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RECENT ECOLOGICAL INVESTIGATIONS AND PRESENT STATUS OF THE ENDANGERED SANTA ANA RIVER WOOLY-STAR, ERIASTRUM DENSIFOLIUM SSP. SANCTORUM (MILLIKEN) MASON

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INTRODUCTION

Eriastrum densifolium ssp. sanctorum (E.d.s.) is a member of the phlox family, Polemoniaceae. The plant is a short-lived perennial sub-shrub found only in the floodplain of the Santa Ana River in San Bernardino County. Terminal bracteate heads produce clusters of showy tubular flowers that attract hummingbirds, swallowtail butterflies, skippers, blue butterflies and many species of bees and flies. E.d.s. is a primary source of seasonal color, forming an attractive profusion of blue when aggregations of plants flower in late May, June, and July.

The restricted range and potential vulnerability of E.d.s. was first reported by Zembal and Kramer (1984). Historically, E.d.s. probably occurred along approximately 60 miles of the Santa Ana River, but the plant is now restricted to about eight linear miles of floodplain. The habitat is located from near the mouth of the Santa Ana River canyon, at the foot of the San Bernardino Mountains, and extending west to the floodplain in the vicinity of Norton Air Force Base in San Bernardino County.

In addition to a restricted geographical range, Zembal and Kramer (1984) recognized that E.d.s. was apparently confined to certain flood-mediated habitats within the floodplain such as sand terraces and washes. Areas downstream from the present range are no longer suitable E.d.s. habitats due to development, river channeling, and flood control activities (Zembal and Kramer, 1984; Walt Wright, personal communication).

In 1984, Zembal and Kramer strongly recommended the protection of remaining E.d.s. habitat and a study of E.d.s. autecology. In October 1987, E.d.s. was listed as endangered by the Federal Government. The following report summarizes the ecological behaviors and habitat requirements of the Santa Ana River Wooly-star, **Eriastrum densifolium sanctorum**, as they are currently understood based on recent investigations (Burk **et al**, 1987). The status of remaining habitat in terms of human mediated disturbance is also discussed. This research is ongoing and will provide guidelines for mitigation of the effects of Seven Oaks Dam, a Corps of Engineers flood control project currently under construction in the Santa Ana River canyon upstream from all verified E.d.s. habitat. E.d.s. habitat is ephemeral with respect to successional time. Rejuvenation of habitat is therefore threatened by the control of periodic flooding.

METHODS

Habitat analysis: In June 1987, we mapped the distribution of E.d.s. in the Santa Ana Wash (Burk **et al**, 1987). In late June and early July, five large subpopulations were selected for intensive sampling. We intentionally chose widely separated sites so that variability of habitat throughout the floodplain could be investigated. These five sites were each paired with a nearby site that did not support E.d.s., resulting in five pairs of sites. The pairing of sites was possible because of the aggregated nature of E.d.s. dispersion. The five sites supporting E.d.s. were named 1A-5A; each paired site without E.d.s. was named 1B-5B.

At each site a 100 meter east/west axis was established. Five points along this axis where randomly selected. Northward from each point, a 30-meter line transect was used to record cover based on intercept length of perennial plant species, combined annuals, dead shrubs, and rock (Burk et al, 1987). Of the five randomly placed lines at each site, the center and end lines were utilized to collect surface (0-10 cm depth) and subsurface (15-25 cm depth) soil samples and data on ambient and surface insolation. The soil samples were analysed to provide values for surface and subsurface pH, salinity, micro-organics, and texture. Soil texture was classified as large gravels (1.25-10 cm), small gravels (0.2-1.25 cm), sand (0.05-2 mm), silt (0.002-0.05 mm), and clay (< 0.002 mm). Soil texture was analysed using the standard Bouyoucos hydrometer method as outlined by Cox (1985).

The line intercept and site data were organized for two separate multivariate DRA (detrended reciprocal averaging) analyses (Pimentel and Smith, 1986). To clarify whether E.d.s. habitat differed from adjacent paired sites in terms of constituent species, a species response matrix (excluding E.d.s.) vs. sample sites was analysed. A second matrix of environmental characteristics (substrate and insolation) vs. sample sites was then analysed to identify differences, if any, in environmental conditions between habitats supporting E.d.s. and adjacent unpopulated habitats.

Seedling survivorship: On 6 and 7 November 1987, initial sets of individual seedlings were permanently marked for the purpose monitoring suvivorship at the five E.d.s. study sites. Permanent plots (0.25 m^2) were systematically positioned within 1.0 meter and generally southwest of the base of reproductive E.d.s. adults. Preliminary seed dispersal measurements conducted in late September and October 1987 indicated that most seeds disperse within 1.0 meter of the mother plant; moreover, preliminary measures of seedling density taken on 28 October similarly indicated maximium densities within one meter and generally southwest of the mother plant.

Rain data are those recorded by the nearby Redlands Daily Facts newspaper. Measurements obtained from a raingauge I installed on 29 November 1987 at a central location within the floodplain coincide well with measurements of precipitation taken on the newspaper premises from 29 November 1987 to 11 April 1988.

From 15 November through 9 December 1987, I placed supplemental plots at four of the five sites. No supplemental plots were established at site 3A because this site seems to represent habitat that is modified regularly by seasonally active, minor washes. Seasonal disturbance would have regularly reversed any local successional processes on the 3A site. The other sites (1A, 2A, 4A, and 5A) represent terrace habitats that have apparently been modified only during flood years. These terrace sites are similar in that successional processes would not have been reversed since the initial formation of the terrace.

It was not possible to mark all seedlings of the initial cohort at each site on one day. Seedlings marked later than 6-7 November but before 10 December 1987, were considered to be members of the initial cohort based on: 1) limited precipitation during this period (only 23 mm spread over 5 separate dates) and 2) the absence of subsequent recruitment during this period in plots established on 6-7 November. All seedlings marked between 6 November and 10 December were therefore assumed to be members of the cohort that germinated in response to 104 mm of precipitation recorded from 12 October to 5 November 1987 (spread over 12 separate dates).

A total of 125 permanent 0.25 m^2 plots were placed in the field between 6 November and 9 December 1987. At sites 1A, 2A, 4A, and 5A respectively, 31, 26, 31, and 31 plots were established. These plots have been monitored regularly from time of placement to the present in order to follow seedling survivorship and recruitment over time.

Adult mortality: Dead E.d.s individuals were collected at each of the five study sites. The root crown was sectioned and the cut surface polished to allow descrimination of growth rings.

RESULTS

Habitat and vegetation analyses: With a single exception, DRA analyses (Fiq. 1 and 2) showed that habitats supporting E.d.s. differed from adjacent habitats without E.d.s., both in species composition and environmental characteristics. Sites 1A-5A (those supporting E.d.s.) are relatively open. Surface insolation is higher, and clays and silts form a lower percentage of the soil composition. The percentage of sand in the soil is higher at the A sites. Salinity and percent micro-organics are lower in habitats supporting E.d.s. The analysis suggests that Croton californica, Heterotheca fastigiata ssp. villosa (formerly Chrysopsis fastigiata), Ericameria pinifolia (formerly Haplopappus pinifolius), Eriodictyon trichocaylx and Lepidospartum squamatum are species with distributions and habitat requirements that are similar to E.d.s. In contrast, species occurring on B sites such as Adenostoma fasciculatum, Artemisia californica, Brickellia californica, Prunus illicifolia, Rhamnus crocea, Rhus ovata, and Solanum xanti were never found on E.d.s. sites.

The exception was site 5B, which was more closely related to the A sites than to B sites, based on either associated species or physical characteristics. See discussion for an explanation of this anomaly.

Except for site 5B, the A sites are distinctly segregated from B sites (Fig. 1 and 2). In addition, A sites form a spectrum with respect to the B group of sites. Two of our A sites (2A and 4A) plotted relatively close to the grouping of B sites; this indicates that habitats in 2A and 4A exhibit characteristics that relate them to the B group. Two other sites (1A and 5A) plot away from the B group; habitats at 1A and 5A are relatively less similar to habitats on B sites. One site (3A) plots in an intermediate position.

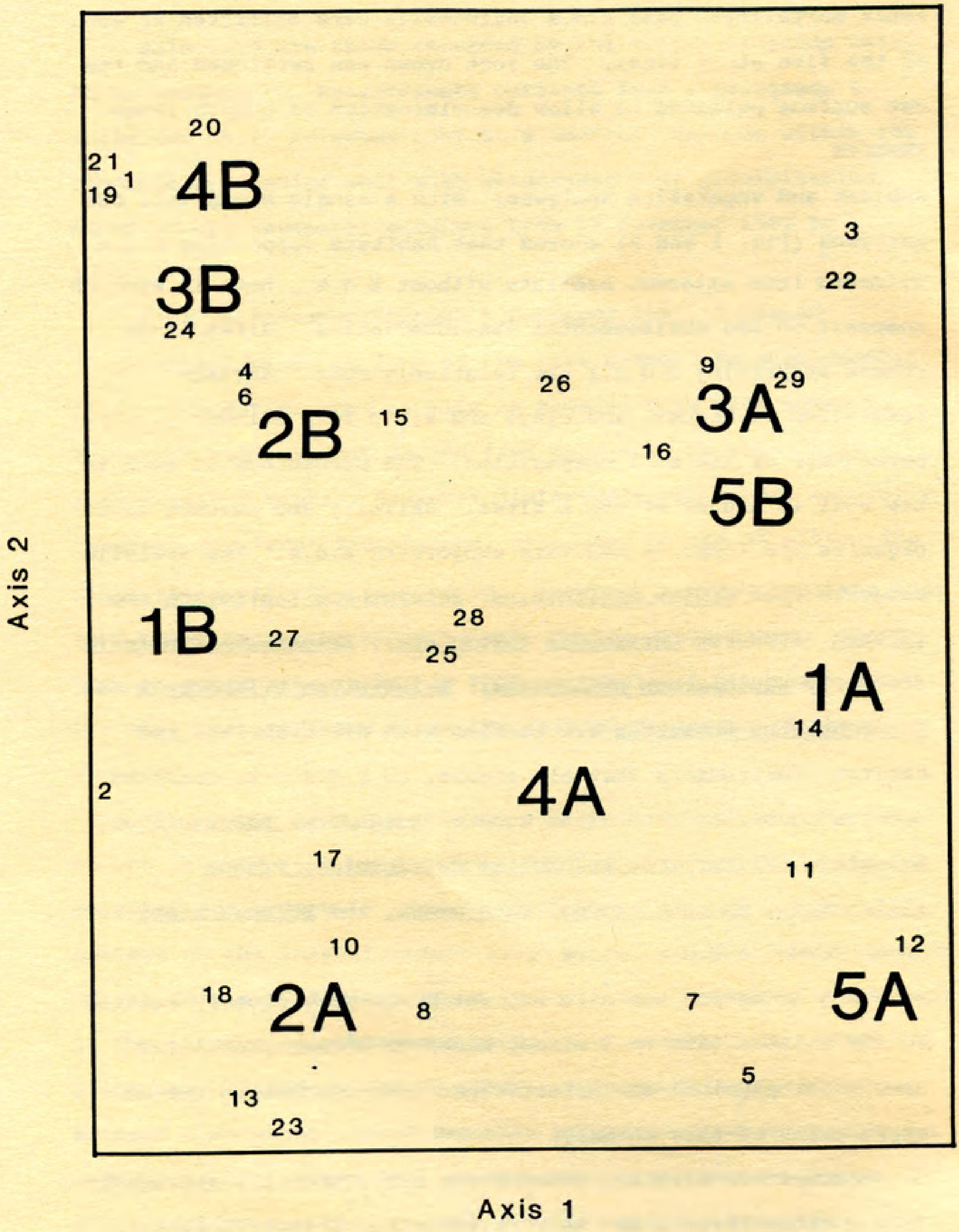

Figure 1. Ordination diagrams showing results of DRA analysis of the species vs. samples data matrix. I have superimposed the species ordination onto the samples (sites) ordination. The proximity of sites and species on the graph implies positive association in nature. The placement of site labels on the figure represents the geometric center of the coordinates of transects per site. Numbers 1-29 represent species codes (see Table 1). E.d.s was not included in the data; its location on the figure was approximated from separate DRA runs where it was included.

Table 1. Summary of cover by species at all sites (% of total cover), at A sites plus site 5B (group 1), and at B sites (group 2). Where a species occurred in both groups, Mann-Whitney U tests were used to determine significance. ns = not significant, ** = significant (P < .01)

Species	Species code	Total cover	Cover Group 1	Cover Group 2	
Adenostoma fasciculatum	1	1.57	0.00	3.94	
Artemisia californica	2	0.22	0.00	0.55	
Bebbia juncea	3	0.08	0.13	0.00	
Brickellia californica	4	0.07	0.00	0.19	
Croton californicus	5	1.90	2.74	0.66	ns
Encelia farinosa	6	0.42	0.13	0.85	ns
Eriastrum densifolium	7	0.83	1.66	0.00	
Eriodictyon trichocalyx	8	5.16	8.19	0.62	ns
Eriogonum fasciculatum	9	10.87	10.60	11.28	ns
Gutierrezia bracteata	10	0.60	0.56	0.66	ns
Ericameria pinifolia	11	0.07	0.12	0.00	
Heterotheca fastigiata	12	1.71	2.86	0.00	
Juniperus californica	13	0.32	0.13	0.62	ns
Lepidospartum squamatum	14	4.03	4.97	2.62	ns
Lotus scoparius	15	0.67	0.43	1.02	ns
Melica frutescens	16	0.01	0.02	0.00	
Opuntia littoralis	17	0.54	0.34	0.83	ns
Opuntia parryi	18	0.54	0.08	1.24	ns
Prunus ilicifolia	19	0.33	0.00	0.84	
Rhamnus crocea	20	0.01	0.00	0.04	
Rhus ovata	21	0.05	0.00	0.14	
Salvia apiana	22	0.22	0.37	0.00	
Senecio douglasii	23	0.26	0.22	0.32	ns
Solanum xanti	24	0.15	0.00	0.39	
Stephanomeria pauciflora	25	0.09	0.13	0.04	ns
Yucca whipplei	26	0.89	0.88	0.90	ns
Annual plants	27	38.67	19.07	68.08	**
Dead shrubs	28	4.41	3.65	5.55	ns
Cryptogams	29	0.05	0.09	0.00	

Table 2. Statistical comparison of environmental factors in plots contained in Group 1 (A sites plus 5B) and Group 2 (B sites excluding 5B). ns = not significant, * = significant (P = < .05), ** = significant (P = < .01) as determined by Mann-Whitney U Two Sample Test.

Factor	Code	Group 1	Group 2	
Ambient light	1	85.5	88.7	ns
Reflected light	2	48.2	30.0	*
Rock > 10 cm	3	5.6	6.2	ns
Bare ground	4	30.6	4.6	**
Surface sand	5	97.1	77.9	**
Subsurface sand	6	98.1	87.3	**
Surface silt	7	2.3	20.3	**
Subsurface silt	8	1.3	11.6	**
Surface clay	9	0.7	1.9	**
Subsurface clay	10	0.6	1.2	*
Surface particles <2mm	11	91.0	94.3	ns
Subsurface particles <2mm	12	88.1	85.2	ns
Surface gravel 0.2 - 1.25 cm	13	4.5	2.6	ns
Subsurface gravel 0.2 - 1.25 cm	14	6.5	3.7	ns
Surface gravel 1.25 - 10cm	15	3.9	3.2	ns
Subsurface gravel 1.25 - 10cm	16	5.4	9.8	ns
Surface salinity (% of max)	17	52.9	68.4	*
Subsurface salinty (% of max)	18	47.6	53.9	ns
Surface micro-organics	19	0.5	1.9	**
Subsurface micro-organics	20	0.3	0.9	**

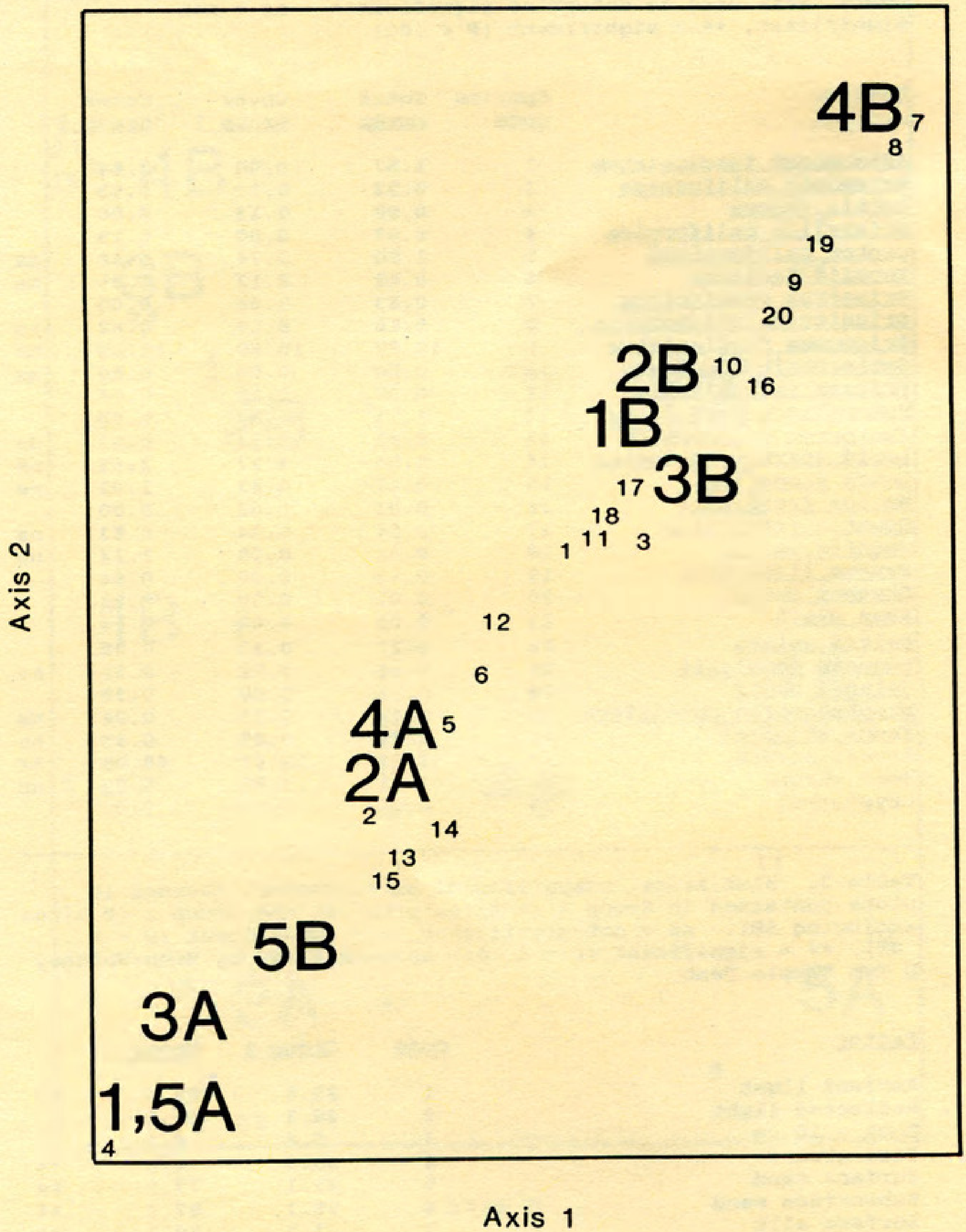

Figure 2. Ordination diagrams showing results of DRA analysis of the environmental factors vs. samples data matrix. I have superimposed the factors ordination onto the samples (sites) ordination. The proximity of sites and environmental factors on the graph implies a positive association in nature. Numbers 1-20 represent codes for environmental factors listed in Table 2.

Adult mortality: Growth ring counts are summarized in Table 1. On the average, E.d.s. individuals live for five years. Observations in the field suggest that plants are reproductive by their second year. An area known to have been disked in October 1984 supports fully grown and even senescent individuals.

Table 3. Summary of growth ring analysis at the five Eriastrum densifolium sanctorum study sites. Numbers represent age at death for all plants on each site for which root crowns remained in place.

	Site				
	1A	2A	3A	4A	5A
N	24	26	29	39	35
Mean	5.00	4.96	5.03	4.62	4.71
Maximum	7.00	8.00	10.00	9.00	7.00
Std. dev.	1.00	1.22	1.79	1.27	1.03

Seedling survivorship: The first rainfall after E.d.s. seed dispersal, in the Fall of 1987, occurred on 12 October (13.2 mm) followed on 23 October 1987 (the largest storm in October) by 27.4 mm of precipitation. Seedlings were first noticed on 26 October. Preliminary seedling densities were measured on 28 October. Prior to 10 December 1987, a final sample size of 453, 310, 387, and 514 seedlings were individualy marked at sites 1A, 2A, 4A, and 5A respectively.

E.d.s. seedling survival through 11 April 1988 is summarized in Figure 3. The four survivorship curves document the survivorship of individual seedlings on each site. Survivorship has been lowest on site 2A; only 7.6% of the initial cohort remain alive. Survivorship has been highest on site 1A where 77.8% of the initial cohort remain alive. At site 5A, 48.3% of the initial cohort remain alive; at 4A, 29.0% are living. Herbivores are probably not the cause of mortality because I found > 80% of the dehydrated remains of dead seedlings in the field.

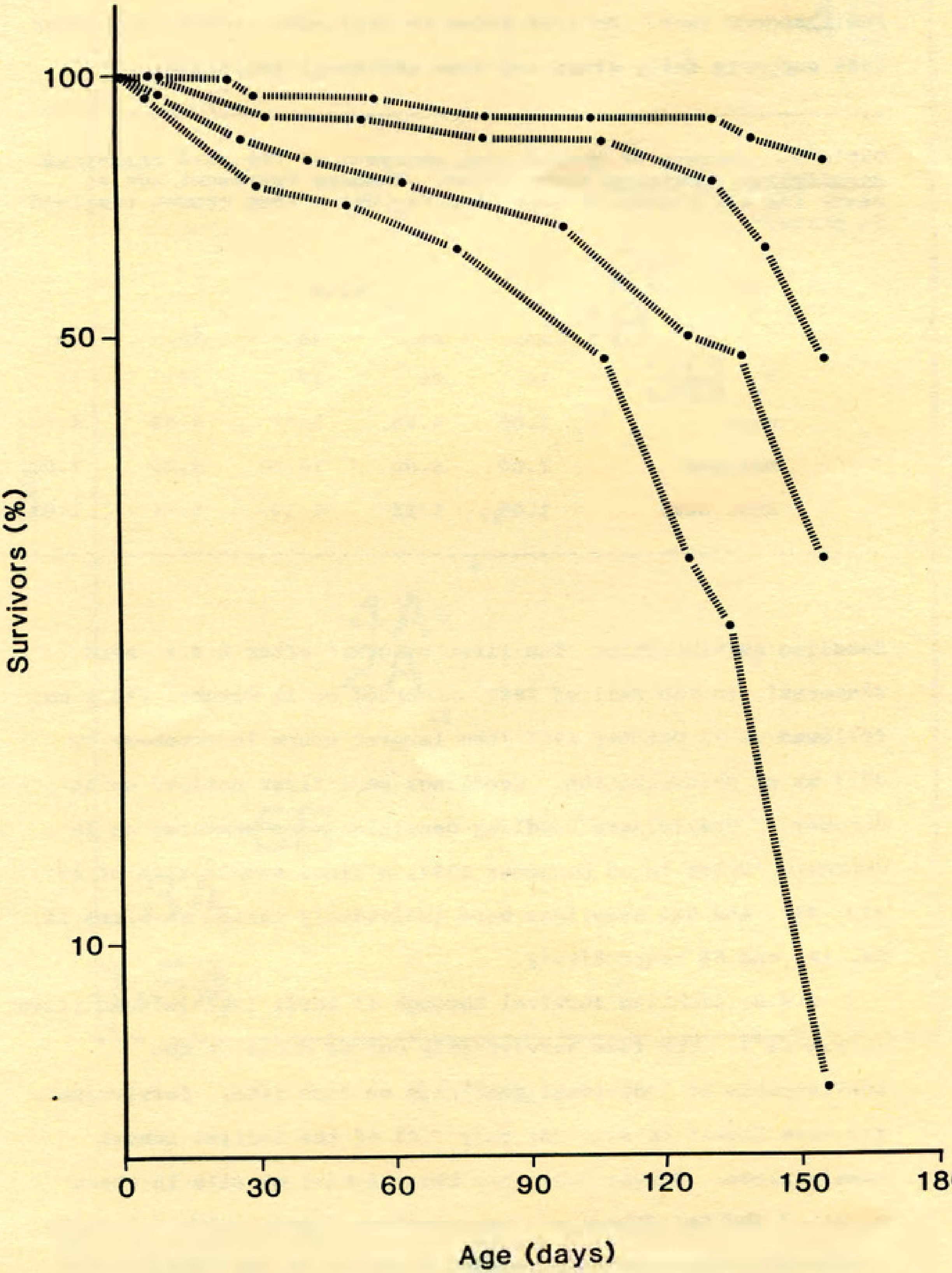

Figure 3. **Eriastrum densifolium sanctorum** seedling survival through 11 April 1988. The four survivorship curves document the survivorship of individual seedlings on sites 1A, 2A, 4A, and 5A. N = 453, 310, 387, and 514 respectively. The vertical axis is on log scale.

DISCUSSION

Southern California represents a main center of endemism for the family, Polemoniaceae; of 54 species in cismontane Southern California, 35 are endemic (from Munz, 1974). The genus **Eriastrum** contains one perennial woody species: **E. densifolium**. Perennial woody tissue is thought to indicate a primitive state, whereas the annual habit is considered to be a derived state. **E. densifolium**, therefore, is considered to be the most primitive extant species in the genus (Grant, 1959).

Craig (1934) and Mason (1945) recognized five subspecies of **E. densifolium**. **E. d. densifolium (typica)** occurs in coastal areas from Santa Barbara County northward to the Monterey area. **E. d. mohavensis, E. d. austromontanum,** and **E. d. elongatum** occupy transmontane, montane, and cismontane habitats respectively from central California to lower California. **Eriastrum densifolium sanctorum** (E.d.s.) is an exceptional local subspecies apparently restricted to the Santa Ana River drainage in San Bernardino County. E.d.s. is easily distinquished from the other subspecies because of its large stature (25-75 cm to rarely 100 cm) and large corolla (25-32 mm). E.d.s. is also the only subspecies that is conspicuously lanate throughout. The California Flora (Munz and Keck, 1959) recognizes the above five subspecies; however, **E. d. elongatum** was somehow omitted in the Flora of Southern California (Munz, 1974).

The verified present range of E.d.s. is about eight miles of floodplain mentioned above. Additional E.d.s. populations have been reported in association with the Lytle Creek and Cajon Washes to the west (Zembal and Kramer, 1984; Krantz, 1985). However, two lines of evidence suggest that individuals in these populations clearly differ from the pure E.d.s. type. In July 1987, I visited **Eriastrum densifolium** populations in the Lytle Creek Wash. With respect to floral size (16-22 mm), branching pattern, stature, and pubescence they resemble **E. d. elongatum** or perhaps an intermediate between **E. d. elongatum** and

sanctorum. In addition, Craig (1934) documented the occurrence of **E. d. elongatum** in the Cajon Wash one mile above Devore and at Highland Blvd. He mentioned no E.d.s. associated with the Cajon Wash. Craig then recorded intermediates (**E. d. elongatum** X **E. d. sanctorum**) near the cities of Colton and San Bernardino. These localities are associated with the Lytle Creek drainage.

Eriastrum densifolium individuals associated with Lytle Creek Wash appear to form a hybrid swarm that is in need of taxonomic resolution. They are variable, but clearly different from E.d.s. Craig's (1934) historical records indicate that plants in the Cajon Wash (Devore area) may also differ. If these populations are, in fact, taxonomically separate or genetically diluted then the known range of pure E.d.s. is restricted to the single population north of Redlands.

Within its range, E.d.s. is confined to flood-mediated habitats. Taken together, sites supporting E.d.s. exhibit species compositions, surface light levels, and substrate characteristics that indicate these habitats were established by sand deposition during flooding and are young in successional time. In contrast, sites without E.d.s. exhibit the characteristics of older successional habitats.

One pair of sites that does not show the above trend is 5A and 5B. Site 5B resembles A sites in both species composition (except E.d.s.) and physical factors. Sites 5A and 5B are located downstream of all other sites in a relatively homogeneous portion of the floodplain south of Norton Air Force Base. We suspect that E.d.s. is not found in site 5B because of dispersal limitations rather than elimination in successional time. Smooth E.d.s. seeds exhibit no features that would facilitate either wind or animal dispersal.

E.d.s. individuals produce abundant viable seed. Seeds stored in the lab for 7-8 months are > 90% viable. Our field work suggests that essentially all seeds germinate with the first rain(s) of the season and that no scarification is required.

Seedling survivorship at each site generally correlates with relative successional age of the terrace. Cohorts of seedlings on A sites that are most similar to the B group in both multivariate analyses, exhibit low survivorship, whereas cohorts on A sites that are less related to the B group exhibit higher survivorship.

In the DRA analyses, annuals are associated with the B sites. Conditions on relatively older successional sites favor the establishment and reproduction of certain annual species. Alien species such as Schismus barbatus, Erodium cicutarium, and Bromus rubens are ubiquitous at all sites. Relative cover of annuals probably accounts for some of the differences in seedling survival on A sites. At sites with high cover of annuals, they conceivably could monopolize soil moisture and/or light during the establishment phase of E.d.s. seedlings. The fact that I was usually able to find the dehydrated remains of dead seedlings corroborates this idea, barring mortality due to pathogens.

Habitat characteristics and seedling survival both indicate that E.d.s. habitat naturally deteriorates in successional time. In this respect, appropriate habitat is ephemeral. Habitat analyses show that E.d.s. is confined to open, well lighted areas with abundant washed sand. In addition, E.d.s. habitats themselves form a spectrum of successional states. In other words, some areas that support E.d.s. are older and relatively deteriorated; seedling mortality is higher in these areas.

E.d.s. colonizes freshly deposited terraces and reproduces by seed until the habitat reaches a point in successional time where seedlings can no longer establish. For adult plants, the average age at death is five years; maximum age appears to be about ten years. In the absence of flooding, E.d.s. stands eventually decline as establishment decreases and adults became senescent. Under normal conditions, however, periodic flooding would tend to renew E.d.s. habitats and prevent local extirpation events.

Seven Oaks Dam will prevent the periodic flooding upon which E.d.s. depends for rejuvenation of its habitat. Eventually, artificial manipulation will be necessary to arrest succession in existing E.d.s. habitats.

Germination, seed bank, and competition analyses are underway to help resolve this complicated problem. Preliminary analysis of lab work and field observations indicates that E.d.s. seeds are present in the soil for less than one year. E.d.s. seeds require leaching and therefore probably contain water soluble inhibitors. The lack of a permanent seed bank is indicated for two reasons: 1) > 95% of the seeds germinate in the lab under constant drip within 24 hours and 2) no recruitment was observed at site 1A on 22 April 1988 despite heavy rains (a total of 57 mm) in the prior week. No recruitment on 22 April suggests that in the field all viable seeds had either reached the leaching threshold and germinated or had been removed by animals. No seeds were found in soils collected prior to dispersal of the 1987 seed crop. Interestingly, transient seedbanks are often associated with rare taxa (Fiedler,1987).

In the short term, it is imperative that remaining E.d.s. habitat be protected from human disturbance. A recent publication by the California Native Plant Society featured an article that placed E.d.s. in a top-twelve priority list of California's most endangered plants (York, 1987). At present, existing E.d.s. habitats are heavily used and regularly disturbed. Habitat protection is essential so that ongoing autecological studies can continue and maximum numbers of individuals saved for a source of seed.

Reclamation of disturbed areas and future mitigation strategies will most certainly require large numbers of seeds. Habitat integrity is even more critical in view of the short life span of adults. Seeds for future use will come from the seedlings of today, not the adults, because adults will soon become senescent. For this reason, seed collection should be a careful and conservative process. Liberal harvest of seeds on a yearly basis would reduce recruitment in existing stands.

Based on modern distribution, large tracts of optimum habitat already have been removed by sand and gravel interests west of Orange Street. Suboptimal (older) habitats east of Orange Street are currently being mined. Plans are underway to reclaim exhausted pits. Reclamation of pits involves modification of the pit walls until substrate reaches the angle of repose. E.d.s. seeds can then be introduced to these surfaces.

Illegal unrestrained off-road vehicle use is also alarming, especially in open (optimum) habitats west of Orange Street. Part of the off-road vehicle problem stems from the confusing diversity of land juristiction and law enforcement on the floodplain. Ownership should be consolidated to facilitate management and protection of remnant E.d.s. habitats.

SUMMARY

Eriastrum densifolium sanctorum, the Santa Ana River Wooly-star, is restricted in geographical range to about eight miles of floodplain habitat. Moreover, recent visits and historical records suggest that populations reported in the Lytle Creek and Cajon washes are phenotypically different from E.d.s. If true, then E.d.s. exists as a single relatively continuous population in the main Santa Ana River floodplain in San Bernardino County.

In addition to its restricted range, E.d.s. is further confined to flood-mediated habitats within the floodplain. Flood deposited sand terraces are the most important habitat.

The sand terraces are not static; E.d.s. habitats deteriorate as normal successional processes modify the environment. Multivatiate analyses involving measures of perennial plant species, combined annuals, dead shrubs, rock, insolation, and substrate indicate that E.d.s. habitats are relatively young in successonal time when compared to adjacent habitats without E.d.s. Moreover, when E.d.s. sites are considered in isolation, they form a spectrum of successional states.

Studies of seedling success on sites with different successional (flooding) histories, show that seedling survivorship decreases as habitats age. If E.d.s. habitats succeed to climax, seedling establishment would undoubtedly cease. Encroachment by annuals, especially alien species, also seems to hasten habitat deterioration.

Normally, periodic flooding would tend to recycle E.d.s. habitat. However, Seven Oaks Dam will stop the flooding upon which E.d.s. depends for rejuvenation of habitat. If flooding is stopped, artificial habitat manipulation will be essential to simulate the effect of flooding and prevent extinction of the plant. Protection of existing stands is urgently needed to preserve the integrety of remaining habitat and retain existing individuals for an immediate source of seed.

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Thanks are due to Richard Zembal and Karla Kramer for first noticing E.d.s., publicizing its status, and initiating the research. Tim Krantz has also invested personal time in the study of this vulnerable plant.

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ANNOUNCEMENTS

Biogeography of Southern California. The Southern California Botanists are sponsoring their fourteenth annual symposium to be held on October 29, 1988. Mark your calendars now. Among the speakers will be Dr. Robert Thorne of Rancho Santa Ana Botanic Garden who will speak on the history of southwestern deserts and Dr. Richard Minnich of the University of California, Riverside who will discuss the influence of fire on the distribution of native southern California vegetation.

SCB Board of Directors Looks for Volunteers. Due to an untimely sequence of events, the SCB Board of Directors has experienced a depletion of its ranks. If you would like to be a participant in the planning of SCB events, ie. symposia, field trips, or social gatherings, please contact Geoff Smith at (714) 526-6963. The Board of Directors meets once a month, usually on the first Thursday of the month.