadrat. Scale is 1:13,500.

Although the overall distribution of the species appears to have remained fairly constant, local changes in population levels are apparent from 1990 to 1991. The number of *C. palmatus* individuals on Springtown west increased dramatically (109%) between years, as did the number of plants on Springtown northwest and northeast (44% and 166%, respectively). The number of plants on Springtown southwest increased 43%.

On the southeast portion of Springtown, which supports 57% of the *Cordylanthus palmatus* population and where density was significantly higher than in any other area (between 1.4 and 1.5 plants/100m^2, as compared to a Springtown average of 0.5-0.6 plants/100m^2), the overall number of plants decreased 5% between years.

On the lands with the largest increase in numbers of the bird's beak (Springtown northwest and northeast), grazing was removed at the beginning of the growing season in 1991. While no evidence exists to suggest that the removal of grazing caused this increase in population size, future experimental work could identify any relationship between grazing patterns and population size for this plan. There is no apparent explanation for these or other local increases in population size, or for the decreases on Springtown southeast.

Among the various portions of Springtown, year-to-year changes in *Cordylanthus palmatus* population levels varied in both magnitude and direction. This suggests that in this population during the course of this study, *C. palmatus* is not responding synchronously to local weather patterns. Data from this study likely document natural within-population fluctuations for this species; however, long-term data on population sizes are necessary to substantiate this. Such a spatially asynchronous or varied response to weather could afford the plant a degree of buffering from environmental extremes. This suggests that preservation of the variety of habitat types at Springtown may be important for the long-term persistence of *Cordylanthus palmatus*.

Mid-level monitoring

While the coarse-scale monitoring provided data on general distribution patterns, the mid-level monitoring allows the examination of between-year changes in density and individual plant size at a very localized scale. Differences in these two factors between the habitat types and between the two years were evident. Data from this study indicate a high degree of annual localized variation in number of individuals and mean number of stalks per individual.

In the transects located in the large channel in Springtown southeast, the number of individuals in fifteen of the twenty subdivisions changed from 1990 to 1991, with declines being evident in ten of the subdivisions and increases in five of the subdivisions. In the overall area, a decline of approximately 25% in total number of individuals was observed. Interestingly, the mean number of stalks per plant more than doubled to 16.5 stalks per individual in 1991. In terms of *Cordylanthus palmatus* seed production, this increase in mean number of stalks appears easily to have offset the decline in number of individuals. In the shallow side channel a pattern similar to that in the large channel was observed: in 1991 plants were fewer, but mean stalks/plant was greater.

In the intermediate-sized channel, the mid-level monitoring activities yielded a very different result. In this habitat type, the number of individual plants in each of the three subdivisions was approximately the same in both years, but there was a significant decrease in the mean number of stalks per individual. This implies a decreased reproductive output in this habitat type.

The possible relationships between these patterns of local change in number of individuals or mean size of individuals and environmental parameters are unfortunately very opaque. It is tempting to relate increased number of stalks, a rough measure of size, with a decreased number of individuals, but data from this level of monitoring on the potential effects of intraspecific competition are far from conclusive (see following section for a more on the potential role of intraspecific competition). Further analysis of these data, especially when coupled with work in progress on the distribution of soil types, will help clarify some of the factors contributing to the distribution and abundance of *Cordylanthus palmatus*.

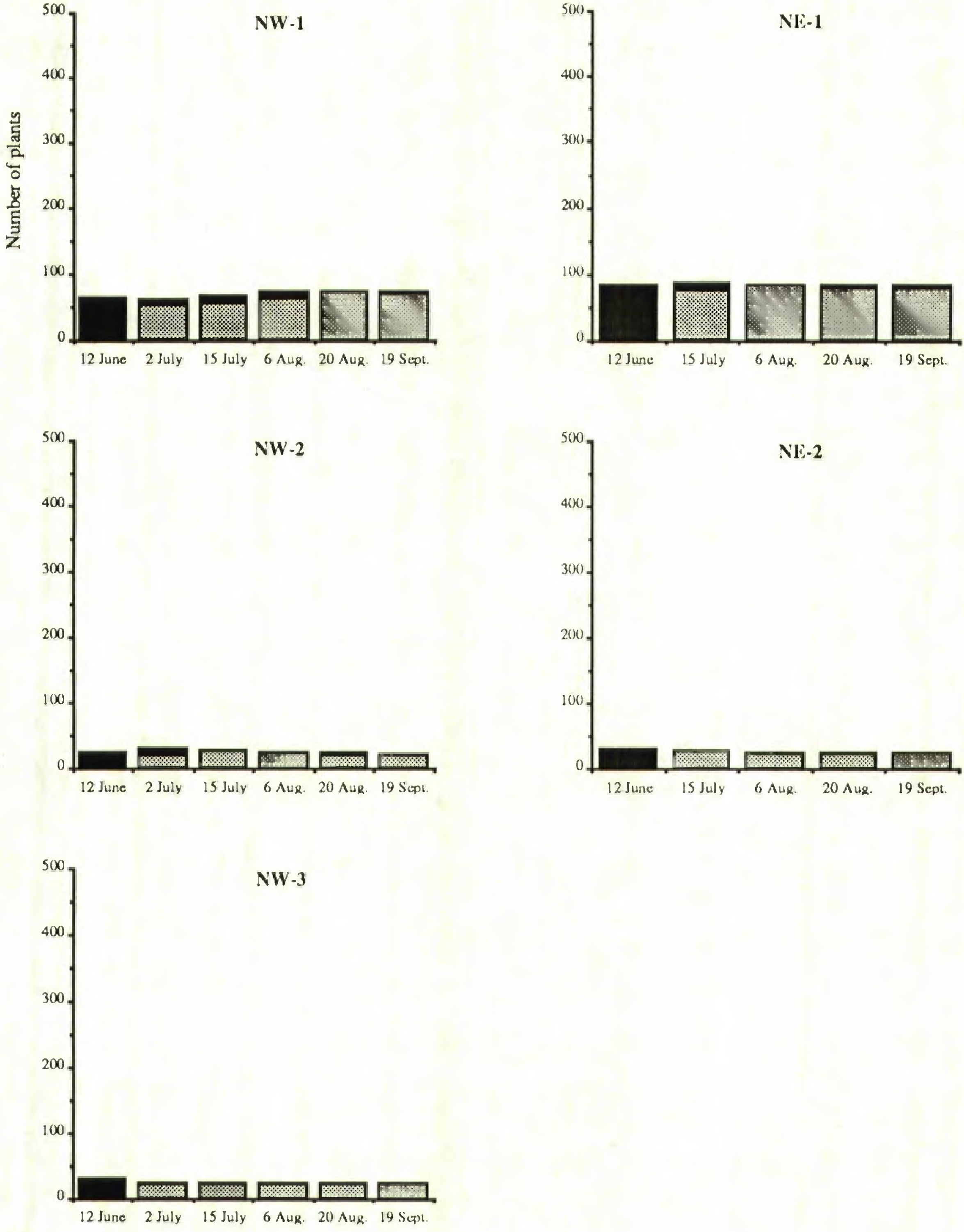
The results of this mid-level monitoring are very valuable for the design of a long-term monitoring plan for the palmate-bracted bird's beak at the Springtown Alkali Sink. Monitoring efforts based on a few comparatively small areas, on the order of tens of square meters, are likely to detect numerous changes in local distribution and abundance that do not necessarily reflect the status of the population as a whole.

The data also clearly indicate that some measure of plant size, such as the mean number of stalks per individual plant, greatly enhances the value of yearly population estimates -- if a decrease in number of individuals is coupled with an increase in number of stalks, then the overall reproductive output may not have changed.

The conservation implications of such highly localized changes, given the present level of knowledge, are difficult to determine. However, these local and apparently asynchronous changes in density and individual plant size support arguments for the preservation of multiple habitat types throughout Springtown. The maintenance of the variability that allows such varied responses to environmental variation will likely over the long term allow *Cordylanthus palmatus* to respond at a subpopulation level, thus buffering the entire population from potentially devastating events. A conservation plan for this species focusing on only one or a few of the microhabitat types available at Springtown may be much less stable than one that integrates the importance of habitat heterogeneity to the long-term persistence of this species.

Fine-scale monitoring

Fine-scale monitoring of 1882 individual plants growing across environmental gradients in 1991 suggested several interesting things about the annual life cycle of *Cordylanthus palmatus*. In all five transects on the City of Livermore property (Springtown northwest and northeast), the number of viable individuals remained nearly constant throughout the monitoring period; very little pre-reproduction mortality was observed (see Figure 15). In contrast, all four transects in southwest Springtown and southeast Springtown showed significant and steady mortality of *C. palmatus* throughout the growing season. While there is obvious microtopographical variation between the sites of the fine-scale monitoring, future studies are necessary to document ecological or edaphic variation that may affect local survivorship of this species.


NW-1
NE-1
NW-2
NE-2
NW-3
Number of plants
0
100
200
300
400
500
12 June
2 July
15 July
6 Aug.
20 Aug.
19 Sept.

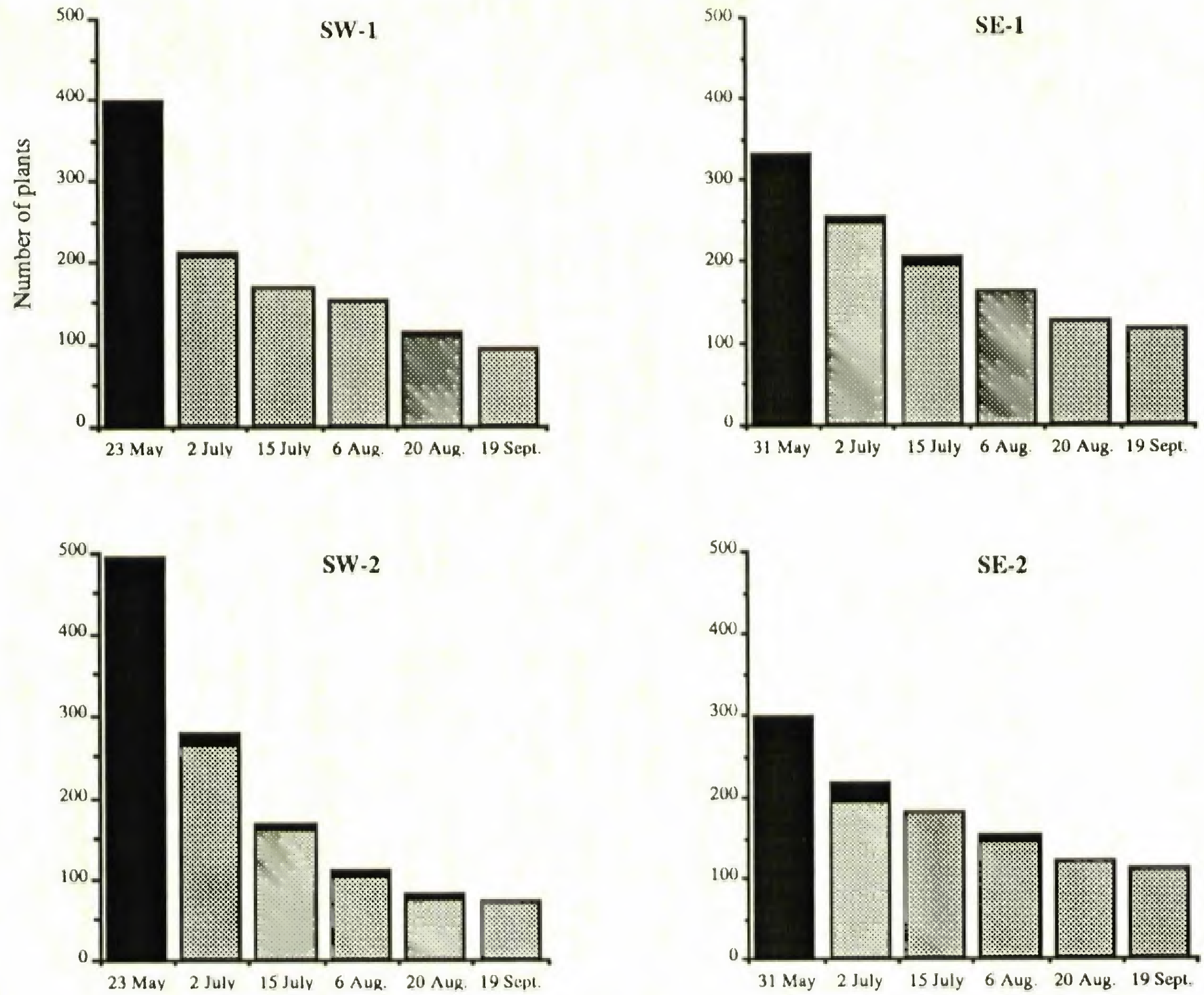


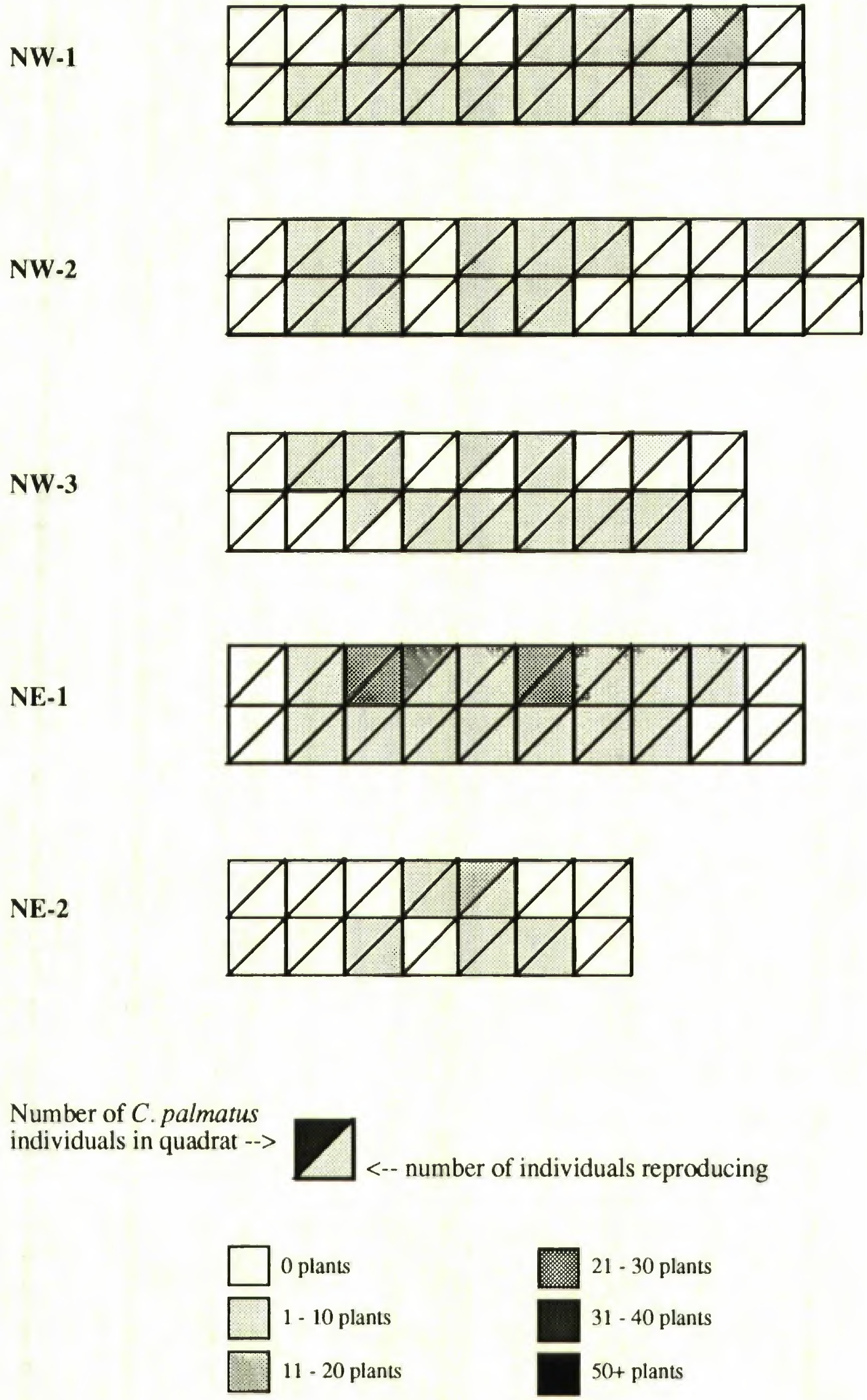
Figure 15. Number of *Cordylanthus palmatus* individuals recorded during fine-scale monitoring, 1991. Graphs represent number of plants in each of the nine line-transects across the 1991 growing season. Plants noted for the first time are indicated in black; previously censused individuals are represented by the grey portions of the bars. All plants had reproduced or senesced by the final monitoring date for each transect.

The overall rate of survivorship to reproduction differed greatly between groups of plants in the five north Springtown transects (in a small channel or wash) and the four transects on Springtown southwest (scald) and southeast (disturbed grassland/channel) (see Table 4 and Figure 17). The highest rates of survivorship were recorded on Springtown northwest and northeast, where as many as 86% of the plants in a transect survived to reproduce. The mean rates of survivorship, based on individual quadrats, did not differ significantly between transects in these two areas. These values are significantly higher than those for Springtown southwest and southeast, where as few as 13% of the plants reproduced. Overall, more than 75% of the plants on north Springtown survived to reproduce, as compared to nearly 25% of the plants on south Springtown. Even in the highly disturbed habitats of SE-1 and SE-2 more than one-third of the plants reproduced.

Transect	No. of plants	No. of plants reproducing	% reproducing
NW-1	92	71	77%
NW-2	36	20	56%
NW-3	32	21	66%
NE-1	95	82	86%
NE-2	29	24	83%
SW-1	404	94	23%
SW-2	520	68	13%
SE-1	345	117	34%
SE-2	329	111	34%
Overall	**1882**	**608**	**32%**

Table 4. Percent of *Cordylanthus palmatus* individuals observed at beginning of season surviving to reproduction. Data from fine-scale monitoring, Springtown, 1991.

The transect-wide summaries of survival to reproduction hide the great variation in survivorship within transects. For a given transect the percent survivorship of plants in different meter squares (quadrats) within that transect varied; on transect SW-1, for example, individual quadrat survivorship ranged from 0% (n=2) to 100% (n=2), with the rest of the quadrats (n=14) ranging from 9.4% to 71.4%. As well, plant density per quadrats varied within transects. Figure 16 shows spatial patterns of *Cordylanthus palmatus* density and reproduction across all nine line-transects.


NW-1
NW-2
NW-3
NE-1
NE-2
Number of *C. palmatus* individuals in quadrat -->
<-- number of individuals reproducing
0 plants
1 - 10 plants
11 - 20 plants
21 - 30 plants
31 - 40 plants
50+ plants

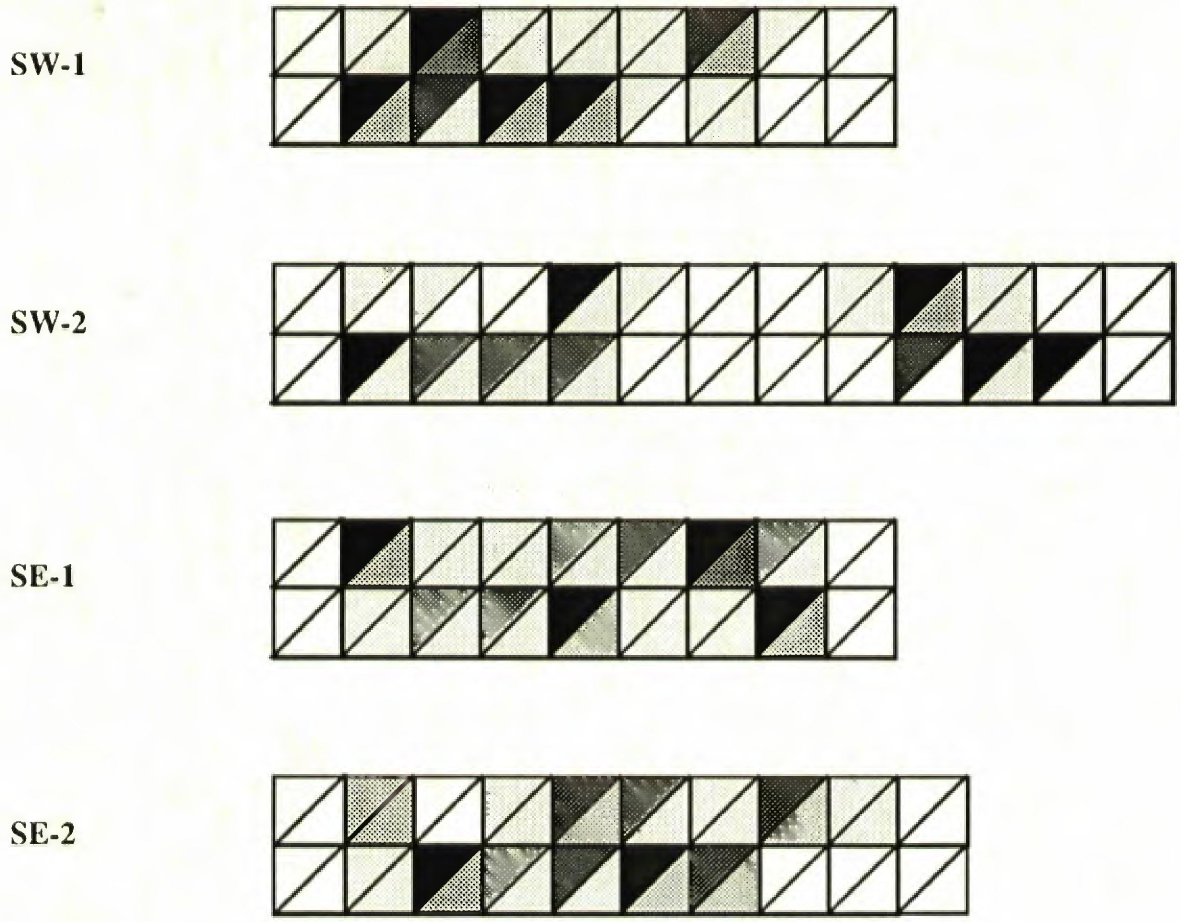


Figure 16. Local spatial patterns of *Cordylanthus palmatus* density and reproduction recorded during fine-scale monitoring, 1991. Figures represent the actual transects; each square represents one square meter. The upper left half of each square is colored to represent the total number of plants observed in that quadrat; the lower right half represents the total number of plants reproducing.

In addition to documenting differences in *Cordylanthus palmatus* survivorship between subareas of Springtown, these data suggest that density-dependent mortality may be occurring. Figure 18 indicates that the percent of plants in a quadrat surviving to reproduction is somewhat correlated with the density of plants in that quadrat. Density-dependent mortality appears to be important in areas where the total density of *Cordylanthus palmatus* was higher than approximately 25 plants/m^2. In these high-density areas, the percent of *Cordylanthus palmatus* individuals surviving to reproduction was never greater than 55%. In contrast, areas of *Cordylanthus palmatus* density less than 25 plants/m^2 showed no clear correlation between density and survivorship to reproduction; in many of these low density areas 100% of the individuals survived. These data suggest an upper limit to the number of *Cordylanthus palmatus* plants that can survive to reproduce in a given small (1 m^2) area. This may be important for future efforts aimed at establishing or reestablishing this species; initial densities of seedlings exceeding approximately 25 plants/ m^2 could be subject to increased density-dependent mortality and waste both seed stock and restoration efforts.

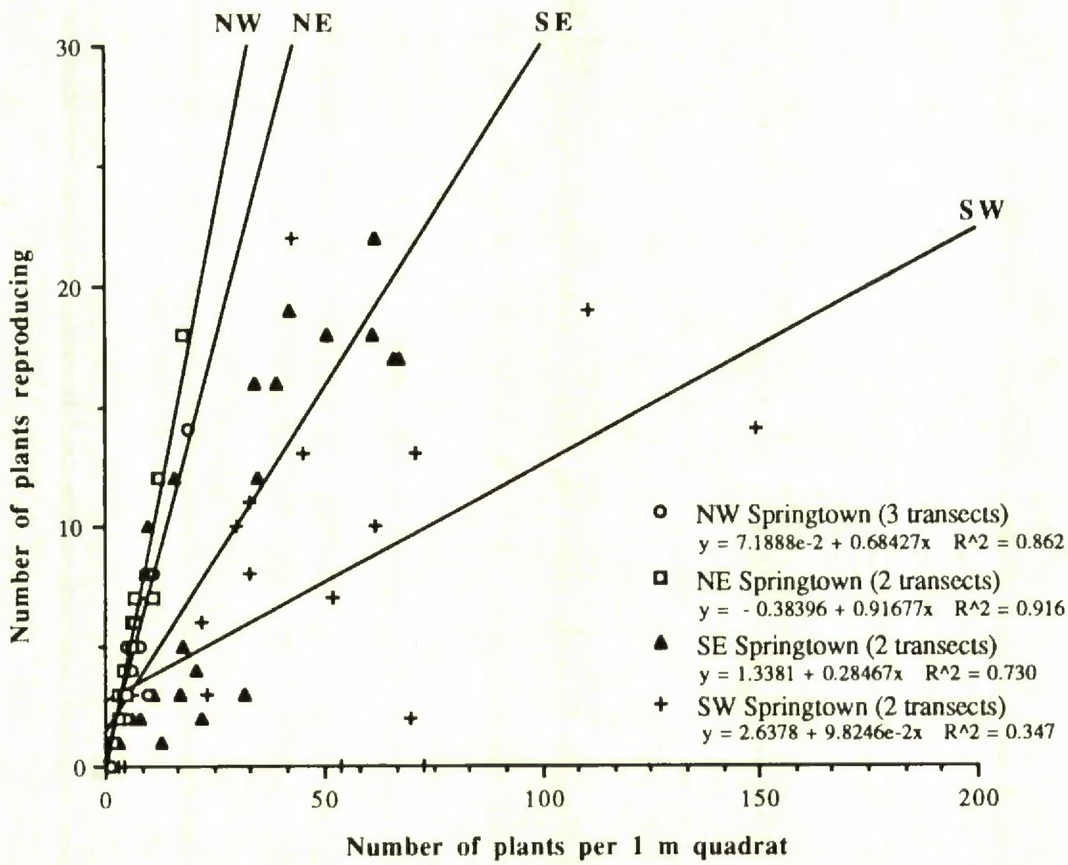


Figure 17. Density of *Cordylanthus palmatus* vs. number surviving to reproduction, per 1 m quadrat. Data from fine-scale monitoring, 1991, at Springtown Alkali Sink.

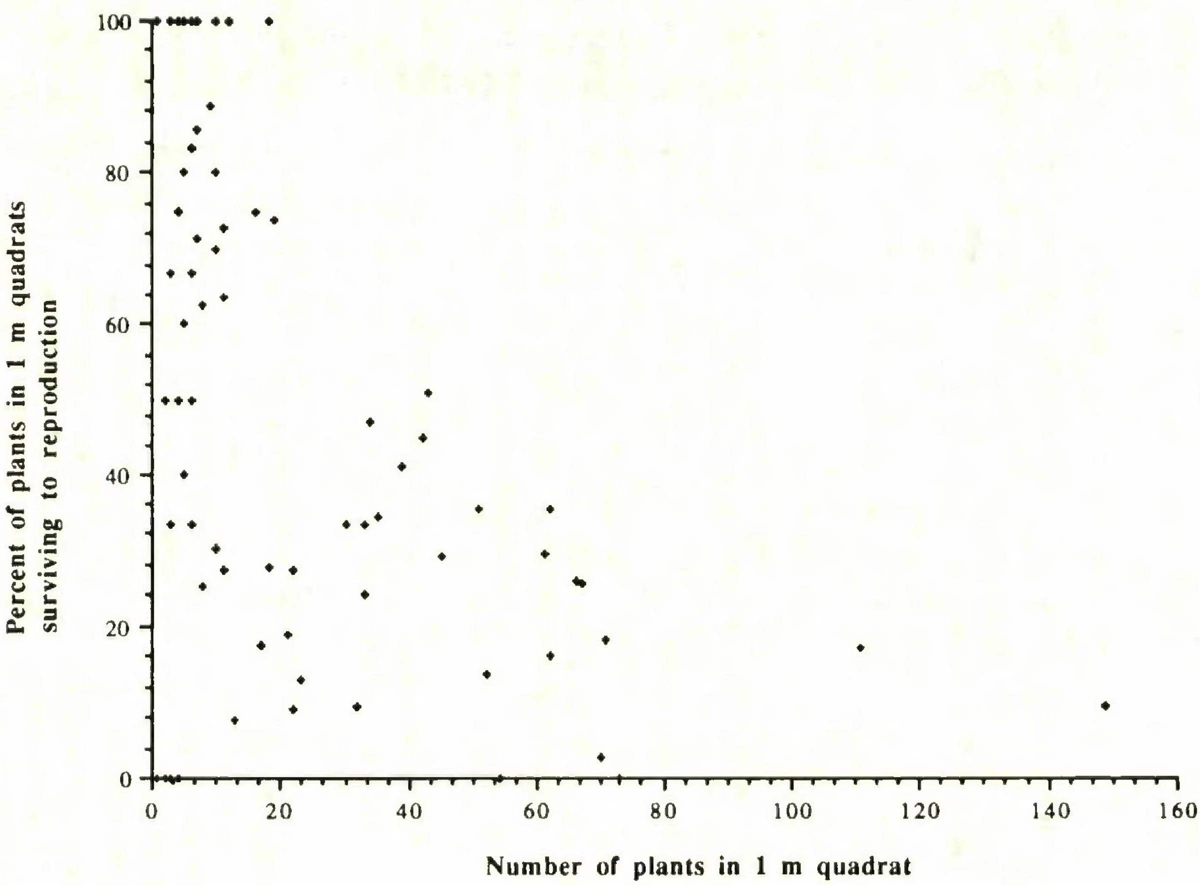


Figure 18. Density of *Cordylanthus palmatus* (per 1 m quadrats) vs. percent surviving to reproduction. Data from all nine fine-scale monitoring transects, Springtown Alkali Sink, 1991.

These data are important in several respects. The varying patterns of survivorship in different areas imply that *Cordylanthus palmatus* individuals are being subjected to different environmental conditions. Whether these conditions are physical (e.g. the availability of water or geochemical factors) or biological (e.g. availability of host plants, intraspecific or interspecific competition) cannot be determined from this study and presently is being investigated. However, as suggested by other monitoring results, a long-term management plan for this species at Springtown must consider the fact that some sort of environmental variation at the microhabitat level affects *Cordylanthus palmatus* survivorship, and this fact necessitates the preservation of the range of environmental variation present at the study site. Preservation of multiple microhabitats will likely buffer the plant against conditions that may cause localized reproductive failure.

Because of the temporal patterns in mortality for this species, early-season surveys are likely to misrepresent the actual size of the population of reproducing *Cordylanthus palmatus*. Similarly, these data suggest that surveys during very early parts of the growing season may produce numbers equal to three to six times the reproductive population of *Cordylanthus palmatus*.

Although it seems likely that local temperature and precipitation patterns (see Appendix 4) influence pre-reproductive mortality in *Cordylanthus palmatus*, such patterns in weather-dependent mortality will become apparent only after data have been collected over a number of years. Further, the variation in mortality between transects indicates that survivorship is dependent upon factors more localized than weather. Locally variable environmental factors affecting reproductive success may include topography, hydrology, and soil chemistry. Future research could address any correlation of soil types, topography, and plant distribution, abundance, and reproductive success.

Seed production and viability

Data collected from several randomly selected plants indicated that the number of seeds per *Cordylanthus palmatus* fruit varies considerably, from 2 to 14 (see Figure 19). The mean number of seeds per fruit in this sample (n=97) was 9.09 (s.d. = 2.54).

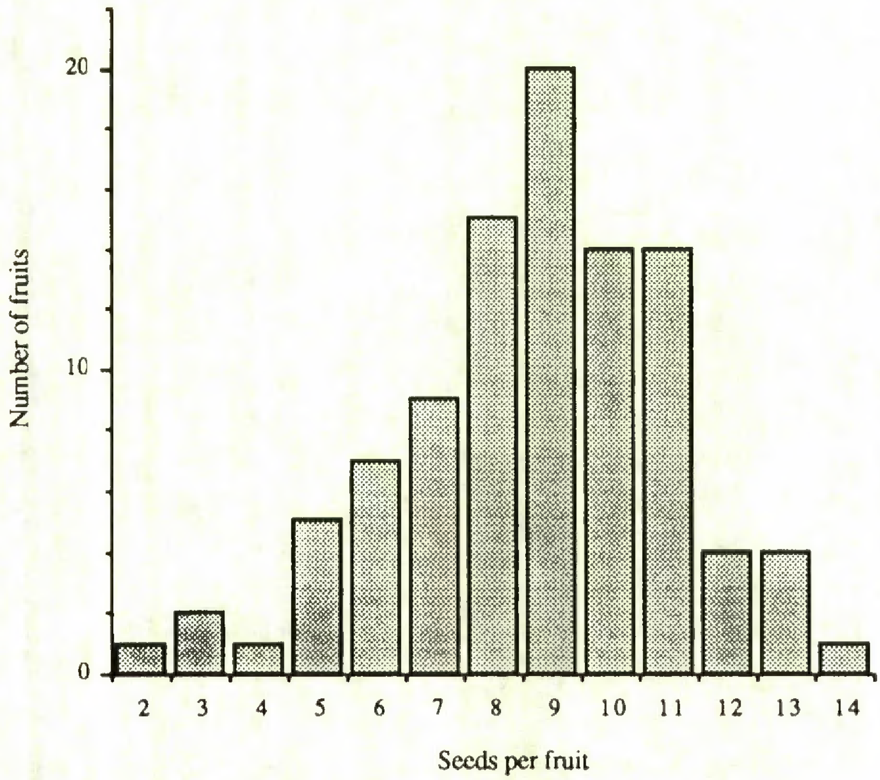


Figure 19. Number of seeds per fruit, *Cordylanthus palmatus*, in a sample of 97 fruits.

As shown in Figure 19, the number of seeds per fruit varies significantly. Further studies might investigate whether plants with large fruit output have fewer seeds/fruit than do plants with fewer fruits. Other investigations could address the relative reproductive success of plants with different numbers of seeds/fruit.

Seed dispersal of *Cordylanthus palmatus* was also investigated. Several characteristics of *C. palmatus* seeds suggest that they may be dispersed by water: their small size, seed coat hairs, and crested seed coat are all morphologically adapted to water dispersal (Howe and Smallwood 1982). We found that, under laboratory conditions, the seeds are quick to float, and long-floating. If *C. palmatus* seeds are indeed dispersed by water, as seems likely, one would expect to see patterns of plant distribution moving gradually downstream in areas with arroyos. Winter rains in 1991, although below average for the area, were sufficient to produce significant local surface flow. Observations made during the course of this study, however, do not indicate that surface flow is carrying *Cordylanthus* seeds far at all; this is reinforced by results shown in Table 5. Additionally, seedling distribution in spring 1991 was generally clustered around the large adult plants of 1990, suggesting that gravity is the key dispersal agent for this species. These observations are consistent with data from mid-scale monitoring, which show little year-to-year change in localized distribution, at least in recent years, and suggest that most viable seeds are not dispersed far from adults.

Flats of soil collected from Springtown in summer 1990 produced a high number and variety of Springtown plant species, confirming that greenhouse conditions met germination requirements for many species. Among the seedlings appearing were 25 *C. palmatus* seedlings (Table 5). An additional 38 individuals germinated from the 150 *C. palmatus* seeds scattered in the three control flats. Samples from which no *Cordylanthus palmatus* appeared were retested; in all five cases, the second trial also had no germination of the bird's beak.

Sample no.	Habitat type	Flat no(s).	Plants T1	T2	Notes
A	**heavily occupied** (within 1 m of an adult *Cordylanthus palmatus*)	A1	6	-	
B	**occupied** (within 1 m of an adult *Cordylanthus palmatus*)	B1	11	-	
C	**occupied** (within 1 m of an adult *Cordylanthus palmatus*)	C1	1	-	
D	**occupied** (within 1 m of an adult *Cordylanthus palmatus*)	D1	3	-	
E	**downstream** of occupied (at least 3 m from an adult *C. palmatus*)	E1, E2	0	0	tested twice
F	**downstream** of occupied (at least 3 m from an adult *C. palmatus*)	F1, F2	0	0	tested twice
G	**downstream** of occupied (at least 3 m from an adult *C. palmatus*)	G1	4	-	
H	**unoccupied**, apparent habitat (more than 10 m from any *C. palmatus*)	H1, H2	0	0	tested twice
J	**unoccupied**, apparent habitat (more than 10 m from any *C. palmatus*)	J1, J2	0	0	tested twice
K	**unoccupied**, apparent habitat (more than 10 m from any *C. palmatus*)	K1, K2	0	0	tested twice
L	**unoccupied**, apparent habitat very far from occupied areas	L1	17	-	50 seeds added
L	**unoccupied**, apparent habitat very far from occupied areas	L2	15	-	50 seeds added
L	**unoccupied**, apparent habitat very far from occupied areas	L3	6	-	50 seeds added

Table 5. Results of greenhouse germination of soil collected from Livermore Springtown Alkali Sink, summer 1990. Flats from samples from which no *Cordylanthus palmatus* germinated were replanted with a second set of soil from the same samples; these (E, F, H, J, and K) showed 0% germination in both tests.

These results suggest that at least some of the *Cordylanthus* germinated in these tests are from seeds produced in the field prior to 1990, and that a viable seed bank for this species does exist at Springtown. Interestingly, all samples from occupied areas (A,B,C, and D) showed some germination; the fifth sample from which *C. palmatus* germinated was downstream of occupied habitat. The lack of germination in samples taken more than 1 m from adult *C. palmatus* suggest that the species' seeds did not travel far at all from the parent plants during recent years.

The control flats, to each of which 50 *C. palmatus* seeds were added (L1, L2, and L3), had an average germination rate of 25%, significantly lower than the 94% germination of Chuang and Heckard (1971). This suggests that the greenhouse conditions of this experiment may have produced artificially low numbers of seedlings. Alternatively, if greenhouse conditions adequately mimicked field conditions that were less than adequate, these results may indicate the presence of seed dormancy in *Cordylanthus palmatus*.

The presence of a seed bank for an annual species such as *Cordylanthus palmatus* has many important conservation implications. It provides the annual plant with some safety in the event of a temporally "local" environmental catastrophe (e.g., fire, disease, or predation). A seed bank can also provide a source of genetic variation for an isolated population (Baskin and Baskin 1978). It effectively spreads out the age structure of a population; if seeds remain viable for four years, for example, at a given time the seed soil bank may represent four generations of individuals.

Germination in various environments

Results of germination experiments with *Cordylanthus palmatus* in various nutrient solution environments (Figure 20) indicate very high germination rates in low-salinity solutions (neutral - 10,000 µmho) regardless of solution pH. This is consistent with the fact that *Cordylanthus palmatus* are found growing in very alkaline scalds (with pH as high as 8.8) where conditions are likely too harsh for other species.

Cordylanthus palmatus was able to germinate (although at low rates) even in very saline solutions (our 80,000 solution is ~5.3% salt, as compared to sea water at 4.04%). This refutes the proposal (USFWS 1985) that *C. palmatus* has salinity tolerances similar to those of *Cordylanthus maritimus maritimus*, which can germinate in water no saltier than 1.2%.

	Alkalinity (pH)				
	6	**7**	**8**	**9**	**Avg.**
Electrical conductivity (µmhos)					
neutral	49.0%	58.0%	60.0%	73.0%	**60.0%**
5,000	45.0%	67.0%	59.0%	67.0%	**59.5%**
10,000	33.0%	22.0%	30.0%	26.0%	**28.0%**
20,000	1.0%	4.0%	5.0%	14.0%	**6.0%**
40,000	14.0%	15.0%	14.0%	10.0%	**13.5%**
80,000	11.0%	8.0%	15.0%	13.0%	**12.0%**
Avg.	**25.5%**	**29.0%**	**30.5%**	**34.0%**	**29.5%**

Figure 20. Germination rates for *Cordylanthus palmatus* in nutrient solutions varying in pH and salinity. Actual *C. palmatus* habitat ranges in pH from 6.0 to 8.8 and in salinity from 800 to 110,000 µmhos.

As shown in Figure 21, patterns in germination rates across solutions of increasing salinity were similar at all four levels of pH. Perhaps most surprising is that, while germination rates were high in pH neutral solutions of low salinity, they were approximately as high or slightly higher at pH 8 and pH 9.

Results of germination experiments in various environments indicate that soil salinity is a major determinant of where and when *Cordylanthus palmatus* seeds will germinate. Seeds grown in solutions that were relatively low in salt had significantly higher germination rates than those in saline solutions – regardless of solution pH (see Table 6). Surprisingly, even in a highly alkaline solution that was low in salt (9N), nearly 75% of the seeds germinated.

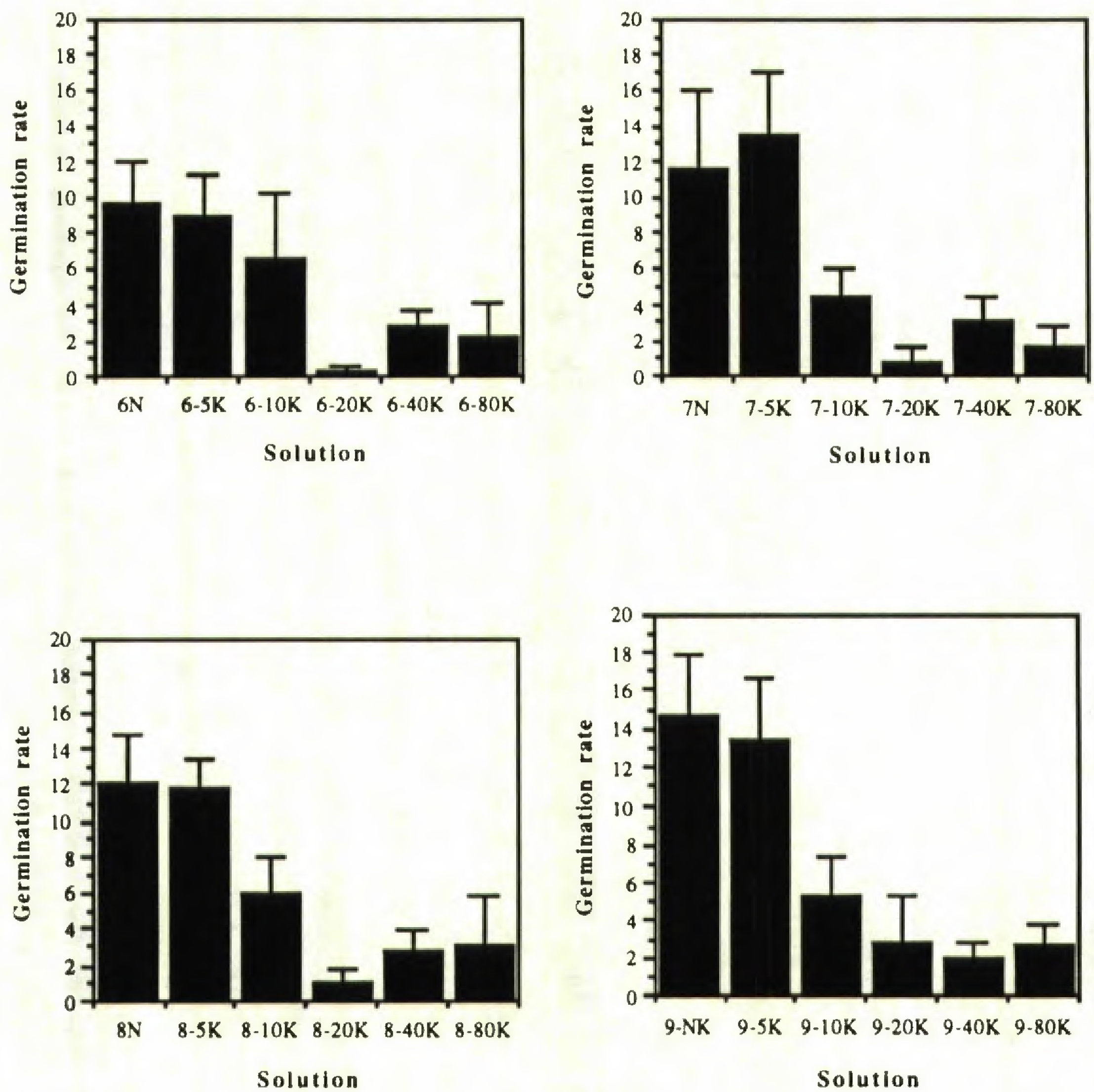


Figure 21. Germination rates for *Cordylanthus palmatus* in varied nutrient solutions, grouped by pH. Rates shown represent the average number of seeds germinated in groups of five replicates of 20 seeds each.

Source	df	Fs		
Subgroups				
A (pH)	3	2.76	$p \approx .05$	marginally significant
B (salinity)	5	90.23	$p <<< .001$	significant
AxB (interaction)	15	1.70	$p \approx .075$	not significant
Within subgroups (error)	96			

Table 6. Two-way analysis of variance of germination rates in nutrient solutions varying in pH and salinity.

Coats *et al.* (1988) found *Cordylanthus palmatus* growing at Springtown in soils that ranged in salinity from 24,000 to 42,000 µmho. The results of our experiment suggest that this observed range is only a portion of the entire range of acceptable germinating habitat for the species. Seeds in the very saline solutions, which correspond to habitat occupied by *Cordylanthus palmatus*, had a very low germination rate (less than 20%, regardless of solution pH) indicating that *Cordylanthus palmatus* is occupying a range of available habitat that is only marginally acceptable.

One hypothesis is that introduced grasses that grow on the less saline soils are crowding out *Cordylanthus* seedlings before they have a chance to become established. This leaves only the saline soils; the relatively small population of adult plants there may represent the tiny proportion of the *Cordylanthus* population able to survive in the harsh conditions. Alternatively, grasses may retard dispersal of *Cordylanthus* seeds, may create an inhospitable environment for their germination, or may provide cover for small mammalian seed predators.

Importantly, wintertime overland flows of water at Springtown create environments that vary in salinity and alkalinity both spatially and temporally. Little is known about the species' ability to survive extreme environments after germination. In this preliminary experiment, a small sample (n=3) of healthy seedlings that readily germinated in a 9N solution were moved after planting to a more saline 9-40K solution (in which no seedlings germinated). Qualitative observations of these seedlings indicated no reaction to the more extreme environment: their growth rates were apparently equivalent to those of individuals that were not moved from the 9N solution. More experimentation is needed to determine quantitatively the effects of saline environments on early growth.

Variation in soil environments

Chemical analysis of soil samples taken across a range of habitat types at Springtown showed great variation across space, even among areas occupied by *Cordylanthus palmatus*. Soil analyses indicated that the electrical conductivity (EC) of soils at Springtown varies from

800 - 110,000 µmho/cm. Soil analysis also indicated that Springtown soil alkalinity ranges from 6.0 to 8.8. Sampled areas that were occupied by *Cordylanthus palmatus* ranged in salinity from 2700 to 110,000 µmho/cm. These areas also ranged in pH from 7.1 to 8.8. Of all areas sampled, *Cordylanthus palmatus* occupied the most saline and the most alkaline. Analysis data are in Appendix 2.

While this small sample set does not give a comprehensive picture of the range of soil environments available at Springtown, it is clear from these measurements of alkalinity and salinity, and from others of calcium, magnesium, sodium, chloride, and boron that environmental variability is very high, and that *Cordylanthus palmatus* persists in a wide range of that variability. Figure 22 displays that variability in the soils of Springtown, and in surface water, all sampled at the time of *Cordylanthus palmatus* germination.

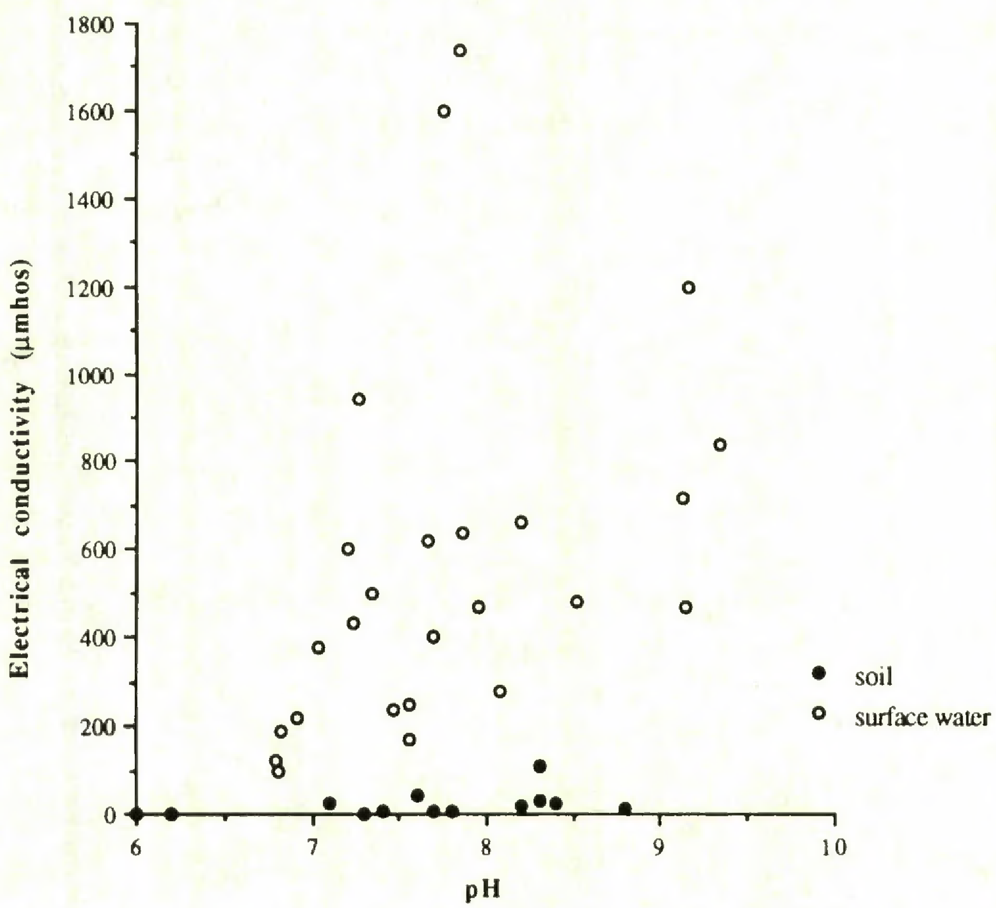


Figure 22. Environmental variability at Springtown as measured in soils and in standing water.

Both salinity and alkalinity were significantly higher for the standing water than the soils, likely due to the water's pooling on soils high in surface salts. These wintertime vernal pools last the entire rainy season at Springtown, and their extreme environments may play an important role in excluding plants that are potential competitors with the bird's beak. (The saltiest pools are classified as oligosaline according to categories drawn up by Cowardin *et al.* 1979).

During this study a qualitative correlation was observed between local distribution of *Cordylanthus palmatus* and wintertime pooling of rainwater. Importantly, examination of aerial photographs taken of the Springtown area over the past 45 years documents that the spatial distribution of these pools has not changed significantly over that period. Unfortunately, no records exist for *Cordylanthus palmatus* at Springtown prior to 1982, so analyses of long-term trends in environmental variation and population size are not possible.

It is clear from this study that salinity and alkalinity of the sink soils varies spatially. Whether this spatial variation is correlated with the distribution of *Cordylanthus palmatus* will be examined in further studies. Variation of sink soils across time also will be followed up in future analyses.

Ecological relationships at Springtown

Pollination biology

Scanning electron micrographs of pollen collected from *Cordylanthus palmatus* clearly show the details of the pollen grains (Figure 23). *Cordylanthus palmatus* pollen is between 10 and 20 μ long, elliptical or spherical, with three lobes. This is relatively small for pollen grains, which range from 5 to 200 μ in size. While the small size of the pollen grains suggests that the species could be wind-pollinated (Iwanami *et al.* 1988), the closed flower morphology of this species makes that unlikely. The strands clearly visible in Figure 24 are likely viscin threads, structures that are thought to help attach pollen grains to the legs of insects (Iwanami *et al.* 1988).

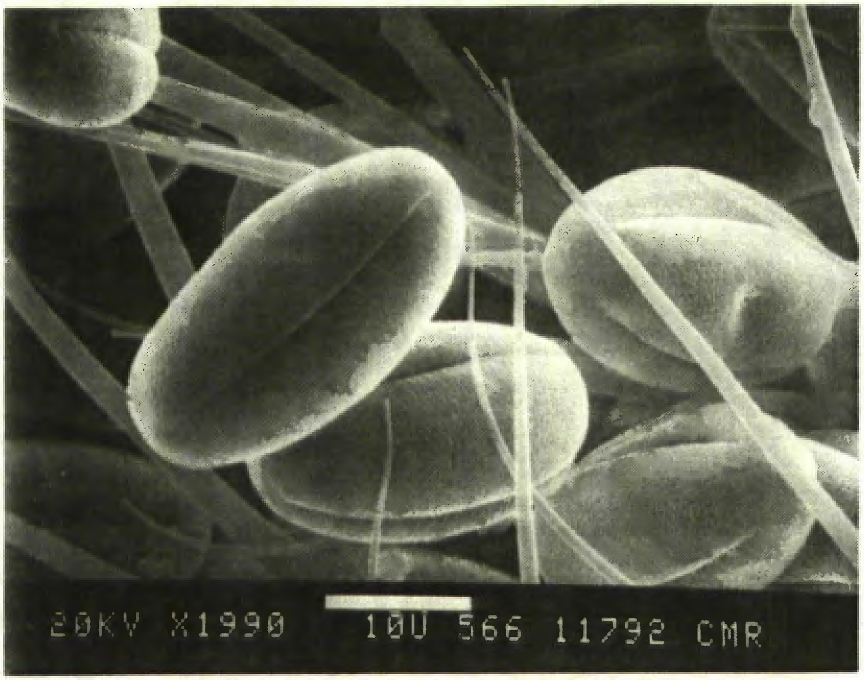


Figure 23. Scanning electron microscope photograph of *Cordylanthus palmatus* pollen. Magnification is 2000x. The white bar at the bottom of the photograph represents 10μ.

In the 1990 and 1991 field seasons, solitary bees (family Halictidae) were observed at *Cordylanthus palmatus*. Scanning electron micrographs of the pollen on the legs of these bees, collected in July 1991, indicates that these bees were carrying bird's beak pollen (see Figures 23 and 24). Bees of this family are known to pollinate at least one other species of the *Cordylanthus* genus, *C. maritimus* (USFWS 1985), and generally are known to be efficient pollinators.

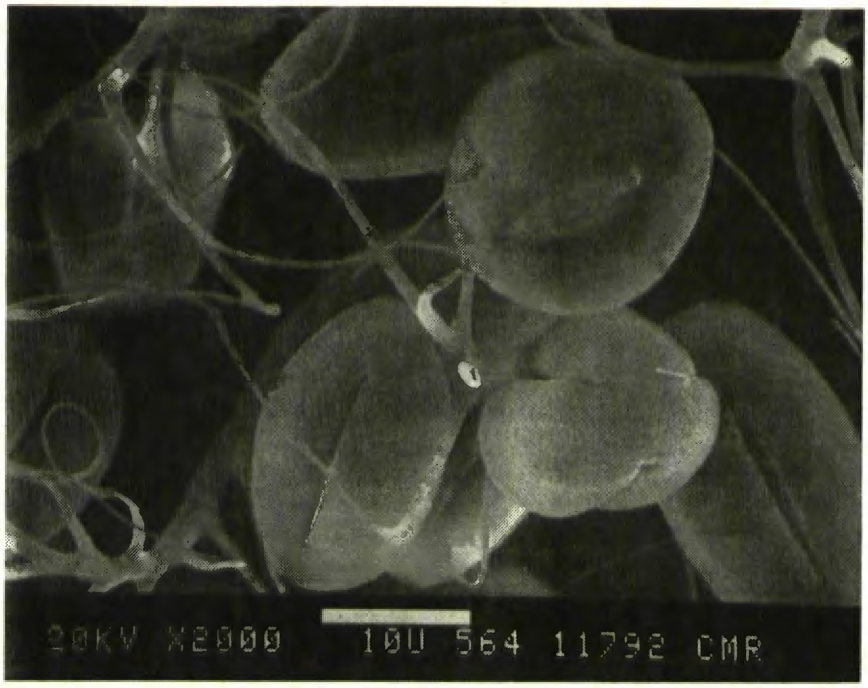


Figure 24. Scanning electron microscope photograph of pollen found on legs of solitary bees visiting *Cordylanthus palmatus* at Springtown. Magnification is 2000x. The white bar at the bottom of the photograph represents 10µ.

While it is not likely that the *C. palmatus* population at Springtown is pollinator-limited, the relationship between the species and its pollinators is in need of further study.

Host-parasite relationships

Observations made in the course of these monitoring efforts did not indicate any pattern of co-distribution of *Cordylanthus palmatus* and other species of the Springtown Alkali Sink. This is consistent with work done in this study and others (Chuang and Heckard 1971) which show that *C. palmatus* can be grown in a greenhouse with or without a host. Field observations of individual adult *C. palmatus* growing meters away from plants of other species suggest that this species also can survive in its naturally harsh environment without a host.

It is likely that *C. palmatus*, like its congener *C. maritimus maritimus*, can establish haustorial connections to any of a number of species. *C. maritimus maritimus*, a salt marsh annual, has been observed in the laboratory and the field to have established connections with *Distichlis spicata* (the salt grass species found at Springtown) and *Salicornia virginica* (pickleweed, also found at Springtown) (USFWS 1985). Chuang and Heckard (1971) also found *C. palmatus* (and other *Cordylanthus* species) to parasitize the common sunflower

(*Helianthus annus*) in the lab, providing evidence that the genus is not host-specific. Unfortunately, the below-ground haustorial structures of this species are extremely delicate, making their examination and study quite difficult.

Given this evidence, it seems unlikely that *Cordylanthus palmatus* is limited by host availability. However, increasing pressure on the groundwater supply, and general changes in hydrology in the Springtown region, may eventually have a negative impact on any or all of the suite of available host species in the sink, thus indirectly affecting the *Cordylanthus palmatus* population at Springtown.

Herbivory

There were very few observations of herbivore damage. The eggs of two species of herbivorous insects of order Heminoptera (the true bugs), most likely one species of pentatomid and one species of lygaeid, were found on mature *Cordylanthus palmatus* plants. However, no larval or adult herbivorous insects were observed on *Cordylanthus* plants. In 1990, cattle appeared to inadvertently uproot *Cordylanthus* plants, but it did not appear that cows were eating significant numbers of individuals. Along the paths in the southeast portion of the site uprooted *Cordylanthus* plants were occasionally seen; these plants seemed to have been disturbed by human foot or bicycle traffic.

Conclusion, summary, and recommendations

Although restricted in overall distribution to only four known locations in central California, the federally- and state-endangered *Cordylanthus palmatus* (palmate-bracted bird's beak) is locally abundant at the Springtown Alkali Sink in Livermore, California. This population is one of the two largest populations of the species (along with that of the Delevan National Wildlife Refuge) and the only population whose size has been reliably measured.

The Springtown population consisted of roughly 10,000 individuals in both 1990 and 1991. Population size and distribution across the site varied little between years. While the number of individuals and overall distribution of occupied habitat remained consistent, the number of individuals present in specific regions of the Springtown sink changed greatly in magnitude and direction between years. Further work is necessary to identify the apparently local factors causing the slight decline in number of individuals in the southeast portion of the site, the increases elsewhere, and the very substantial increase in the western portions of Springtown.

While it is tempting to attribute the *Cordylanthus palmatus* population increase in the northwest portion of the site to the removal of cattle in early 1991, such a link is not substantiated by this study. Likewise, while the observed increase on the FCC lands (west Springtown) could reflect the continual recovery of the species on that site following the cessation of major habitat disturbance (agriculture and discing), it is impossible to conclusively link the two without experimental manipulation.

Fortunately, the Springtown population of *Cordylanthus palmatus* apparently is robust, is resistant over the short-term to habitat alteration, and persists even in the face of at least some small-scale disturbances, thus is not restricted to "relatively undisturbed saline-alkaline soils" as has been reported (Showers 1988 and others). At Springtown, the plant has survived in or recolonized areas that have been significantly disturbed; in both years of study, large numbers of plants were found on the formerly agricultural lands of the FCC as well as along paths in the southeast portion of Springtown that are heavily traversed by foot, bicycle, and ORV traffic.

Given the general propensity of wetlands to undergo substantial natural environmental variation (for example, in the amount of surface flow, or pattern of silt deposition), it is not surprising that an inhabitant of such an ecosystem seems to be fairly resistant to short-term and localized disturbances. Natural disturbances can be an integral part of such ecosystems; by creating a mosaic of microhabitats, disturbances can increase the potential biological diversity an area can support. However, the lack of historical data precludes correlation of natural habitat disturbance with changes in *Cordylanthus palmatus* distribution and abundance. In addition, the natural disturbance regime at Springtown has been radically changed (notably through alteration of the region's hydrological patterns) and suggests that experimental studies of the impacts of anthropogenic habitat disturbance are more immediately important.

The data from this study represent a baseline from which future measurements or estimates of population size and distribution can be compared. Although data from two years cannot allow definitive assessments of population viability, the large number of plants maturing in each of these two years and the presence of a seed bank for this annual plant indicates that this species is not at immediate risk of extinction. Large numbers of seeds survive through germination, and a large percentage of seedlings receive enough water and nutrients to mature and produce seeds. Herbivory does not appear to be substantially impacting the plants. And, the tremendous number of seeds produced each year indicates that pollination is not likely to be limiting population size. While additional ecological research at Springtown is required to elucidate the relationships among species there, no species- or community-level threats to *Cordylanthus palmatus* were obvious at Springtown.

However, incremental habitat loss continues to threaten *Cordylanthus palmatus* and the entire Springtown Alkali Sink ecosystem. Much of the sink has already been lost to a housing development, and modification of the remaining areas has been substantial. Discing of *Cordylanthus* habitat included in and adjacent to the study site is likely disrupting the site's hydrologic patterns and may constitute a source of excessive silt. Illegal dumping and ORV use continue to impact Springtown habitats directly and may have long-term effects on both the ecosystem and the plant.

The 180 ha Springtown study area represents much of the remaining habitat for this species: although distribution of the valley sink scrub in California was once extensive, today less than 20% of the original habitat area remains (Showers 1988). The population of palmate-bracted bird's beak at Springtown includes approximately half of all remaining individuals of this species. Of this population, approximately 75% was on privately owned property in 1991; the remaining habitat of this species is far from well-protected.

Our specific management recommendations over the short term are as follows.

1. Protect Springtown as an ecosystem. Given the evidence that distribution of the *Cordylanthus palmatus* population shifts across available habitat at Springtown (Showers 1988, Coats *et al.* 1988, this study), the only rational long-term conservation strategy is to protect as much of the remaining sink habitat at Springtown as possible. Heterogeneity in topography and soil type are likely key to local distribution of *Cordylanthus palmatus* and other alkali sink species. Local shifts in distribution may be the species' response to variation in environmental or ecological parameters, and habitat heterogeneity may provide a necessary buffer against such variation. There exists an excellent opportunity to restore portions of the Springtown Alkali Sink ecosystem to provide additional habitat for the bird's beak; however, it is essential that this restoration provides for the maintenance of habitat refugia for *Cordylanthus palmatus* by leaving untouched existing habitat.

A biological community-level approach to conservation planning, including

Cordylanthus palmatus and selected other species as target organisms, likely is the only method for successful preservation of Springtown's biological diversity.

2. Maintain current hydrologic patterns. Hydrologic patterns are clearly important to this annual plant. Until more is understood about dispersal of *Cordylanthus palmatus* seeds, the species' ability to tap groundwater resources, and host-parasite relationships, existing groundwater and surface flow patterns should be protected. The conservative route is to maintain current surface flow and groundwater patterns, a regime in which the plant apparently does well. The integrity of the shallow groundwater basins must be maintained; tapping of the water table should be minimized. Because the Springtown study area receives surface and groundwater flows from the entire 7000 ha basin, maintenance of the existing hydrologic regime will require protection and monitoring of the entire large sink region.

It is important to note that maintenance of current hydrologic patterns does not necessarily eliminate the possibility of development in the basin. Evaluation of proposed development must include consideration of the potential hydrologic changes the project would bring to the overall Springtown system. Both the quantity and quality of water entering the sink must be taken into consideration. In addition, upstream development should not alter the amount of silt being deposited on the site, and extreme care must be taken to control the types and amounts of fertilizer, herbicides, pesticides, and other contaminants entering the Springtown system.

3. Minimize destructive land use practices. This study indicates that the bird's beak population has been stable over the past two years and thus that present land use patterns, especially on the north and southwest portions of the site, are compatible with short-term survival of this species. Again, before data have been collected to suggest how changes in these patterns may affect the species, land use should not be dramatically changed. Grazing should be kept to a minimum, particularly during those times of the year when the ground is wet, as livestock are attracted to wet areas. This is likely most important in the winter months when *Cordylanthus palmatus* seedlings are small and most subject to damage from trampling. Experimental work is necessary to determine whether late spring or summer grazing is compatible with *Cordylanthus palmatus* in the Springtown ecosystem. Finally, experimental habitat restoration efforts should be confined to small areas until their effects on the species are known.

Off-road vehicle use has severely degraded parts of *Cordylanthus palmatus* habitat, particularly in the southeast but also in the southwest portions of the site. In these and other areas occupied by *Cordylanthus*, vehicle use and other habitat disturbance should be eliminated.

4. Minimize site contaminants. Dumping of debris, including household and garden trash, is common in parts of the Springtown alkali sink and should be eliminated. Small-scale dumping is most likely not much of a threat because it occurs largely along the unoccupied perimeter of the site. However, large-scale dumping and all dumping in occupied areas and stream channels could easily eliminate large areas of occupied and unoccupied *Cordylanthus* habitat and disrupt significant portions of the ecosystem.

Perhaps more threatening to *Cordylanthus palmatus* habitat are herbicides that have been applied to vegetation growing along adjacent roads. These chemicals could drift aerially onto *Cordylanthus palmatus* or, worse, enter the water supply and threaten a variety of Springtown vegetation. Roadside herbicides should be immediately banned on roads adjacent to the Springtown study area. As well, agricultural runoff (silt, fertilizer, etc.) from upland portions of the sink should be minimized.

5. Implement experimental management regimes. The complexity of *Cordylanthus palmatus* and the Springtown ecosystem preclude the possibility of completely understanding all aspects of the system before conservation efforts are established. This does not imply the need for endless research; rather, it calls for the implementation of experimental restoration and conservation activities. Initial restoration activities should be conducted on a small scale and monitored for impacts on *Cordylanthus palmatus* as well as other members of the ecosystem.

As different areas of Springtown are under different experimental regimes (e.g. invasive restoration efforts, limited grazing), some areas must be left unchanged both to provide experimental controls and to allow for environmental heterogeneity.

6. Monitor the Springtown population on a regular basis. Evaluation of the efficacy of these management recommendations requires regular mid-summer monitoring of the distribution and abundance of the palmate-bracted bird's beak at the Springtown site. This may be most efficiently executed by monitoring of a select set of 50 m quadrats encompassing a range of currently occupied and unoccupied habitat types available at the sink. This set of quadrats will be identified prior to the initiation of monitoring in summer 1992.

7. Encourage local participation in conservation planning. The juxtaposition of the Springtown Alkali Sink and a growing residential population presents an excellent opportunity for local participation in conservation planning. The involvement of Livermore citizens at the early stages of conservation planning can only encourage cooperation. The matrix of land ownership at Springtown and the variety of legal jurisdiction over the lands can complicate the planning process, however, and requires the involvement of all parties in the planning process. Federal, State, and City agencies, WetlandX, local landowners, and others knowledgeable about or interested in the Springtown habitat or *Cordylanthus palmatus* must continue to communicate with each other through the Working Group and to be involved with regional planning efforts to protect the Springtown ecosystem.

The CCB studies are among only a handful ever attempted on *Cordylanthus palmatus*. The Center's intensive monitoring efforts document the status of the Springtown population during the past two years, but no way exists to know whether measured changes reflect natural fluctuations in population size or indicate responses to increasing human pressures. Only with long-term data collection and analysis will the pieces fit into a coherent conservation planning effort.

It is important to remember that *Cordylanthus palmatus* is but one member of an ecosystem. Its endangerment is a signal that California's alkali sink scrub ecosystems are dwindling to dangerously low levels. Especially where the threat of development is great, protection of the alkali sink as a healthy whole will mean more – ecologically and socially – in the long term than mere conservation of the bird's beak, one of the ecosystem's first species to attract our conservation attention.

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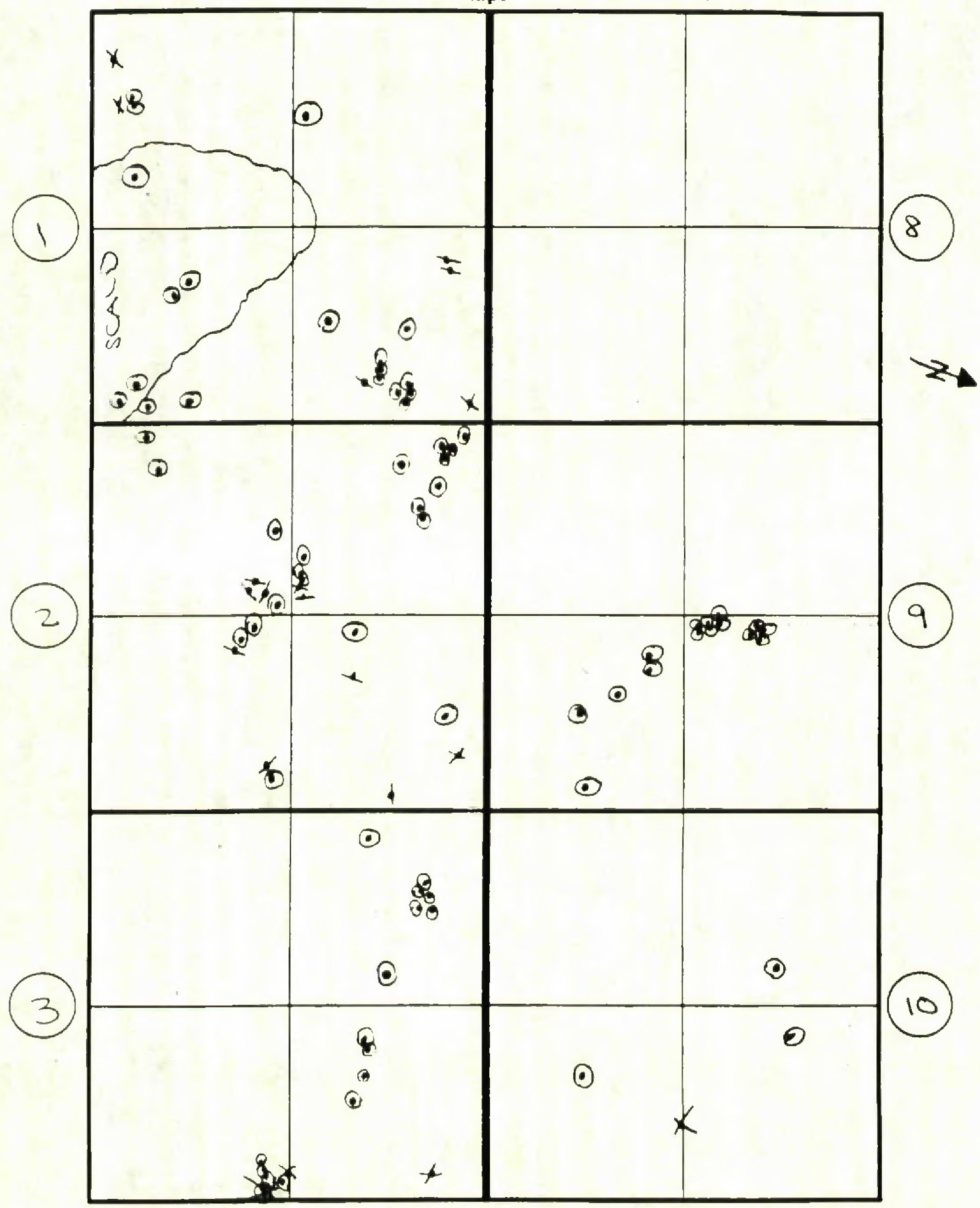
Appendix 1: Sample demographic monitoring data sheet

Plot name: Anden 1

Monitoring date: as of 2 July 1991 **tape** monitored 15 July 1991



Appendix 2: Soil and water chemistry test results

Habitat type	pH	EC	SP	Ca+Mg	Na	Cl	SAR	ESP	Boron
occupied channel bottom	7.7	3.6	64	8.6	26.6	28.4	13.0	15.0	6.2
unoccupied channel bottom	7.4	3.4	76	10.7	3.3	22.4	1.4	1.6	5.0
occupied channel side	8.2	19.5	30	59.7	176.0	220.0	32.0	32.0	22.5
occupied channel bottom	8.3	110.0	25	194.0	182.0	232.0	19.0	21.0	25.0
occupied channel	8.4	21.3	46	74.6	240.0	198.0	39.0	36.0	22.5
unoccupied grassland	6.0	1.1	35	4.4	4.8	5.4	3.2	3.6	6.6
occupied scald/grassland	7.1	23.5	42	87.6	160.0	260.0	24.0	26.0	22.5
occupied scald/grassland	7.3	2.7	34	2.7	20.0	21.2	17.0	19.0	8.0
occupied scald	8.3	29.0	25	10.8	117.0	270.0	50.0	42.0	25.0
unoccupied scald	7.6	40.0	25	117.6	366.0	440.0	48.0	41.0	24.2
occupied upland	7.8	7.7	79	12.8	56.7	68.0	22.0	24.0	11.4
occupied upland, sandy	8.8	12.5	48	8.3	130.0	80.0	64.0	48.0	11.3
unoccupied mima mound	6.2	0.8	44	3.6	4.2	2.6	3.1	3.5	1.8

Figure A2-1. Chemical analysis of soil samples taken mid-January 1991 at Springtown Alkali Sink. EC (electrical conductivity) is measured in mhos; SP is saturation percentage; Ca + Mg is measured in milliequivalents (me/l) per liter of saturation extract; Na (in me/l); Cl (in me/l); SAR is sodium adsorption ratio; ESP is exchangeable sodium percentage; boron is measured in ppm.

Appendix 3: Groundwater in the Springtown area

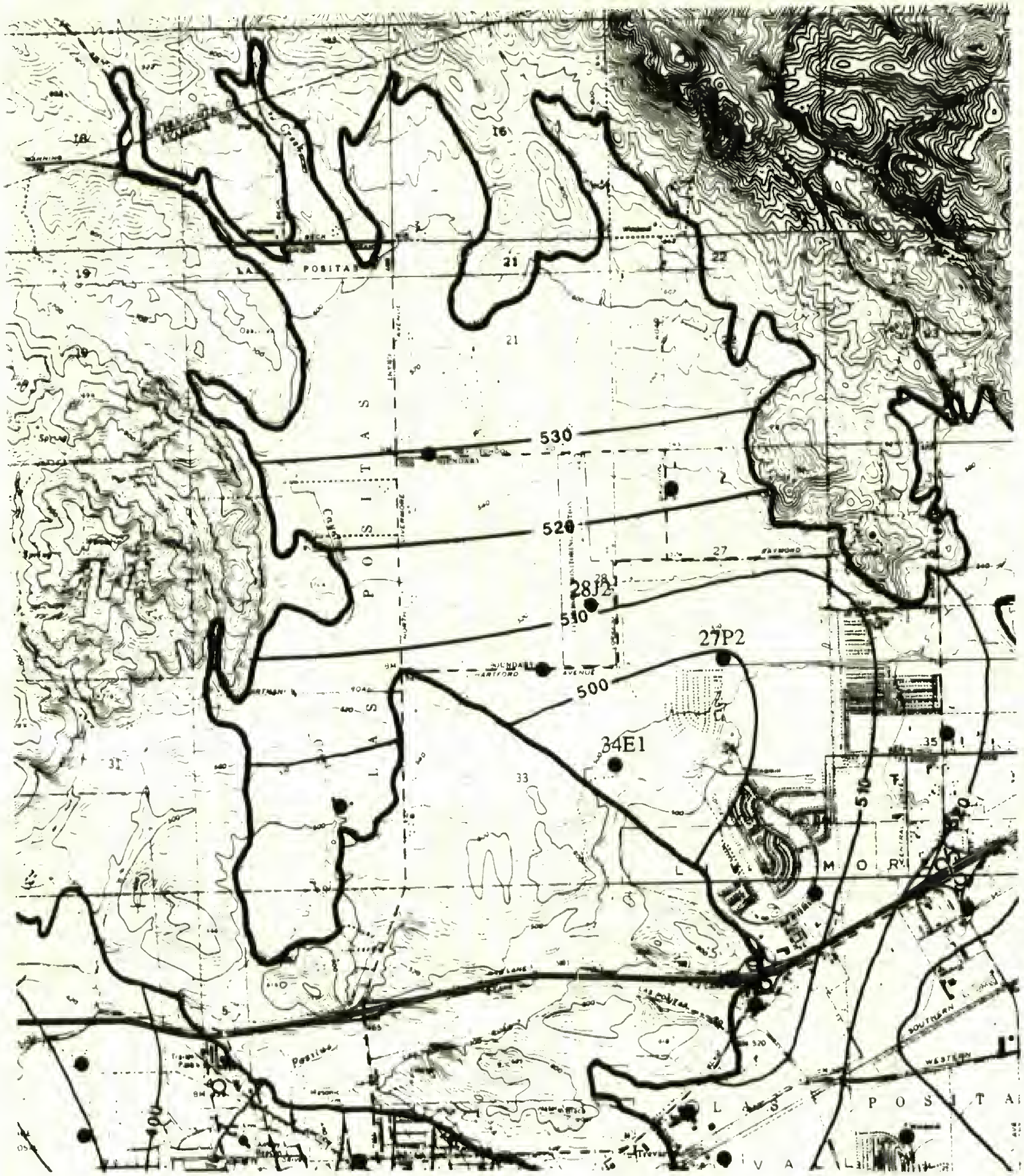


Figure A3-1. Groundwater wells near Springtown Alkali Sink. Wells are kept by Zone 7 of the Alameda County Flood Control and Water Conservation District. The hygrochemographs on the following pages correspond to the well numbers marked on this map.

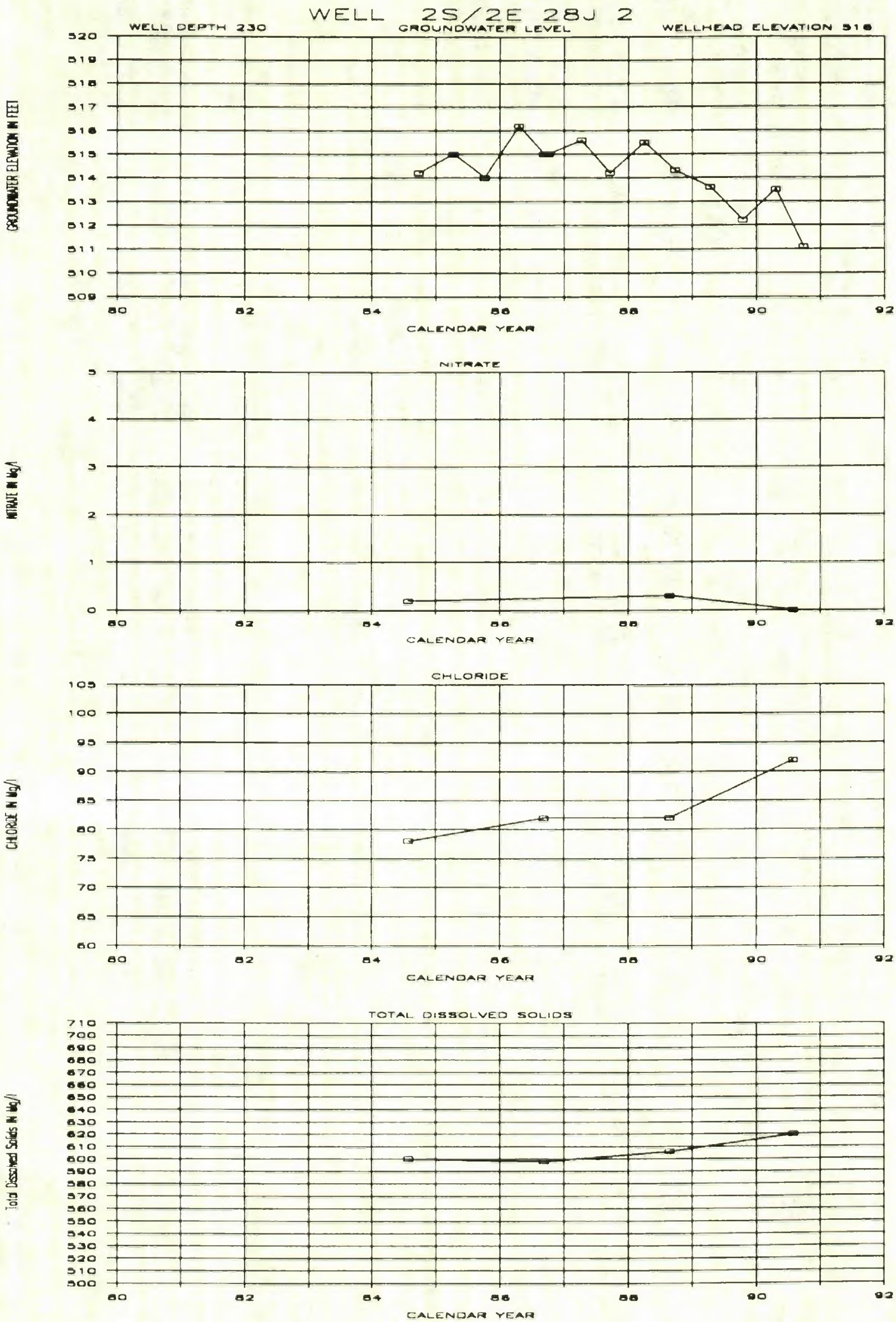


Figure A3-2. Hygrochemograph, well number 28J2.

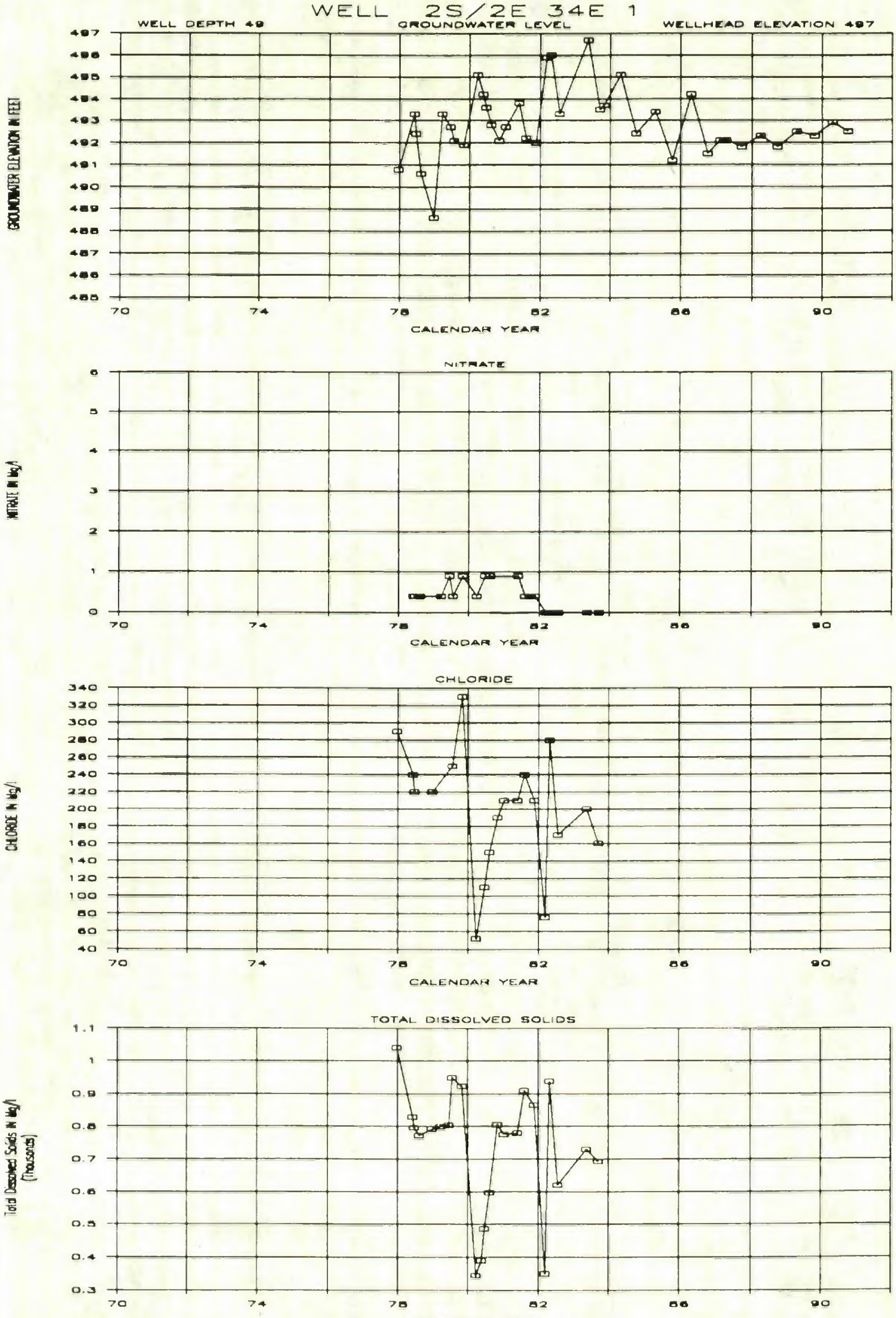


Figure A3-3. Hygrochemograph, well number 34E1.

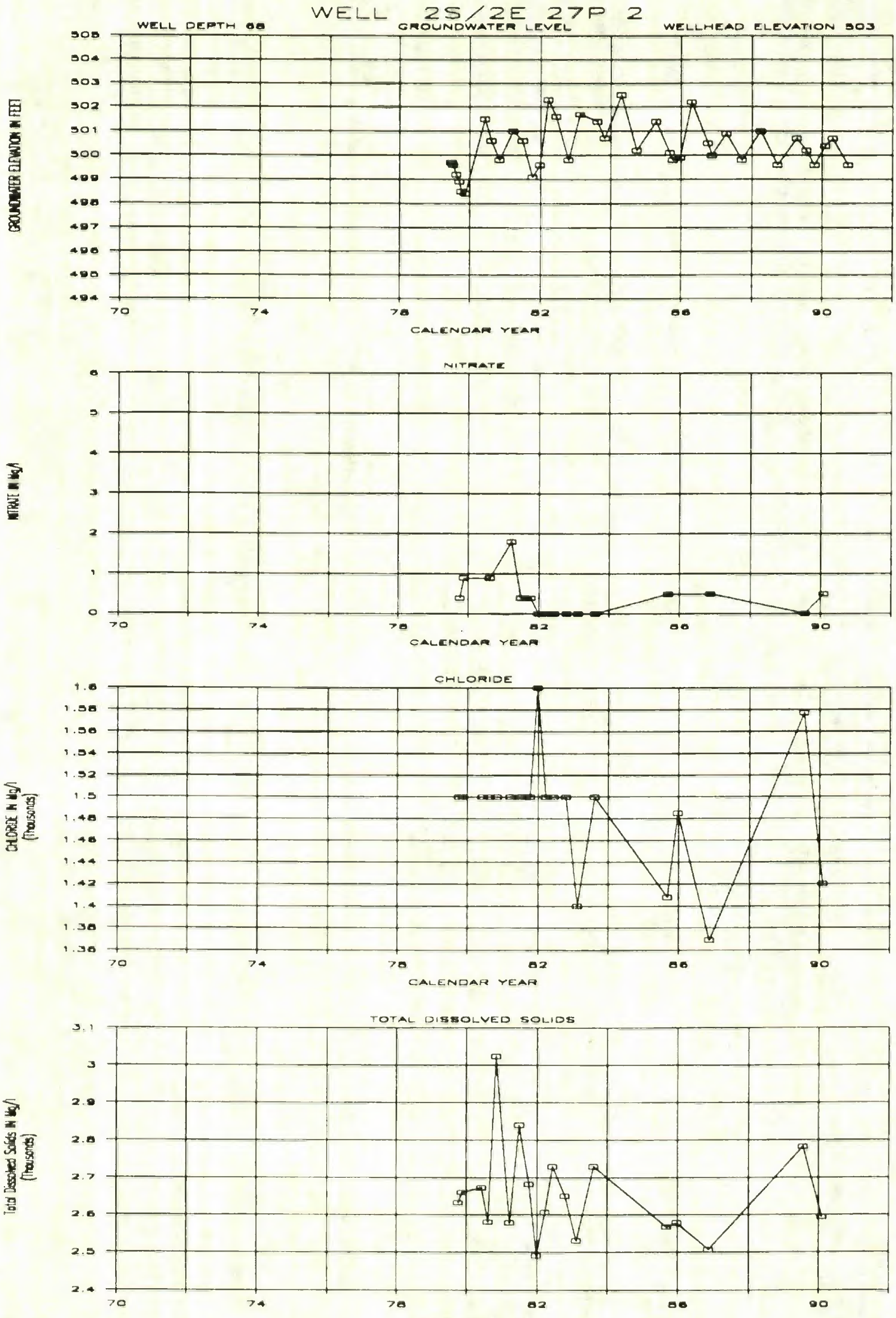


Figure A3-4. Hygrochemograph, well number 27P2.

Appendix 4: Weather in the Springtown area

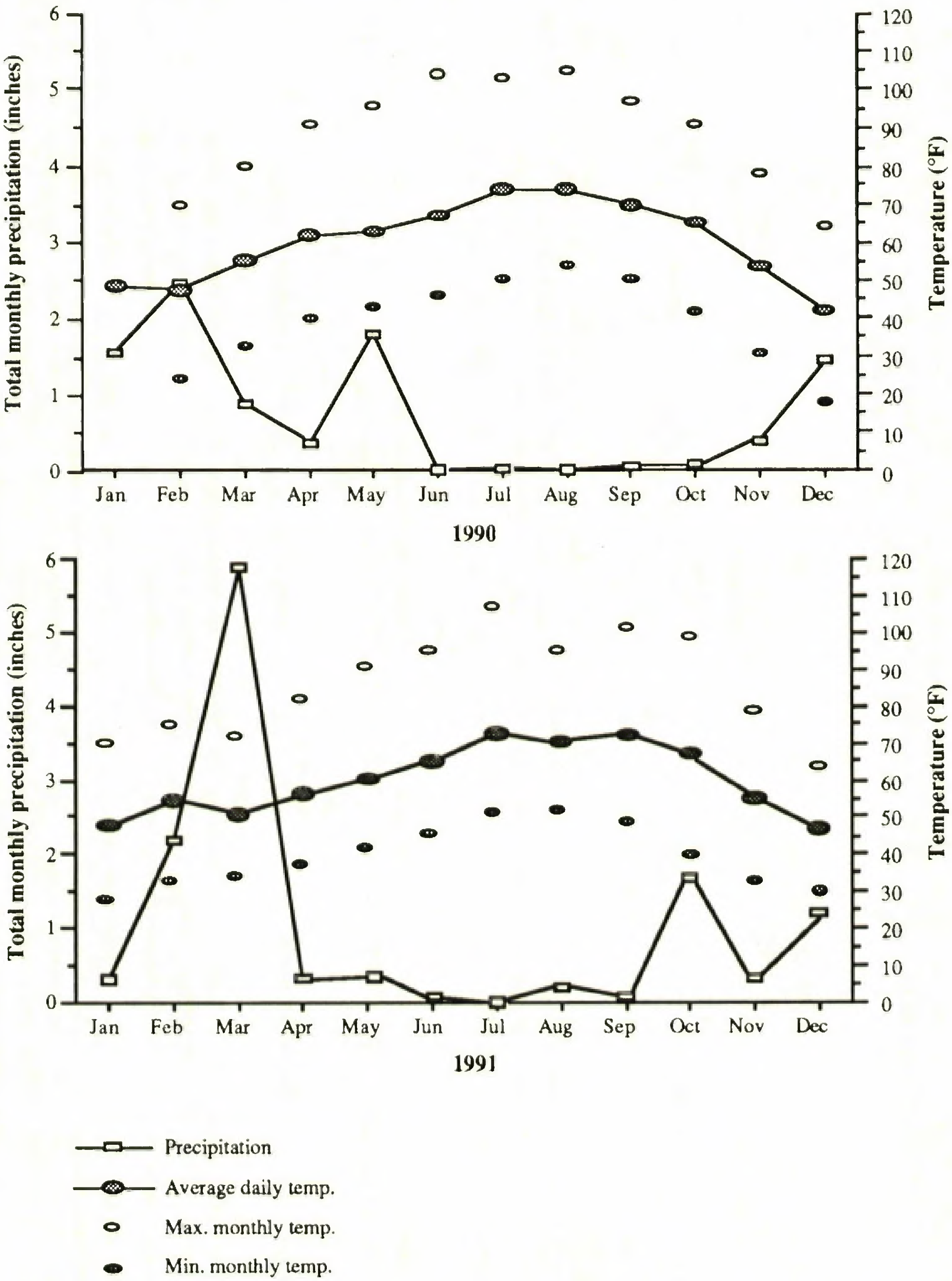


Figure A4-1. Annual weather patterns at Springtown Alkali Sink. Data recorded at Livermore monitoring station.

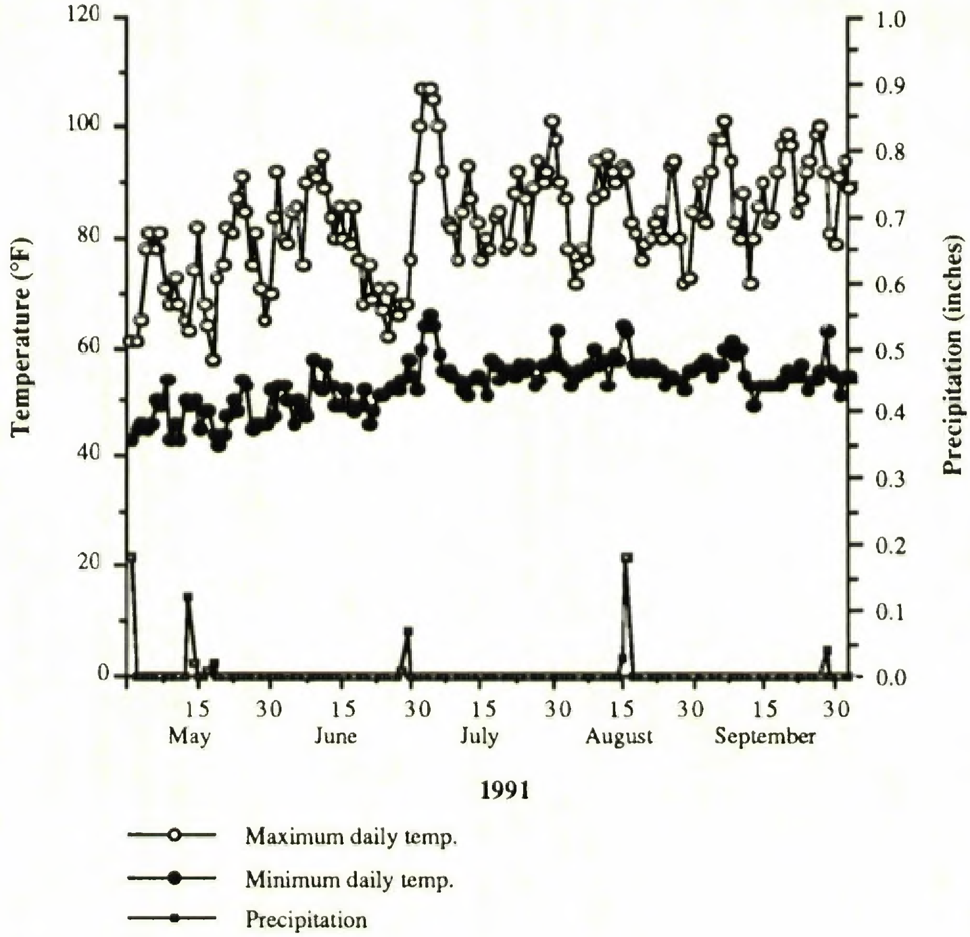


Figure A4-2. Temperature and precipitation patterns at Springtown Alkali Sink during the 1991 growing season.

Appendix 5: Project personnel

Alan E. Launer, Ph.D., project co-coordinator, has been involved in biological research throughout the western United States and New England for more than ten years. His recent research includes work on the distribution of plant and moth species native to the serpentine soil-based grasslands of central California, the trophic ecology and conservation biology of lower vertebrates, and the evolutionary ecology of *Euphydryas* butterflies. Dr. Launer has experience with the management and propagation of native California plant species, reserve design, species conservation plans, and the design and implementation of demographic monitoring plans.

Kathy Rehm Switky, project co-coordinator, has a broad background in conservation biology, ecology, and the communication of scientific results. She has participated extensively in a number of Center field and laboratory research projects, including studies of several of California's endangered plant species, a phenological study of native grassland plants in Santa Clara County, and experimental and monitoring studies of invertebrates and small mammals.

Erica Fleishman, research assistant, has over four years experience assisting on a variety of Center projects. As a Stanford University student she has been extensively involved with field studies in California and Colorado, with the design and manipulation of large computer data bases, and with greenhouse propagation of endangered plants.

Stuart B. Weiss, research associate, has been involved in field research on endangered species in California for ten years. He has been a major contributor to the Center's long-term Bay checkerspot butterfly research program, including development of a solar exposure/topoclimate model for California grasslands, the basis for an innovative approach to conservation planning. He has contributed to the San Bruno Mountain Habitat Conservation Plan and the Kirby Canyon Conservation Agreement.