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HABITAT CHARACTERISTICS AND DISTRIBUTION OF *ERODIUM MACROPHYLLUM* (GERANIACEAE)

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ABSTRACT

Ecological data are lacking for many species covered in multi-species habitat conservation plans and other regional conservation plans. *Erodium macrophyllum* (Geraniaceae) is a rare native annual forb found throughout California, southern Oregon, and northern Baja California (Mexico) for which very little ecology is known. I report on the habitat characteristics and current and historical distribution of *E. macrophyllum* by collecting data on populations in Riverside and San Louis Obispo Counties and by conducting an herbaria search and electronic-mail survey. *Erodium macrophyllum* population sizes range from a few individuals to over 1000 and are restricted to heavy clay soils. Most populations are found on the eastern side of the coast ranges in California. The clay soils on which it is found typically have low cover of native and exotic species but often have other rare species. They are also generally low in nitrogen and phosphorus, but there is considerable variation. Based on herbaria records and the e-mail survey, *E. macrophyllum* was probably once more common and may have occurred on other soil types.

Key Words: California grasslands, clay soil, edaphic factors, habitat conservation plan, rare plants, *Erodium macrophyllum.*

The collection of ecological data for rare plants is crucial in developing effective conservation plans (Schemske et al. 1994). Very little research has been done on the ecology or biology of the rare forb, *Erodium macrophyllum* Hook and Arn (Geraniaceae, large-leaved filaree). The California Native Plant Society (2001) lists *E. macrophyllum* as a category "2," meaning that it is rare in California but more common elsewhere. The only information on the biology of *E. macrophyllum* is scattered in various regional floras and usually only consists of notes regarding its growth habit, habitat, and flower color. However, some research has been done by a group in Spain working on the systematics of Geraniaceae, and they have placed *E. macrophyllum* into a new monotypic genus and proposed *California macrophyllum* as a new name (Aldasoro et al. 2002). For the purposes of this paper I will follow the nomenclature of Hickman (1993).

The soil and habitat preferences of *E. macrophyllum* are poorly understood. Recent observations suggest that *E. macrophyllum* currently occurs exclusively in clay soil (Boyd personal communication; Gillespie personal observation; Hale personal communication). However, some historical observations, while anecdotal, suggest that *E. macrophyllum* was once common in a broader range of soil textures. For example, Abrams (1904) wrote, "[*E. macrophyllum* is] common in grasslands" and Gray (1876) wrote, "Common in valleys and on the lower hills west of the Sierra Nevada, from San Diego northward to the Sacramento Valley. Next to *E. cicutarium* this is the most abundant species." Given the lack of specificity of such historical accounts, it is possible that *E. macrophyllum* used to occur on a variety of non-clay soil types.

Understanding the basic ecology of rare plants can aid in conservation plans (Simberloff 1988). For example, knowing the habitat requirements of species is paramount when creating reserves for specific target species. *Erodium macrophyllum* is one of more than 160 species included in the multi-species habitat conservation plan for Riverside County, CA, and one of the limits in designating habitat for these species is the little information available (Dudek and Associates 2003).

In this paper I describe the current habitat characteristics of *E. macrophyllum* and its historical distribution and abundance. I also report on the results of a field and electronic-mail survey to better quantify its present distribution. The results of this study are discussed in the contexts of conservation and natural history.

MATERIALS AND METHODS

Study Species

Erodium macrophyllum is a rare annual plant apparently restricted to clay soil outcrops. Like many grassland annuals in California, *E. macrophyllum* germinates in fall or winter at the onset of the winter rains and usually flowers between March and May (Munz 1974). *Erodium macrophyllum* forms a basal rosette until it bolts in the spring when it sends up determinate and/or indeterminate umbellate inflorescences. The size of the basal rosette can

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vary from a few centimeters in diameter to at least 30 cm (Hickman 1993).

Erodium macrophyllum is self-compatible and will self-pollinate in the field. This has been confirmed by field and greenhouse observations. The flowers of *E. macrophyllum* are open for only one day and the petals usually only remain on the flower until mid-day. The anthers dehisce in the morning and after the petals drop, the anthers enclose the stigma and effectively pollinate it (personal observation). When the fruits of *E. macrophyllum* mature, the carpel bodies detach from the fruit base and peel away from the style column. When a carpel body finally releases from the style column it propels itself up to 1.25 m from the parent plant, although further dispersal may occur with wind (personal observation).

Habitat Characteristics

Soils from five different *E. macrophyllum* populations were sampled and analyzed for nutrients (N, P, Ca, Mg). Two populations (Davis Road and Bitterwater Road) were located in eastern San Louis Obispo County (35.50206°N × 120.07846°W; 35.71380°N × 120.26716°W, respectively). The other three populations were from western Riverside County: Bachelor Mountain (33.6006°N, 117.0528°W), Oak Mountain (33.5156°N, 116.9767°W) and De Palma Road (33.7416°N, 117.4387°W). For comparison purposes, soils were also collected from the Santa Rosa Plateau Ecological Reserve (Riverside Co., CA, USA) and from Crown Valley in the Lake Skinner/Shipley Multi-Species Reserve (Riverside Co., CA, USA). The additional locations were chosen because they are sites where I have re-introduced *E. macrophyllum.* Each soil core was 15 cm deep by 2 cm in diameter and at least 1 m from all other sample cores. The cores from the Bachelor Mountain and De Palma Road populations were collected April 2000, Bitterwater Road and Davis Road were collected in April of 2002 and Oak Mountain in January 2003. The samples were analyzed for total percent Kjeldahl N, extractable Olsen-P, and extractable Ca^{++} and Mg^{++} at the Soil Analytical Laboratory of the Division of Agriculture and Natural Resources, University of California, Davis, California. For soil nutrient data student t-tests were used to determine whether the measured variables differed significantly between site locations. Soils were identified using soil survey maps from Riverside County (Knecht 1971) and San Louis Obispo County (Lindsey 1983).

At each population site I recorded percent cover of three life form groups (exotic grass and native and exotic forbs) from five randomly placed 1.0 × 0.5-m quadrats. Percent cover was estimated to the nearest 1% using a gridded frame. For the Davis Road and Bitterwater Road populations, the estimates were made in April 2002 and for the De Palma Road, Oak Mountain and Bachelor Mountain populations the estimates were made in March 2003. For the percent cover data, a multiple analysis of variance (MANOVA) was used to determine if the plant communities at each population differed significantly from one another based on the dependent variables measured (species groups: native forbs (excluding *E. macrophyllum*), native grass, *E. macrophyllum,* exotic forbs and exotic grass). Because the two sites in San Louis Obispo County were sampled in a different year than the Riverside County sites, separate MANOVAs were conducted for the populations in San Louis Obispo County and Riverside County.

Survey of Occurrence

The current distribution of *E. macrophyllum* was determined by examining herbaria records from seven different herbaria (Rancho Santa Ana Botanic Garden, University of California Riverside, Jepson Herbarium, University of Arizona, Utah State University, California Academy of Sciences, San Jose State University), searching the California Natural Diversity Database (CNDDB) and by conducting an electronic-mail survey to 255 professional botanists throughout the western United States. The following questions were asked in the survey: 1) How many populations of *E. macrophyllum* do you know of in your area? 2) Approximately how many individuals are/were in each population? 3) If you recall, on what type of soil were the populations found? 4) If you recall, what associated species were growing with *E. macrophyllum*? 5) Is/are the population(s) that you know of accessible, if so, would you be willing to take me to it/them? 6) Do you have any additional concerns/comments regarding *E. macrophyllum*?

Results

Habitat Characteristics

The soil from the Santa Rosa Plateau site was classified as a clay loam in the Monserate series and Crown Valley as a sandy loam from the Friant series (Knecht 1971). Bachelor Mountain, De Palma Road and Oak Mountain soils were classified as clay from the Auld series (Knecht 1971). Soils from the Davis Road and Bitterwater Road populations were classified as a clay in the Diablo series (Lindsey 1983). The clay soils tended to be low in total N, low in extractable P, but the Ca : Mg ratios were high (Fig. 1). Although there were differences in Ca : Mg between sites, none of the clay soil sites had Ca : Mg less than 1.0 as can be found on serpentine soils (Harrison 1999). Crown Valley had the highest phosphorus and this site may have been historically cultivated; it also was the only sandy loam soil analyzed.

For the five sites I sampled, mean percent cover of bare ground varied from 16–89. Within San Lou-

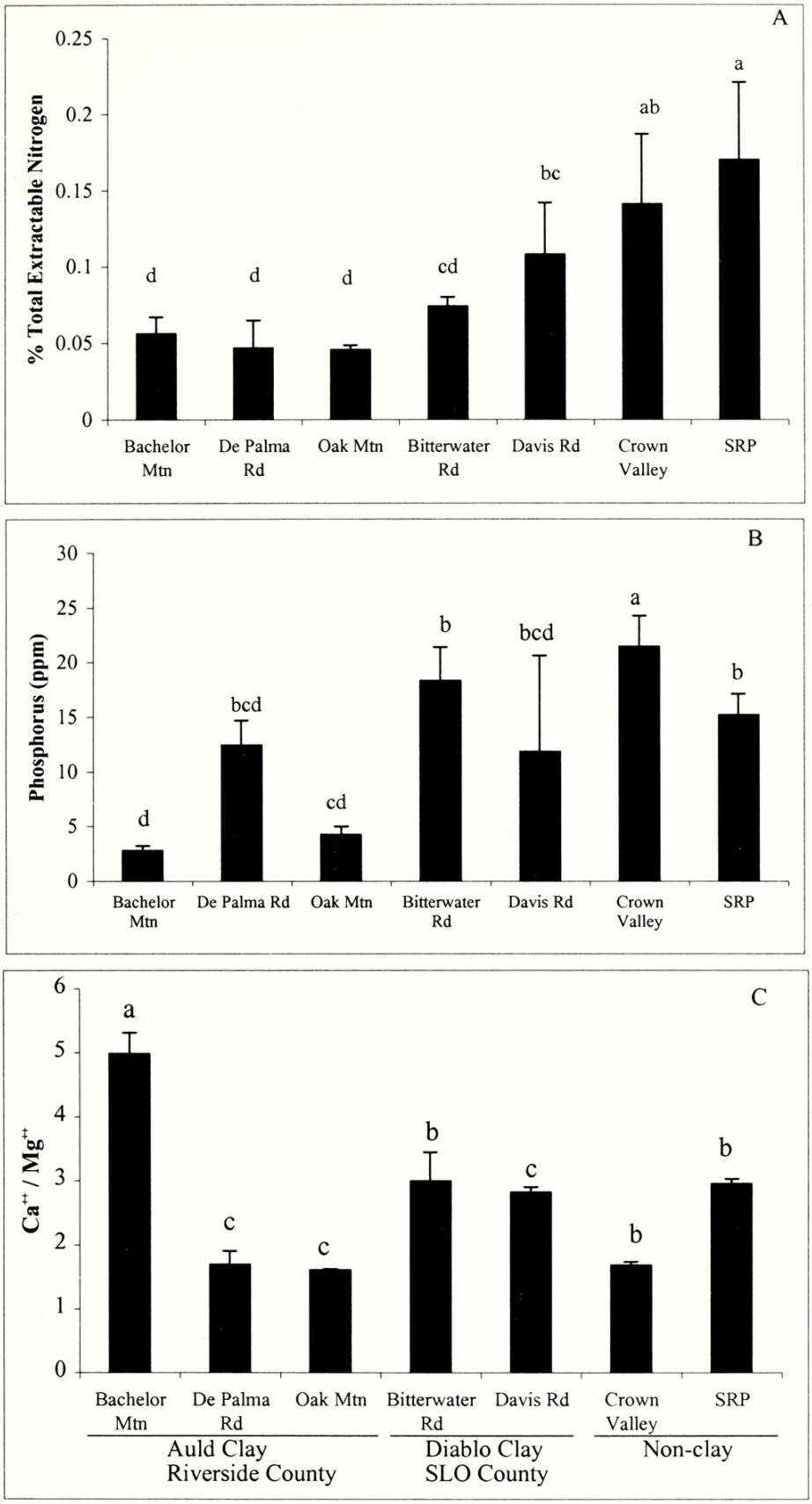

FIG. 1. Percent total extractable nitrogen (NO_3 plus NH_4) (A), extractable Olsen-Phosphorus (B) and Ca : Mg ratio (C) for different sites with and without *Erodium macrophyllum*, Crown Valley and SRP (Santa Rosa Plateau) do not have naturally occurring populations of *E. macrophyllum*. Bars are means ± SE ($N = 5$). Different letters indicate a significant difference between populations ($P < 0.05$).

TABLE 1. CHARACTERISTICS OF FIVE POPULATIONS OF *ERODIUM MACROPHYLLUM*. Different letters indicate a significant difference between locations within counties based on the percent cover data shown (MANOVA, $P < 0.05$).

Location	County	Population size (# individuals)	Percent cover ± SE				
			Native Forbs	Exotic Forbs	Native Grass	Exotic Grass	*Erodium macrophyllum*
Bachelor Mtn.[a]	Riverside	80–100	4.8 ± 1.4	10.2 ± 2.3	None	6.4 ± 1.8	2.6 ± 0.7
De Palma Rd.[b]	Riverside	~700	17.2 ± 3.6	22.4 ± 7.4	None	21.0 ± 11.5	10.8 ± 2.8
Oak Mountain[c]	Riverside	~10	5.2 ± 1.5	0.8 ± 0.2	2.6 ± 1.9	0.6 ± 0.3	1.6 ± 0.4
Bitterwater Rd.[a]	San Louis Obispo	~1000	9.6 ± 3.1	9.4 ± 2.4	None	39.4 ± 4.6	5.6 ± 4.2
Davis Rd.[b]	San Louis Obispo	~200	32.2 ± 17.3	29.6 ± 7.1	None	19.0 ± 5.3	3.2 ± 1.2

is Obispo County, percent cover classes at the Bitterwater Road site were different from the Davis Road site (MANOVA $F_{4,10} = 7.326$, $P = 0.0254$). An ANOVA showed that all species groups differed between the two sites except for their percent cover of *E. macrophyllum* (Table 1). The Riverside County sites differed significantly from each other also (MANOVA $F = 3.335$, $P = 0.0162$). The De Palma Road site had greater percent cover of native forbs and *E. macrophyllum* than the other Riverside County sites. It also had a greater cover of exotic forbs, but only when compared to the Oak Mountain site. The Oak Mountain population had the lowest cover of all species groups, but it was also the only population to have the native grass, *Nassella cernua.*

Several other rare plants can also be found growing in the clay soil habitats where *E. macrophyllum* is found. Rare plants recorded growing in these habitats include: *Allium munzii, Harpoganella palmeri, Convolvulus simulans,* and *Calochortus clavatus* var. *clavatus,* although not all sites contain them. Other more common plants that can co-occur with *E. macrophyllum* are found in Appendix 1.

Survey of Occurrence

Eighty-three herbaria records were obtained from the seven different herbaria. Seventy-three records were found in the CNDDB, most of which matched herbaria records. From the email survey there were a total of 31 responses: 18 reported that it did not occur in a specific geographic area (question 2 from the survey) and 13 reported that they knew of a population. However, several of the responses that indicated the presence of a population matched a record of either an herbarium sheet or a record from the CNDDB. After removing obvious duplicate records from all of the sources in which the description, location and date matched, I determined that a total of 105 unique populations of *E. macrophyllum* have been documented, most of which occur on the eastern side of the California coast ranges (Fig. 2). The first population was documented in 1862 by W. Brewer as part of a California State survey. The most recent populations were noted in 2002 through the email survey. Of these 105 records, 62% mentioned it was found on clay, while the other 28% didn't mention a soil type. Clay soils were first mentioned in the 1930s.

Only a few of the historical sites have been revisited. For example, there is one occurrence of *E. macrophyllum* for Butte County, CA, but it has not been found there again despite extensive surveying. Furthermore, it is possible that it never occurred in Butte County, and the possible misinformation for Butte County may be based on a mislabeled specimen (Lawrence Janeway personal communication). Similarly, *E. macrophyllum* was collected from Santa Cruz Island, California, in 1888 (K. Brandagee, no collection number), yet it has not been re-discovered (Steve Junak personal communication).

Populations of *E. macrophyllum* are also being discovered and extirpated in recent years. For example, *E. macrophyllum* was collected near Murrieta, Riverside County, in 1998 (J. Easton, no collection number), but repeated visits to the site have revealed that the population has been lost to a housing development.

Erodium macrophyllum was previously thought to be found in California, northern Mexico and southern Utah (Hickman 1993). However, *E. macrophyllum* was never collected in Utah and the incorrect information in The Jepson Manual (Hickman 1993) is apparently based on a mislabeled specimen (James Morefield personal communication). (This also explains why the Utah State Herbarium had no records of *E. macrophyllum.*)

Erodium macrophyllum should now be considered endemic to the California floristic province with occurrences on either side of California's north and south borders. I found one collection from Oregon (collected in 1887) and three collections from Baja California (Mexico) dating 1931, 1949, and 1958.

The size of *E. macrophyllum* populations tend to be small ranging from 6–1000 individuals. Of the known occurrences where population size was documented, three populations were estimated to have 100–1000 individuals, two populations had less than 100, five had 20 or less, two had six and one had a "handful of individuals."

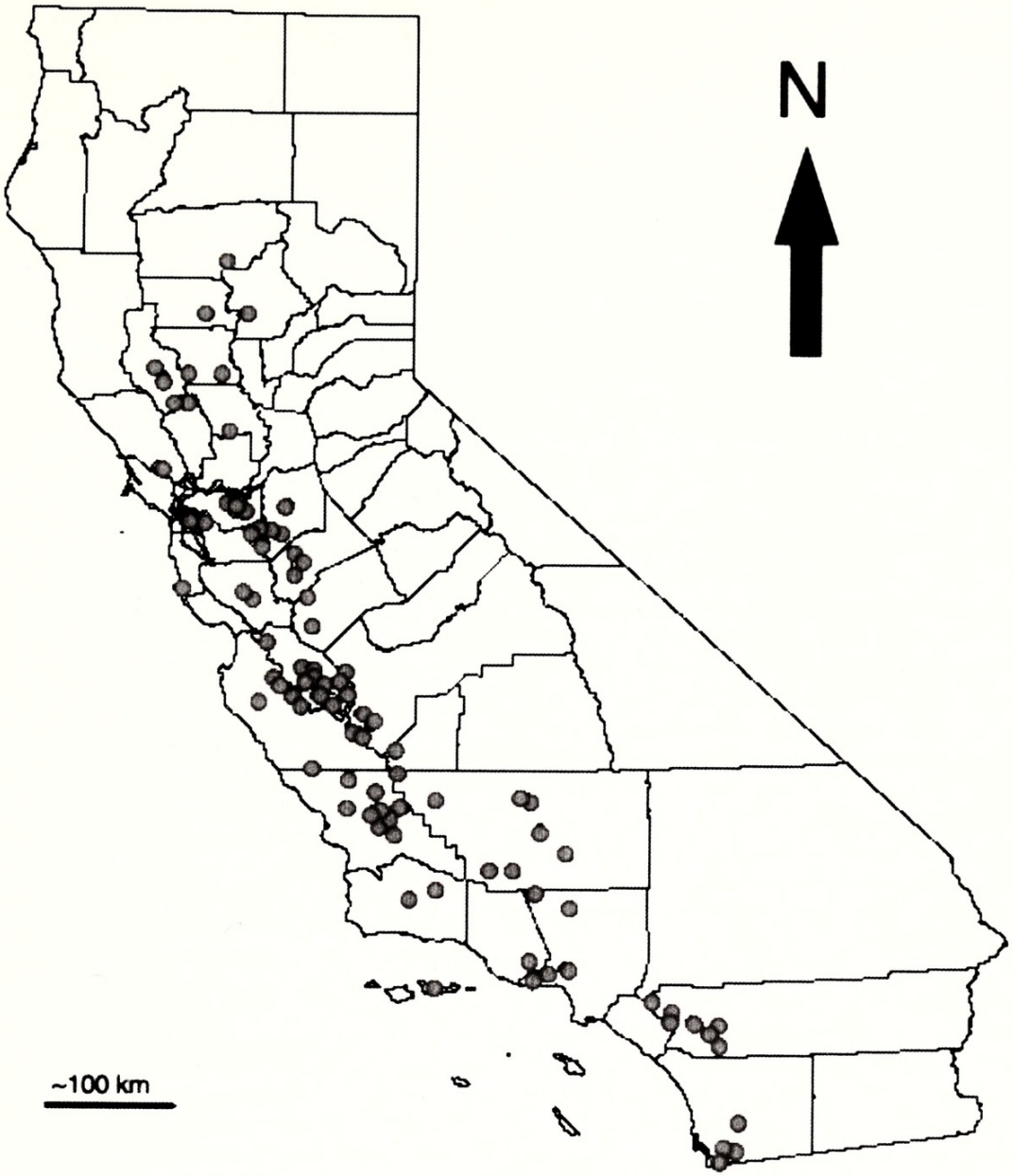

FIG. 2. Known distribution of *Erodium macrophyllum* populations in California based on current and historical occurrences. Circles represent approximate locations of populations. County lines are delineated on the map.

DISCUSSION

Erodium macrophyllum is apparently restricted to heavy clay soils. One hypothesis on edaphic endemism is that endemics are less competitive on other soil types (Wright and Mooney 1965), while tolerating the unfavorable conditions of low productivity environments (Grime 1973; Goldberg and Novoplansky 1997). The clay soils on which *E. macrophyllum* is found are low in nutrients, and the clay texture may restrict water infiltration and root penetration (Knecht 1971; Lindsey 1983).

Percent cover of exotic grasses and forbs is low and bare ground is high on clay soils compared to other grassland soils, which often have no bare ground exposed (Dyer and Rice 1997; DiTomaso et al. 1999); although percent cover of groups can vary between clay soil sites even if they are relatively close to each other (within the same county). While the exact mechanism that explains restriction of *E. macrophyllum* to heavy clay soils is not known, evidence suggests that there is no physiological barrier, and that they can actually grow and reproduce on other soil types (Gillespie 2001). In fact, *E. macrophyllum* produced more biomass when growing on non-clay soils than clay soils (Gillespie unpublished data). It is possible that the high cover and densities of exotic plants on non-clay soils results in an environment where *E. macrophyllum* is out-competed, and it is effectively restricted to clay soils where there is less competition.

The clay soils on which I sampled *E. macrophyllum* were low in N and P. Soils with unusual chemical or physical properties often support a higher diversity of native species and may resist invasion, as in serpentine soils (Huenneke et al.

1990; Harrison 1999). My results and observations suggest that grasslands on clay soils are not as invaded by exotic species as other grasslands in California. This is similar to Stromberg and Griffin's (1996) results where the invasive grass *Elymus caput-medusae* did not invade clay soils unless they were disturbed and the native bunch grass *Nassella pulchra* was most abundant on clay soils. Interestingly the exact mechanism by which clay soils can resist invasion is now known. The low percent cover of exotic species and the high species richness of rare taxa that can occur on clay soils make them important areas of conservation. Many heavy clay soil sites are found in relatively flat grasslands—the same places that are being developed rapidly, but should be considered for preservation.

Erodium macrophyllum is a rare plant today, although historical evidence suggests that it may have been more common. While there is much information missing from these original observations, they suggest that the distribution and perhaps abundance of *E. macrophyllum* has decreased in the last 100–120 years. For example, Olson (from the e-mail survey) wrote, "saw it once in disked field, may no longer be extant. Very rare in east bay [of San Francisco Bay Area]." While historical observations are valuable, their lack of detail can make them problematic for quantification. For example, the first documented occurrence of *E. macrophyllum* on clay was in 1934 (L. Short). It is possible that earlier collections were from clay soil, but the botanists did not mention it. Alternatively, perhaps *E. macrophyllum* was found on common soil types that were not clay, and the collector therefore did not think it was worth noting the soil type. Despite the uncertainties in the absence of specific detail from collection sites, it is fairly certain that *E. macrophyllum* is rare and usually found on clay soils.

Although some places where *E. macrophyllum* is found are not experiencing rapid development now, *E. macrophyllum* faces other threats such as off-highway vehicle activity and grazing. The De Palma Road population now has an off-highway vehicle course going directly through it, and during a visit to the Bitterwater Road population I observed cows happily ingesting the tender leaves of *E. macrophyllum* plants.

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Appendix 1

Common species found growing with *Erodium macrophyllum*. Nomenclature from Hickman (1993).

Native Forbs

Achyrachaena mollis
Ancistrocarphus filagineus
Amsinckia mensiezii
Calochortus splendens
Lasthenia californica
Layia platyglossa
Lupinus succulentus
Plantago erecta
Salvia columbarae
Sisyrinchium bellum

Native Grasses

Nassella pulchra
Nassella cernua

Exotic Forbs

Erodium botrys
Erodium cicutarium
Centaurea melitensis
Hirschfeldia incana
Medicago polymorpha

Exotic Grasses

Avena barbata
Avena fatua
Bromus hordeaceus
Hordeum sp.