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Natural Resource Stewardship and Science

Conservation Assessment for Parish's Daisy (*Erigeron parishii*, Asteraceae) in Joshua Tree National Park

Natural Resource Report NPS/JOTR/NRR—2014/887

ON THE COVER

Parish's daisy in full flower on April 26, 2006, Long Canyon, on the western edge of Joshua Tree National Park, San Bernardino County, California.

Photograph by: Tasha La Doux, Joshua Tree National Park

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Summary

Background

Parish's daisy (*Erigeron parishii* A. Gray) is a perennial herb in the sunflower family (Asteraceae) endemic to southern California. It occurs in the San Bernardino and Little San Bernardino Mountains in San Bernardino and Riverside counties (CNDDB 2014, CCH 2014). In the western portion of its range it generally occurs on calcareous (limestone or dolomite) substrates, often on alluvium in washes and canyon bottoms. In the eastern portion of its range it occurs on gneiss, granodiorite, and monzogranite, often on rocky north facing slopes. *Erigeron parishii* was listed as threatened by the federal government in 1994 due to habitat destruction associated with mining, and threats from off-highway vehicle use, energy development, and urban development near Pioneertown, California (USFWS 1994, 2009). At the time of listing, *E. parishii* was thought to be primarily restricted to calcareous soils in the San Bernardino Mountains. Little information was known about the populations in the eastern portion of its range that occur off limestone, including the occurrences in Joshua Tree National Park (JOTR) (USFWS 1994).

The purpose of this report is to provide a comprehensive review of the species biology, ecology, distribution, taxonomic history, conservation status, and to provide management recommendations for populations that occur within Joshua Tree National Park (JOTR) based on all known current information. In addition we present original research investigating seed germination, reproductive biology, demographics, habitat preference and population genetics for *E. parishii*, with emphasis on plants that occur within JOTR.

Original Research

Germination trials conducted between 1990 and 2013 indicate that plants have a high germination rate (75–100%) and do not require special treatment to break dormancy. Seeds that have been stored for 25 years at low humidity (12–15%) and 20° C remain viable and showed a high germination rate (100%). Demographic studies established long-term study plots to track individuals over time. Reproductive biology data addresses flowering phenology and reproduction as it relates to size class. Plants that belonged to the smallest size class (<50 cm^3) had low survivorship and did not produce flowers. There was a positive relationship between total plant volume and number of flowering heads. The population genetic study using ISSR (inter simple sequence repeat) data was consistent with a previous study and found that populations in the San Bernardino Mountains on calcareous substrates were more genetically diverse than populations on other substrates (in JOTR). However, each population had unique genetic diversity. The GIS habitat model utilized five parameters (elevation, slope, aspect, soil type, and vegetation type) to assign probability values of potential habitat to the landscape. These environmental datasets helped characterize occupied habitat for *E. parishii*.

Recommendations

Conservation efforts for *E. parishii* should focus on building upon baseline data, especially where gaps exist, by supporting research, field surveys, and long-term monitoring. Proposed research includes expanding the current population genetic study to determine levels of genetic diversity

across the range and to further evaluate genetic diversity between central and peripheral populations. Other research that would be particularly useful for future conservation efforts include a phylogenetic study to determine the closest relative of *E. parishii* and its phylogenetic uniqueness, as well as an ecophysiological study to investigate drought tolerance across the range of the species. Management practices should include implementation of a standardized monitoring protocol as presented in this report, as well as continued efforts to survey and map known occurrences. Field surveys utilizing the existing habitat model should be used to search for new populations, as well as improve the habitat model. Management practices should be adapted to include the most recent information.

Acknowledgments

The authors would like to thank the many people who participated in the development and implementation of the rare plant program at Joshua Tree National Park, and in particular to the efforts supporting the protection of *E. parishii* throughout its range. The San Bernardino National Forest and US Fish and Wildlife Service provided access and authorization to collect material as a part of this study. We thank the Rancho Santa Ana Botanic Garden and University of California Riverside herbaria for access to specimens. Finally, we are grateful for the helpful comments and careful review of this manuscript provided by Orlando Mistretta, Scott Eliason, Nita Tallent, and Lise Grace. This report was a collaborative effort between Joshua Tree National Park, Joshua Tree National Park Association, and Rancho Santa Ana Botanic Garden.

Acronyms and Initialisms

JOTR	Joshua Tree National Park
SBNF	San Bernardino National Forest
RSABG	Rancho Santa Ana Botanic Garden
USFWS	United States Fish & Wildlife Service
CCH	California Consortium of Herbaria (http://ucjeps.berkeley.edu/consortium)
CNDDB	California Natural Diversity Database
Herbaria acronyms:	C = Natural History Museum of Denmark; US = Smithsonian Institute; MO = Missouri Botanical Garden; UC = University of California Berkeley; RSA = Rancho Santa Ana Botanic Garden; UCR = University of California Riverside
NRCS	Natural Resource Conservation Survey
PRISM	Parameter-elevation Relationships on Independent Slopes Model
RAWS	Remote Automatic Weather Station
WRCC	Western Regional Climate Center (www.wrcc.dri.edu)

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Introduction

Scope and Purpose

The purpose of this conservation assessment is to review and summarize all known background information on *E. parishii* including its taxonomic history, rarity and conservation status, habitat information, biology and ecology, known and potential distribution, and threats. We also report findings from original research including germination trials and a population genetic study conducted at Rancho Santa Ana Botanic Garden (RSABG) and a pilot demographic and reproductive monitoring study conducted in JOTR. Finally, we provide recommendations for management, specific to JOTR, and suggestions for future research on *E. parishii*.

Background

Two plant species listed under the federal Endangered Species Act are known to occur within Joshua Tree National Park (JOTR) boundaries (Figure 1): *Astragalus tricarinatus* (triple-ribbed milkvetch, Fabaceae) and *E. parishii* (Parish's daisy, Asteraceae). *Erigeron parishii* is endemic to the arid regions of Riverside and San Bernardino counties, California. It is primarily distributed along the north face of the San Bernardino Mountains, but it also occurs in the Little San Bernardino Mountains (Figure 2). This species was listed as threatened in 1994 by the Federal government because of its limited distribution and due to threats to populations across its range. The primary threat to *E. parishii* is mining of carbonate material in the western portion of its range (USFWS 1997, 2009). Threats due to off-highway vehicle use, cattle grazing, and energy development have also been identified. *Erigeron parishii* occurs at elevations between 1035–2015 m (3395–6610 ft), primarily in pinyon-juniper woodland, often on carbonate derived substrates, but also on gneiss, granodiorite, and monzogranite in washes, canyon bottoms, and rocky slopes (CCH 2014, CNDDB 2014, USFWS 2009).

Species Description

Erigeron parishii is a perennial herb to subshrub in the sunflower family (Asteraceae; Figures 3 and 4). It has occasionally been confused with species that appear similar, for example Utah fleabane (*E. utahensis* A. Gray) and Navajo fleabane (*E. concinnus* (Hook. & Arn.) Torr. & A. Gray). Both of these species occur in the eastern Mojave Desert in California, but do not overlap in range with *E. parishii* (Nesom 2012, Sanders 2002, USFWS 1994). *Erigeron parishii* generally blooms between the months of May and June (Munz 1974, Nesom 2006). During years with significant summer rainfall, plants have been observed flowering into July and September (Naomi Fraga, Mitzi Harding pers. obs., Sanders 2002).

Erigeron parishii grows from a thick taprooted caudex and generally ranges from 10–35 cm in height. The stems are erect and silvery with dense eglandular trichomes. The leaves are 3–6 cm long, linear, with entire margins, and the basal leaves are withered or deciduous when plants are flowering (Nesom 2006, 2012). Following the flowering period, as well as during phases of drought, the leaves become dry and stems remain dormant above ground (Figure 4) (Neel and Ellstrand 2001). The number of flowering heads varies greatly per individual and per season. During a four-week survey in May 2009 the mean number of flowering heads ranged between 19 and 25. However, the maximum number of recorded heads per individual was 311 (see Appendix E).

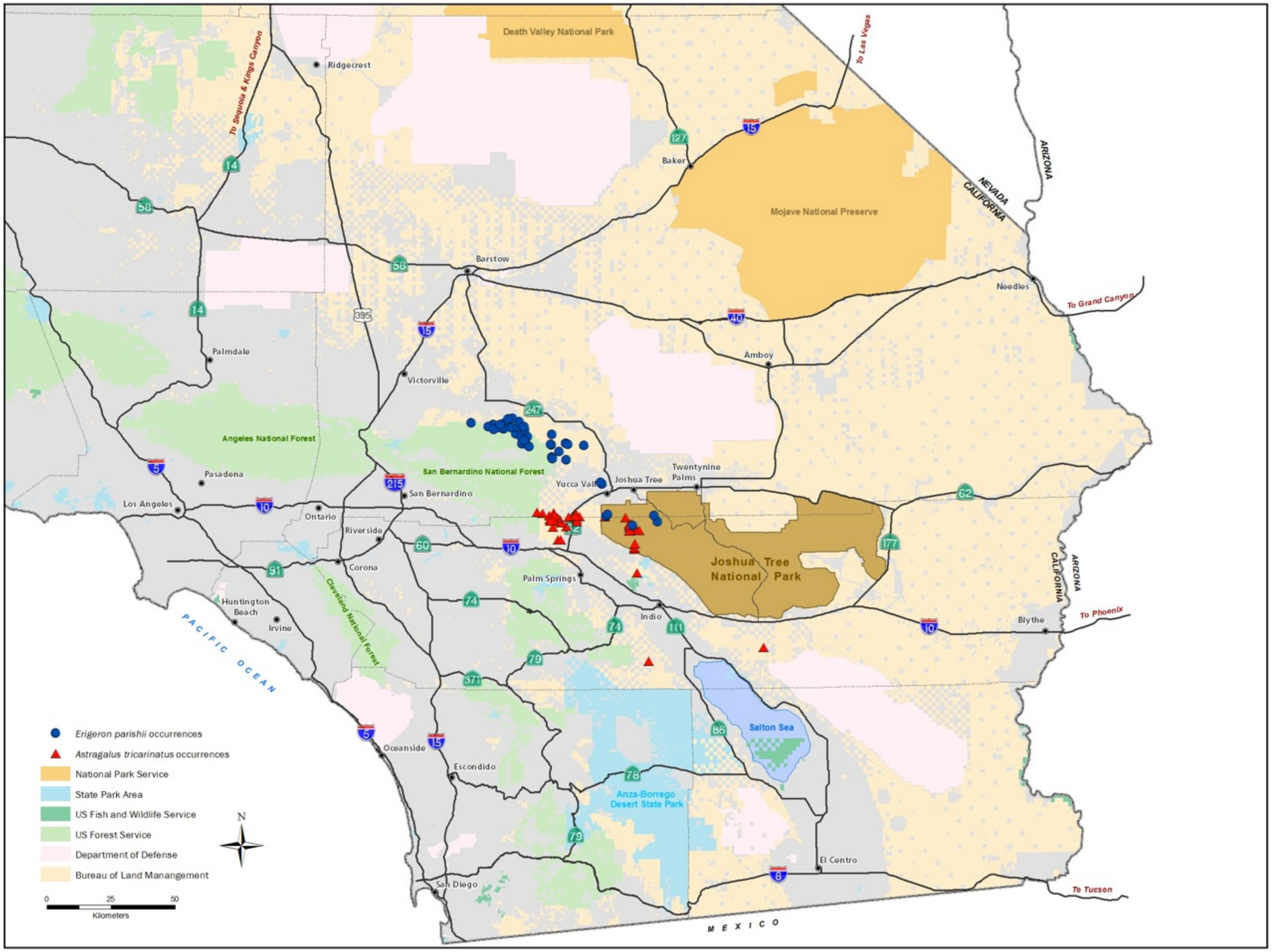

Figure 1. Map showing general location of Joshua Tree National Park (JOTR) in southern California and the global distributions for the two federally listed species known to JOTR: *Astragalus tricarinatus* (red triangles) and *Erigeron parishii* (blue circles).

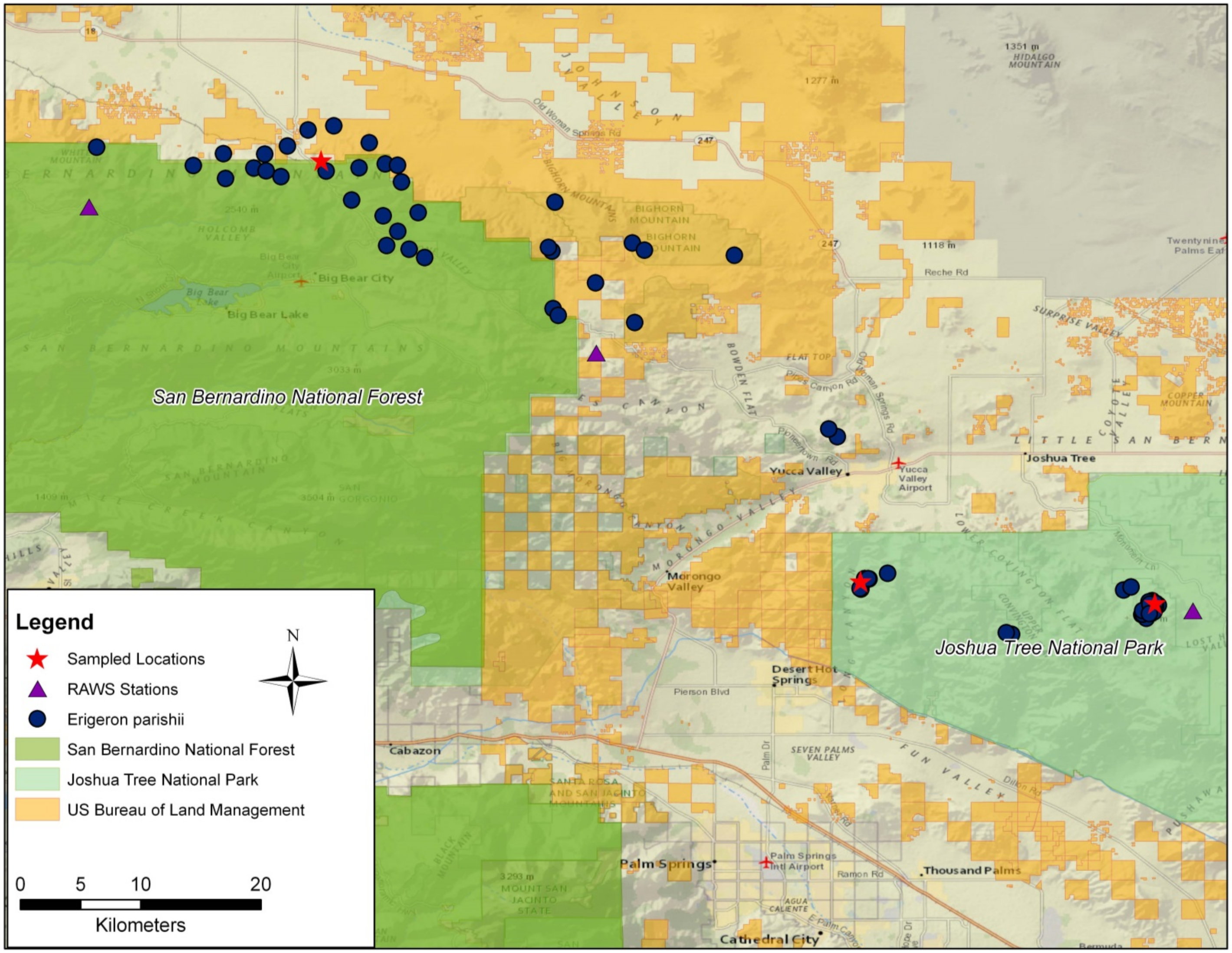

Figure 2. Map showing all known occurrences of *Erigeron parishii* (blue circles) and the land ownership for occupied habitat. Most known occurrences of *E. parishii* are on public lands (67%). Three populations (red stars) were sampled for the genetic study presented in this report. Three Remote Automated Weather Stations (RAWS) located throughout the geographical and elevational range of *E. parishii* are shown for reference (purple triangles).

Figure 3. *Erigeron parishii* in flower, showing light purple ray florets, yellow disk florets, and gray herbage. Photo by Tasha La Doux.

Figure 4. Habit of *Erigeron parishii* showing herbaceous stems from the previous growing season. Photo taken in February of 2009 in Johnny Lang Canyon (JOTR), growing from gneiss outcrop. Photo by Tasha La Doux.

The involucres are 5–7 x 10–15 mm. Phyllaries are in 3–4 series, glabrous or sparsely strigose proximally, and minutely glandular. There are 30–50 ray florets per head that are white to pink to light purple, and 6–13 mm long. The disk flowers are yellow and 3.5–5 mm long. The fruits are 1.8–2.2 mm long, 4–ribbed, and sparsely strigose. There are 18–26 pappus bristles and the outer bristles are white and more conspicuous (Munz 1974, Nesom 2006, 2012). Chromosome counts have not been published for *E. parishii*, but the base chromosome number for the genus is x=9 (Cronquist 1947).

Taxonomic History

There are nearly 400 species of *Erigeron* L. worldwide (Nesom 2006, 2012) with the majority of the species (more than 234) occurring in continental North and Central America. The center of diversity for this genus is in western North America (Nesom 2000). *Erigeron* also occurs in South America, Europe, and temperate Asia (Noyes 2000). Systematic treatments of the group have been regional rather than global, such as the sectional classifications by Cronquist (1947) and Nesom (2000). The North American taxa are currently divided into 21 sections that emphasize variation in bud position (nodding, arching–pendent, or erect), ray flower morphology (straight, reflexing, or coiling), fruit morphology, vestiture, inflorescence, and habit (Nesom 2000, 2006). *Erigeron parishii* is currently placed in section *Wyomingia* along with 10 other species that are endemic to western North America (Cronquist 1947, Noyes 2000). Section *Wyomingia* was previously treated at generic rank, however *E. parishii* has always been placed in the genus *Erigeron* and has no synonyms (Gray 1884, Cronquist 1947, Tropicos 2013).

Erigeron parishii was first described by Asa Gray in 1884 from specimens collected by Samuel B. Parish (1251 GH) at Cushenbury Springs in August 1882 (Cronquist 1947). Specimens housed at the following herbaria C, MO, US, UC, were collected by Parish under the same collection number (1251), but are not duplicates of the holotype because they were collected in May 1881 (Cronquist 1947, CCH 2014). *Erigeron parishii* is considered to be most closely related to *E. utahensis* based on similarities in morphology (Cronquist 1947). *Erigeron parishii* differs from *E. utahensis* in having a more compact habit, a conspicuous outer pappus, and is more densely hairy (Cronquist 1947, Nesom 2012).

Biology and Ecology

Life History

Erigeron parishii is a relatively long-lived perennial that grows from a deep woody taproot (perhaps up to 50 cm long; Sanders 2002). A study by Mistretta and White (2001) found that *E. parishii* had high annual seedling production and mortality. They estimated 13% survival rate for first year seedlings, however once plants became established mortality rates were low. These findings were corroborated by the preliminary studies conducted at JOTR between 2009 and 2013. None of the 11 seedlings (plants <50 cm^3) monitored during that time survived, but plants >50 cm^3 had an 85% survival rate (see Appendix E). The estimated half-life of an established plant was 28 years based on data gathered across three seasons of monitoring seedling establishment and survivorship from experimental outplantings (Mistretta and White 2001). Horticultural trials conducted at RSABG found that *E. parishii* does not require carbonate in the soil for growth. It was successfully grown from seeds and cuttings in soil mixes containing little or no carbonate materials, though seed propagation was slightly more successful (25%–58%) than propagating stem cuttings (15%–18%) (Mistretta 1994).

The plumed pappus bristles on seeds of *E. parishii* indicate they are adapted for wind dispersal (Sheldon and Burrows 1973). This is corroborated by dispersal patterns observed by Mistretta and White (2001), in which observed seedling establishment occurred within about 2 m of the parent plants (Mistretta and White 2001). Neel and Ellstrand (2001) suggested water could be a dispersal mechanism, although there is no direct evidence for this.

Reproductive Biology

A wide variety of reproductive mechanisms are reported for the genus *Erigeron*, including agamospermy, vegetative clonal reproduction, self-pollination, mixed mating, and self-incompatibility (Noyes 2000, Neel and Ellstrand 2001). Neel and Ellstrand (2001) found no evidence for extensive agamospermy or clonal reproduction in *E. parishii* based on high levels of genetic diversity, as well as low levels of inbreeding and population differentiation. The study concluded that *E. parishii* primarily reproduces sexually through outcrossed matings.

There have been no published studies on the pollination biology of *E. parishii*; therefore little is known. However, like many species of *Erigeron*, *E. parishii* has conspicuous ray flowers and relatively numerous disk florets, which are features consistent with cross-pollination (Noyes 2000). Based on the known pollinators for other species in the Asteraceae with similar flower structure, *E. parishii* is presumably pollinated by insects (Waser et al. 1996). Potential pollinators include bees, butterflies, or long-tongued flies. Three taxa of flies (Diptera) and beetles (Coleoptera) were observed visiting *E. parishii* flowers in 2009 at JOTR. Successful reproduction in nursery facilities at RSABG suggests *E. parishii* is not dependent upon a specialized pollinator (Mistretta 1994). Flowering is reported to occur from May to July (Neel and Ellstrand 2001) although the peak of flowering seems to be from mid-May to mid-June. Plants have been observed flowering into late September in years with ample summer precipitation (Sanders 2002; pers. observ. N. Fraga, M. Harding).

Mistretta and White (2001) reported that plants do not become reproductive until at least their second year. Based on a pilot study of reproductive biology and demography conducted at JOTR, it was determined that individuals under 500 cm^3 typically do not flower. This data was collected in May 2009 in Johnny Lang Canyon after a slightly less than average precipitation year. According to the Lost Horse weather station, 10.13 cm (3.99 in) of precipitation fell between 1 July 2008 and 30 April 2009. The annual average precipitation at this location, based on data from last 22 years, is 14.71 cm (5.79 in). During extremely dry years, however, it appears that many plants, independent of size, either do not flower or reduce their reproductive output greatly. For example, in 2013, a year with 7.47 cm (2.94 in) of precipitation (the PRISM estimated 30-yr minimum is 6.88 cm (2.71 in); see Table 1), nearly half (42%) of the plants observed did not produce any flowering heads, and 31% of them had <10 flowering heads (N=111, 65). A positive relationship between total plant volume and number of flowering heads is strongly supported (Spearman's Rho = 0.914, 51 d.f., p=1.31e-21) based on the measurement data collected in May of 2009 (see Appendix E for additional details).

Genetics

To better understand genetic diversity of populations located within JOTR, in 2011 the Laboratory of Molecular Evolution and Systematics at RSABG completed a study of relative genetic diversity using an analysis of Inter-Simple Sequence Repeat (ISSR) genotype data. Two populations within JOTR (Quail Mountain and Long Canyon) were compared to a single population found growing on carbonate substrates in the San Bernardino National Forest (SBNF). These data were compared and contrasted to prior population level research by Neel and Ellstrand (2001). Details of the experimental design, data collection, results and discussion are provided in Appendix B.

Because the two studies used different types of data (allozyme versus ISSR), the data are not directly comparable and cannot be combined, however qualitative comparisons can be made. In general, allozymes generate fewer bands, so less genetic diversity can be detected than with ISSRs. The prior allozyme study found lower genetic diversity (and greater inbreeding) in the population occurring on soils derived from granodiorite as compared to those populations on carbonate-derived soils. Our data were consistent with that finding. The SBNF population had the largest number of unique fragments (35), with each of the JOTR populations having fewer (Quail Mountain w/ 12 unique fragments, Long Canyon w/ 8 unique fragments). Each population was genetically distinct, with varying numbers of population-specific fragments. The population from Quail Mountain had diversity values more similar to the population from SBNF, but was genetically more similar to the second JOTR population.

The Long Canyon population from JOTR was less diverse than either of the other two, based on all available measures of diversity (number of alleles, number of effective alleles, Shannon's Information Index, Nei's diversity, Nei's unbiased diversity, and percentage polymorphic loci). The Long Canyon population is geographically isolated on the southern edge of the known range for the species. Peripheral, isolated populations often have lower genetic diversity than populations closer to the center of the distribution (Durka 1999, Eckert 2008, Moeller et al. 2011, Pouget et al. 2013). This population also had the fewest number of individuals, which may have contributed to the overall lower diversity detected.

Although the two JOTR populations of *E. parishii* sampled for this study had lower genetic diversity than the population from SBNF, there was evidence for past or contemporary gene flow among all three populations. Additionally, the populations in JOTR were each characterized by a number of unique ISSR bands not found in the SBNF population sampled.

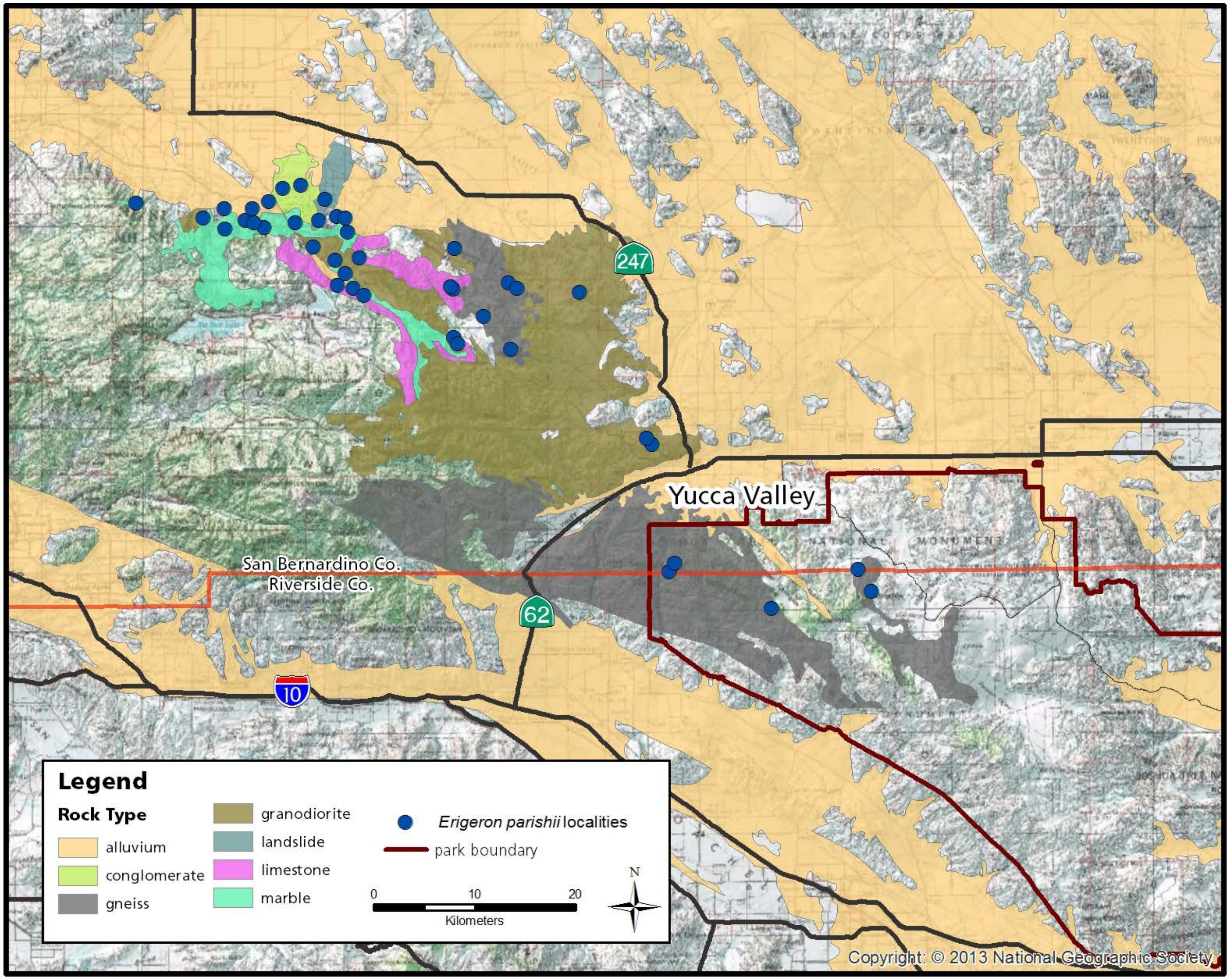

Figure 5. Geologic map from southern California (USGS 2009), showing substrates that *Erigeron parishii* occurs on throughout its range, including within Joshua Tree National Park.

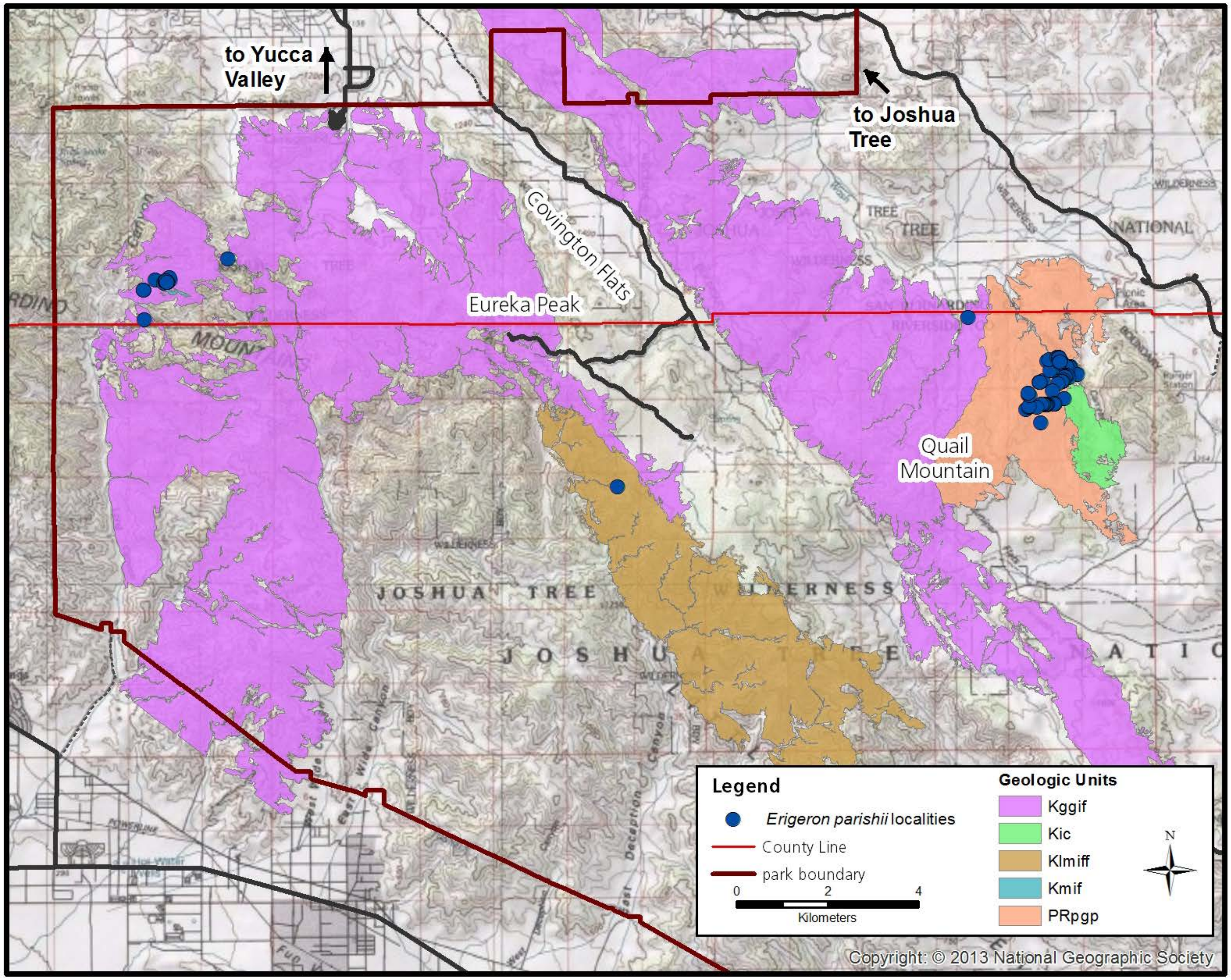

Figure 6. Detailed geologic map of *Erigeron parishii* locations (blue circles) within Joshua Tree National Park. Geologic unit code definitions: Kmif = mafic and intermediate rocks; Kic = Monzogranite of Indian Cove; PRpgp = Metasedimentary rocks and orthogneiss of Pinkham Canyon; Klmiff = Layered mafic, intermediate, and felsic rocks, foliated; Kggif = Granitic, granodioritic, and intermediate rocks, foliated. (NPS GRI 2014).

Habitat

Erigeron parishii occurs in washes and canyon bottoms, but also on rocky and primarily north-facing slopes at elevations of 1035–2015 m (3395–6610 ft) (CNDDB 2014, CCH 2014, Sanders 2002, USFWS 2009). Nesom (2012) and the CNDDB (2014) report this species at a lower elevation limit of 800 m (2624 ft), however this elevation range would put *E. parishii* away from the foothills and mountainous regions where it occurs and onto the flats of the Mojave Desert where it has not been documented (Sanders 2002, CCH 2014). In the western portion of its range, *E. parishii* occurs almost exclusively on substrates derived from limestone or marble (dolomite), but in the eastern portion of its range it occurs on gneiss, granodiorite, and monzogranite substrates (USFWS 2009, NPS GRI 2014, Figures 5 and 6).

According to the unpublished digital geologic map of JOTR (based upon USGS source maps), the Quail Mountain population is situated along the interface of two geologic units described as "metasedimentary rocks and orthogneiss of Pinkham Canyon" (*PRpgp*) and "monzogranite of Indian Cove" (*Kic*). The predominant geologic materials are gneiss and monzogranite, respectively. The Long Canyon population also occurs along an interface of two geologic units: "granitic, granodioritic, and intermediate rocks, foliated" (*Kggif*) and "mafic and intermediate rocks" (*Kmif*). *Kggif* is comprised of granitoid rock material, and *Kmif* is described as "ranging in composition from granodiorite to tonalite and quartz diorite". Both *Kggif* and *Kmif* are widespread throughout the Little San Bernardino Mountains. (NPS GRI 2014, Figure 6).

A report provided by Paul Rindfleisch of Natural Resource Conservation Survey (see Appendix F) identified the soil properties associated with *E. parishii* on Quail Mountain in JOTR and found that this species prefers "very shallow" to "shallow" soils (less than 50 cm), or plants were growing directly out of bedrock. Soils were reported to be principally gravelly loamy sand (80%) weathered from gneiss parent material and plants were found to grow exclusively on northern aspects, primarily on low hills with slopes up to 35% (USDA et al. 2013). Available water holding capacity ranged from 0.12 in/in for sandier soils to 0.34 in/in for loamier soils. The surface pH was reported to be slightly alkaline (7.4). Within JOTR, *E. parishii* is only found on two soil types: Xeric Torriorthents-Bigbernie Association and Pinecity gravelly loamy sand (USDA et al. 2013). Details of the soil analysis are provided in Appendix G.

In 2012, a habitat model for JOTR was created in ArcGIS Desktop using a Python script (v2.6, © Copyright 1990-2014, Python Software Foundation), which has the ability to utilize five environmental parameters (elevation, slope, aspect, soil type, and/or vegetation type) to assign probability values of suitable habitat to the landscape. A data layer representing all known *E. parishii* habitat in JOTR was created using a 15 m radius buffer around known point localities. By overlaying this information with the five environmental parameters, it was determined that there are three major vegetation types and two soil types associated with >90% of known *E. parishii* habitat in JOTR. It was also determined that more than 70% of the mapped occupied habitat is between 1245–1445 m (4085–4740 ft), 97% of occurrences have slopes ranging between 6°–34°, and 83% showed an aspect ranging between 310°–90° (N–NW). Details of the habitat model are provided in Appendix C.

Critical habitat for *E. parishii* was designated in December 2002 by the US Fish and Wildlife Service. In the critical habitat designation rule it was estimated that there was 20,818 acres (8,428 hectares) of suitable habitat across the range of *E. parishii* (USFWS 2002). However, at the time of the rule little was known regarding the occurrences in the eastern portion of its range on gneiss and granodiorite. Areas that were considered for critical habitat included physical and biological features thought at the time to be essential to the conservation of the species, and that may require special management considerations or protection. The primary elements of critical habitat for *E. parishii* consist of, but are not limited to, the following (USFWS 2002):

1) Soils derived primarily from upstream or upslope limestone, dolomite, or quartz monzonite parent materials that occur on dry, rocky hillsides, shallow drainages, or outwash plains at elevations between 1171–1950 m (3842–6400 ft)

2) Soils with intact, natural surfaces that have not been substantially altered by land use activities (e.g. graded, excavated, re-contoured, or otherwise altered by ground disturbing equipment)

3) Associated plant communities that have areas with an open canopy cover.

Climate

Long-term survival of *E. parishii*, within its native habitat and current distribution, is of concern due to its highly restricted global distribution, small numbers of individuals within the majority of known occurrences, and the geographic isolation of these occurrences. In particular, the JOTR populations represent the southeastern extent of the species known distribution, occupying the lower end of its elevational range where environmental conditions are warmer and drier compared to the average values across the rest of its distribution. An analysis of climate variability across the range of occupied habitat for *E. parishii* was conducted in ArcGIS Desktop 10.0 using a spatial climate data set called PRISM (Parameter-elevation Relationships on Independent Slopes Model (PRISM 2014). PRISM climate data provides average values for minimum and maximum temperature and total annual precipitation across a thirty-year period (current data set is from 1981–2010 as 30-arcsec (~800m) grid). Values for total annual precipitation, minimum air temperature, and maximum air temperature across 35 known occurrences for *E. parishii* were extrapolated from the spatial dataset. The maximum, minimum, and average values are reported in Table 1 (PRISM 2014). The lowest annual precipitation values, 6.88 cm (2.71 in), are found in the Little San Bernardino Mountains, including the large population on Quail Mountain in JOTR. The highest value for total precipitation was located in the far western portion of the species range in Furnace Canyon of the San Bernardino Mountains with 19.66 cm (7.74 in). Temperatures at Quail Mountain were also among the highest for both maximum and minimum average annual temperatures, 23.85°C (74.93°F) for the max temp and 8.65°C (47.57°F) for the min temp. This analysis provides evidence that populations in JOTR experience the driest and hottest weather conditions across the range of the species.

Table 1. Thirty-year average climate data across the distribution of *Erigeron parishii* estimated using spatial climate data (PRISM 2014).

	30 year average	30 year minimum	30 year maximum
Precipitation cm (in)	11.81 (4.64)	6.88 (2.71)	19.66 (7.74)
Minimum air temperature °C (°F)	5.6° (42°)	2.35° (36.23°)	8.65° (47.57°)
Maximum air temperature °C (°F)	20.47° (68.85°)	17.71° (63.88°)	23.85° (74.93°)

Actual weather data from three Remote Automatic Weather Station (RAWS) locations (Figure 2), spanning the geographical and elevational range of the species, are presented in Table 2. These data support the PRISM estimates discussed above. The Lost Horse RAWS is located approximately 2 km east from the Quail Mountain population in JOTR. Based on the last 22 years, the mean annual precipitation at the Lost Horse Weather Station (WRCC 2014) is 14.71 cm (5.79 in) with a minimum value of 2.26 cm (0.89 in) in 2002 and a maximum of 37.47 cm (14.75 in) in 2005 (Table 2). Average annual temperature is 16.04°C (60.88°F), with an average maximum of 17.07°C (62.72°F), and an average minimum of 14.29°C (57.72°F) (Table 2). The JOTR plants may be better adapted to surviving hotter and drier climates and therefore may become an important source for future mitigation. Conversely, they could be more vulnerable to projected shifts in current climate conditions because they are at the edge of the range – already occupying the extreme of their physiological tolerance.

Table 2. Weather data from three RAWS stations (WRCC 2014) spanning the geographical and elevational range of *Erigeron parishii* (Figure 2) demonstrating that the Joshua Tree NP populations of *E. parishii*, located near the Lost Horse weather station, are experiencing the hottest and driest conditions within its known range. National Weather Service identification number is in parentheses following the weather station name.

RAWS Weather station (NWS ID):	Lost Horse (45614)	Burns Canyon (45125)	Big Pine Flat (45102)
Mean annual precipitation cm (in)	14.71 (5.79)	16.36 (6.44)	33.32 (13.12)
Mean avg. air temp °C (°F)	16.04 (60.88°)	13.71 (56.68°)	9.97 (49.94°)
Minimum avg. air temp °C (°F)	14.29 (57.72°)	12.09 (53.76°)	8.98 (48.16°)
Maximum avg. air temp °C (°F)	17.07 (62.72°)	14.92 (58.85°)	10.64 (51.16°)
Elevation m (ft)	1280 (4200)	1829 (6000)	2091 (6861)
# of years data collected	22	22	12

Vegetation and Associated species

Erigeron parishii is most frequently associated with the following vegetation alliances as defined by Sawyer et al. (2009): single needle pinyon woodland, California juniper woodland, black brush scrub, and Muller oak scrub (CNDDB 2014, USFWS 2009).

According to the vegetation classification for JOTR (Keeler-Wolf et al. 2005, Evens et al. 2012, La Doux et al. 2013), occurrences of *E. parishii* most commonly occur on the following vegetation associations: Single-leaf Pinyon Pine / Muller's Oak (*Pinus monophylla* / *Quercus cornelius-mulleri*) Woodland Association, California Juniper / Blackbush (*Juniperus californica* / *Coleogyne* *ramosissima*) Association, and Muller Oak — California buckwheat — Narrowleaf goldenbush (*Quercus cornelius-mulleri — Eriogonum fasciculatum — Ericameria linearifolia*) Association.

The following species are commonly associated with *E. parishii* throughout its range: *Coleogyne ramosissima* Torr. (blackbush), *Ephedra viridis* Coville (green ephedra), *Ericameria* spp. (rabbitbrush), *Pinus monophylla* Torr. & Frém. (single leaf pinyon pine), *Juniperus californica* Carrière (California juniper), *Mirabilis laevis* (Benth.) Curran (wishbone bush), *Opuntia basilaris* Engelm. & J.M. Bigelow var. *basilaris* (beavertail prickly-pear), *Scutellaria mexicana* (Torr.) A.J. Paton (bladder-sage), *Stipa speciosa* Trin. & Rupr. (desert needle grass), *Yucca brevifolia* Engelm. (Joshua tree), and *Y. schidigera* Ortgies (Mojave yucca).

In JOTR, *E. parishii* is often associated with (in addition to those listed above): *Acmispon glaber* (Vogel) Brouillet (deer weed), *Brickellia atractyloides* A. Gray var. *arguta* (B.L. Rob.) Jeps. (pungent brickell bush), *Cercocarpus betuloides* Nutt. (mountain mahogany), *Cirsium neomexicanum* A. Gray (desert thistle), *Crossosoma bigelovii* S. Watson (ragged rockflower), *Encelia actonii* Elmer (Acton's brittlebush), *Ephedra nevadensis* S. Watson (Nevada ephedra), *Ericameria linearifolia* (DC.) Urb. & J. Wussow (narrow leaved golden bush), *Eriogonum wrightii* Benth. (Wright's buckwheat), *Hilaria rigida* (Thurb.) Scribn. (big galleta), *Keckiella antirrhinoides* (Benth.) Straw (bush penstemon), *Menodora scabra* A. Gray var. *glabrescens* A. Gray (rough menodora), *Nolina parryi* S. Watson (Parry's beargrass), *Quercus cornelius-mulleri* Nixon & K.P. Steele (Muller's oak), *Rhus aromatica* Aiton (fragrant sumac), *Xylorhiza tortifolia* (Torr. & A. Gray) Greene (Mojave aster), and *Ziziphus parryi* Torr. (Parry's jujube).

Erigeron parishii co-occurs with other carbonate endemics in the San Bernardino Mountains including *Acanthoscyphus parishii* Parry var. *goodmaniana* (Ertter) Reveal (Cushenbury oxytheca, Polygonaceae), *Astragalus albens* Greene (Cushenbury milk-vetch, Fabaceae), and *Eriogonum ovalifolium* Nutt. var. *vineum* (Small) A. Nelson (Cushenbury buckwheat, Polygonaceae).

Distribution and Abundance

The distribution of *E. parishii* spans 83 km (50 mi) from White Mountain in the San Bernardino Mountains southeast to Quail Mountain in the Little San Bernardino Mountains (Figure 2). At present, there are 41 occurrences that are known with a total global population estimated at just over 20,000 individuals (CNDDB 2014, Table D1 in Appendix D). At the time of listing, *E. parishii* was known from fewer than 25 occurrences with a global population numbering approximately 16,000 individuals. The SBNF has at least 87 site-specific occurrences mapped (USFWS 2009); however, occurrences have been subjectively defined across multiple surveys making it difficult to compare occurrences and examine the status of *E. parishii* over time (USFWS 2009). Although there has been an increase in the number of occurrences, likely due to an increase in survey effort after listing, this does not translate to an increase in population size or number of individuals at known occurrences. In fact, population size is thought be decreasing at five of the 41 known occurrences, including the largest population (EO14), which occurs in the San Bernardino Mountains on carbonate habitat (CNDDB 2014). Element occurrence 14 was estimated to have 5500 individuals in 1988 and was estimated to have 1800 plants in 1996. Within other occurrences, population trends are unknown (CNDDB 2014). Abundance at each occurrence ranges from one plant to over 5000 across the range of *E. parishii* (CNDDB 2014). Many occurrences are historic (over 20 years since last surveyed), so fieldwork is needed to determine trends, especially at the most threatened occurrences.

In the most recent five-year review the estimated occupied habitat for *E. parishii* equaled 1029 acres (USFWS 2009). The current analysis differs from the previous estimate with a total of 1953 acres of mapped for *E. parishii* (Figure 2); this nearly doubles the area estimated in 2009. Approximately 1256 acres (67%) are on public lands; however a portion of this may be under mining claim. Private land accounts for 697 acres (36%). Of the 1256 acres of occupied habitat on public lands approximately 208 acres (17%) are on lands managed by JOTR, 681 acres (54%) are on SBNF, the Bureau of Land Management (BLM) manages 361 acres (28%), and 6 acres (0.48%) are located on lands managed by the California State Lands Commission (CNDDB 2014). Of the 697 acres of mapped occupied habitat on private lands, 19 acres (2.7%) are located on lands managed by the University of California Burns Piñon Ridge Reserve. The individual mapped element occurrences often span more than one type of land use (e.g. private and BLM, USFS and BLM) therefore the acreages were divided between these ownership types as part of the current analysis. The majority of occurrences and the most abundant populations of *E. parishii* (Table D1 in Appendix D) are located in the San Bernardino Mountains (CNDDB 2014). The SBNF still has the largest percentage of occupied habitat at 681 acres, accounting for 35% of the total acreage across the species range (USFWS 2009). Within the Little San Bernardino Mountains in JOTR, there are approximately 208 acres of occupied habitat with an estimated 1200 plants (Figure 7). The population near Quail Mountain is the most extensive with an estimated 1000 individuals.

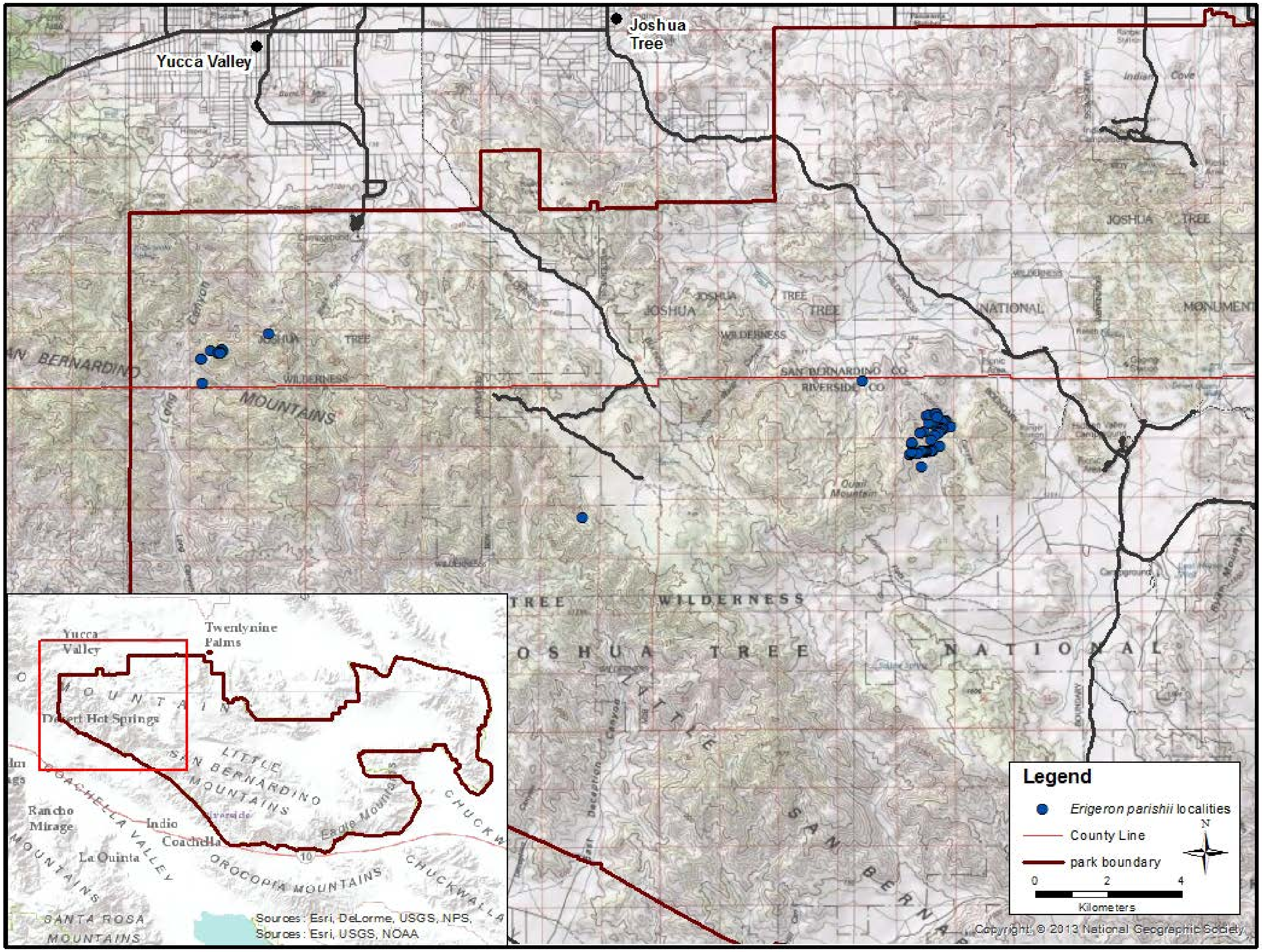

Figure 7. Known locations for *Erigeron parishii* in Joshua Tree National Park. The largest population is estimated at ca. 1000 individuals, located on the northeastern slopes of Quail Mountain.

Status of Populations

Population trends across the range for *E. parishii* are difficult to discern in part due to dated information and a lack of systematic monitoring for this species. Approximately 32% of the occurrences recorded in the CNDDB are historic (i.e. they have not been observed in over 20 years) and most occurrences are known from just a single observation in one year (CNDDB 2014). There are no known extirpated occurrences; however two occurrences that are threatened by mining operations are rated as poor (D) and declining (EO's 25 and 29, CNDDB 2014). Three additional occurrences with ranks of good to fair (B–C) are threatened by mining operation and off-highway vehicle use and are reported to be declining (EO's 13, 14, 17; CNDDB 2014). The trends at most occurrences (85%) are unknown (CNDDB 2014).

Prior to 2008, only two populations of *E. parishii* had been documented within JOTR. These populations are in the Little San Bernardino Mountains above Long Canyon, located in the very western portion of the JOTR. Until recently, the exact locations for these populations were unknown due to vague locality information on three historic vouchers:

1. P. Leary, 1219, collected on May 22, 1975, E of Long Cyn near county line, side of steep slope; T1SR5ES35 elev. 3600 ft. (UNLV09525).

2. E. C. Jaeger, s.n., collected on May 29, 1939, Little San Bernardino Mountains, 6 miles S of Lone Star Service Station, elev. 1220 m (POM248190).

3. E. C. Jaeger, s.n., collected on May 25, 1939, Little San Bernardino Mountains, 8 miles S of Warrens Well. Alt. 4200 ft. (POM248188).

After decades of searching by various botanists and JOTR staff, these occurrences were relocated by Naomi Fraga (RSABG), Bill Truesdell (JOTR), and Tasha La Doux (JOTR) in 2005–2006. The two Jaeger collections from 1939 are attributed to EO#42, where 36 individuals were counted in 2006. This occurrence was revisited in 2011 in order to collect leaf material for a genetic study (see Appendix B). At the time of that visit the population was estimated at 60 individuals. The Leary collection (1975) is attributed to EO#19 where only three individuals were found in 2005. The current status of that occurrence is not known. Due to their distance from a road or trailhead, combined with the steep loose habitat, access to these occurrences will always be difficult and therefore frequent monitoring will not be likely.

In 2008, Sarah De Groot and Naomi Fraga (RSABG) discovered several individuals of *E. parishii* in Johnny Lang Canyon, at the base of Quail Mountain. Through additional surveys, RSABG and JOTR staff discovered that this population is quite large (ca. 1000 individuals, EO#47) and extends from Johnny Lang Canyon up the northeastern slopes and canyons of Quail Mountain (see Figure 7). This population is significant for several reasons. First, it is the southeastern most extent of the known distribution for this species. Secondly, it mainly occurs on alluvium derived from gneiss and monzogranite, rather than carbonate. The status of these populations appear to be stable, however further monitoring efforts will be important in determining any trends, especially for the small isolated populations above Long Canyon. Four long-term monitoring plots have been established near Quail Mountain to assess survival rates and demographics (see Appendix E).

Threats

Several threats have been documented for *E. parishii* including large scale carbonate mining, off-road vehicle use, energy development, dispersed target shooting, dispersed camping, fuel wood collection, fire suppression activities, housing development, and grazing (USFWS 2009). Mining associated with limestone extraction in the San Bernardino Mountains remains the primary threat for *E. parishii* (USFWS 2009, CNDDB 2014). Mining activities can impact plants and habitat through the removal of mined materials, disposal of overburden, spread of fine carbonate dust, and road construction (USFWS 2009). Artificial lighting at mining operations has also been identified as a threat because it can alter the photoperiod response or the behavior of pollinators or seed dispersers (USFWS 2009). Indirect effects associated with carbonate mining and processing include: changes to surface hydrology, soil erosion, increase in non-native plant species abundance, and plant physiological effects from carbonate dust (Padgett et al. 2007, Sanders 2002). Threats on private land include housing developments near Pioneertown (CNDDB 2014).

Disease and predation are not known to be threats affecting *E. parishii* (USFWS 2009). Threat of predation from burro grazing was identified after listing (USFWS 2009); however, the number of burros within the range of *E. parishii* is low at present (about 60), and they are dispersed across a large area (USFWS 2009). The effects of grazing by burros are expected to be minimal and foraging is unlikely. Jesse Walker documented grazing impacts from cattle in the BLM Rattlesnake Canyon grazing allotment in 2000; an exclusion fence was constructed (Scott Eliason pers. comm.).

In JOTR, potential threats are limited to fire suppression activities, dispersed hiking/camping, or other management activities such as restoration or trail building. The Quail Mountain population occupies the Johnny Lang Canyon Trail corridor along a small, faintly defined section (Figure 8). Currently this is not considered a park maintained trail, but it does occur on hiking maps and in hiking publications for the park. If it becomes a park maintained trail, strict measures should be taken to ensure no damage to the population occurs during trail construction and the trail should be located in a way that avoids the plants. This population also occurs in an area that has burned several times over the last four decades. The majority of the plants from this region occur in an area that burned in 1978, 1984, and 1999, all of which were greater than 10 acres in size (see Figure 8). The fire history records for JOTR date back to the 1940’s. Direct and indirect effects of fire or smoke on plant or seed bank survival deserves further study; however, at this time it appears that they are not negatively affected and may be able to resprout from the base post-fire.

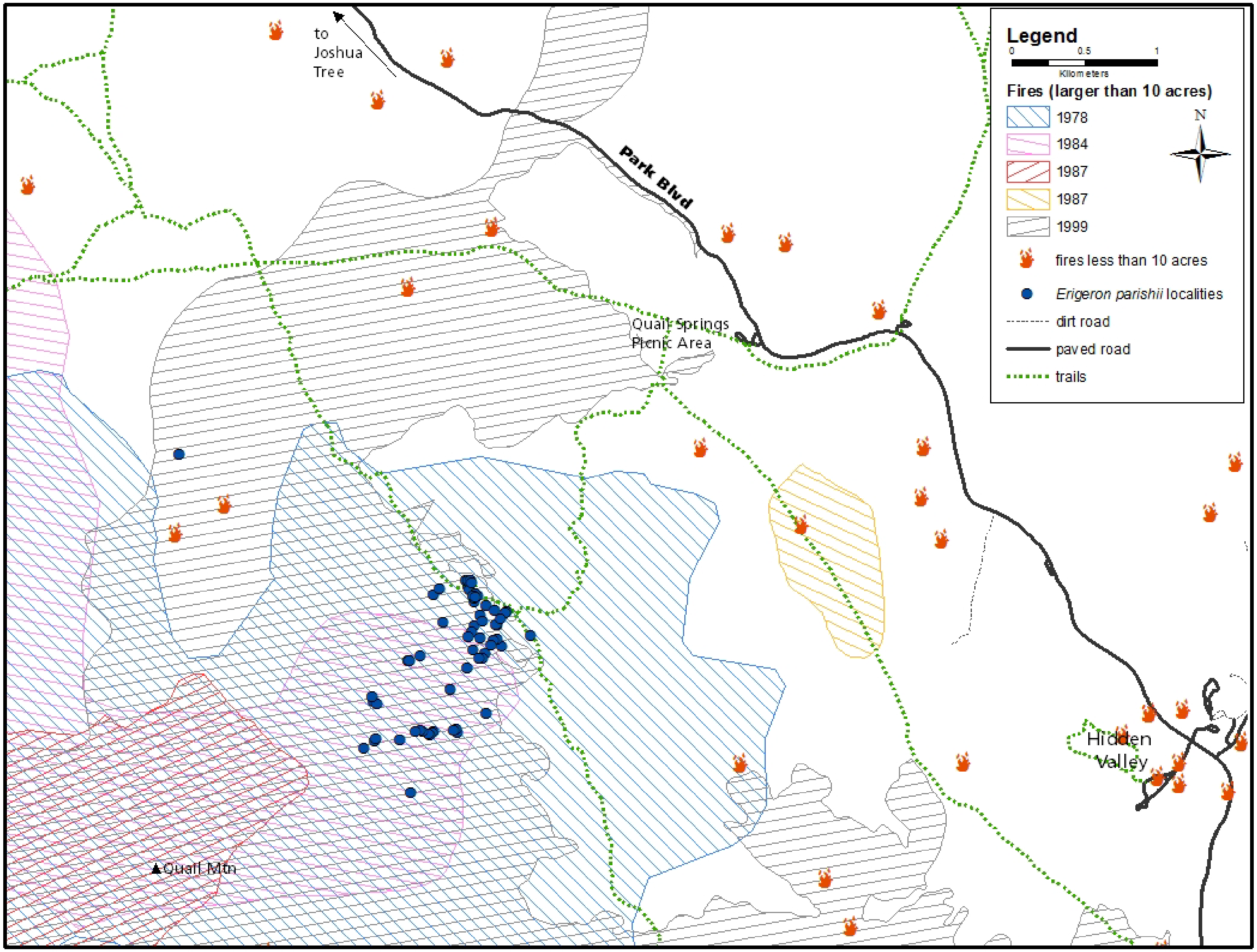

Figure 8. Known fire history and trails near the Quail Mountain population of *Erigeron parishii* in Joshua Tree National Park.

Conservation Status

Erigeron parishii was listed as threatened by the federal government in 1994 and is protected under the West Mojave Plan, an interagency federal land use plan prepared by the Bureau of Land Management in 2006 (Sanders 2002). Critical habitat for *E. parishii* was designated in December 2002 (USFWS 2009).

The current rarity ranking of this species is provided below (CNPS 2014).

- **Federal Listing Status**: Threatened
- **State Listing Status**: None
- **State Rank**: None. S2
- **California Native Plant Society**: 1B.1 (Seriously endangered in California)
- **Global Rank**: G2

Ex-situ Conservation: Seed Bank Holdings

There are currently ten seed accessions of *E. parishii* stored in the seed bank at RSABG (Table 3). There are two seed accessions from populations within JOTR. Seed germination of *E. parishii* varies between 45 to 100% depending on the quality of the seed accession (Table A1). Fresh and stored seeds are readily germinated without pretreatment and seeds retain high viability in cold storage (-20 C) for over 20 years (see Appendix A). Germination trials conducted in 1991 for accession 15781 at RSABG showed low germination rates (30%) due to a poor quality seed lot that had not been screened for viability prior to testing (Table A1). This seed lot was reprocessed in 2013 to remove the sterile seed, and follow-up germination tests showed 100% germination. Considering RSABG accession 15781 is over 25 years old (collected in 1988), these results demonstrate that traditional means for seed storage (cold storage and low relative humidity (ca. 13%) is an effective long-term conservation strategy for securing germplasm of *E. parishii*.

Table 3. Current seed bank holdings of *E. parishii* at the Rancho Santa Ana Botanic Garden seed storage facility.

Acc.	Date	CO	Geographic area	Location	Land Manager	Collector	Coll.#	Quant.
15781	21-Jun-1988	SBD	SBD Mtns	White Ridge-White Knob	SBNF BLM	Kelly, David	SN	128235
17366	1-Jul-1991	SBD	SBD Mtns	Cushenbury Grade, E-side of Hwy 18	SBNF BLM	Hammitt, Mike	SN	4805
18515	13-Sep-1994	SBD	SBD Mtns	RSABG, (F1)	NA	Wall, Michael	SN	3761
20332	23-Jun-1999	SBD	SBD Mtns	Marble Cyn on Mitsubishi Cement Plant Property	Private	Seal, Don	SN	9065
21888	22-Jun-2006	SBD	Little SBD Mtns	Long Canyon	JOTR	Fraga, Naomi	1663	4952
23220	8-Jul-2010	SBD	SBD Mtns	NE of Monarch Flat near 4wd road.	BLM	Fraga, Naomi	3471	61939
23300	27-Jul-2010	SBD	SBD Mtns	Cactus Flats, off Smart's Ranch Road	SBNF	Scott Eliason	Craig 1617	781
23437	17-Jun-2011	RIV	Little SBD Mtns	Johnny Lang Canyon	JOTR	Mitzi Harding	SN	14430
23484	29-Jun-2011	SBD	SBD Mtns	Whiskey Springs	SBNF	Christine Craig	1646	3534
23485	29-Jun-2011	SBD	SBD Mtns	Cactus Flats, off Smart's Ranch Rd	SBNF	Christine Craig	1617	3221

Future Recommendations

Research

Many knowledge gaps still exist with regard to the life history, geographic distribution, habitat preference and ecology of *E. parishii.* Research questions that are outlined in this section aim to advance our knowledge of *E. parishii* to inform management strategies and long term conservation efforts for this species.

Population-level and phylogenetic studies

We recommend pursuing population genetic and phylogenetic research that would further our current knowledge of the genetic distinctiveness and diversity present within and among populations throughout the range. These studies could inform the prioritizing of conservation efforts. Examples include:

1. Expanding the population genetic study presented in this report to include additional populations across the range. The initial study indicates that there are alleles present in the JOTR populations that are not present in the San Bernardino Mountains. Due to limited sampling it is unclear if that diversity is unique to populations located within JOTR. Expanding this study will provide information regarding the uniqueness of the JOTR populations.

2. The current study supports previous studies that demonstrate that populations on calcareous soils are more genetically diverse than peripheral populations occurring on other substrates. A more complete sampling of individuals that represent the range of environmental conditions where *E. parishii* grows will further inform how genetic diversity is partitioned across the landscape.

3. Levels of gene flow between populations of *E. parishii* are not currently well understood and the parameters that were analyzed in the current study are not well suited to study contemporary gene flow. An expanded paternity analysis utilizing the genotypes of the mother plants and their offspring compared with a pool of potential fathers within a population would provide information on contemporary gene flow and directionality.

4. There are no published phylogenetic studies that have sampled *E. parishii* or its close relatives. It is hypothesized that *E. utahensis* is the closest relative based on morphology, however additional information is needed regarding the phylogenetic position of *E. parishii* and its evolutionary history.

Life-history and reproductive biology studies

We recommend ecological studies addressing any gaps in current knowledge of the basic biology for this species. In particular, studies that would significantly add to the conservation assessment and long-term management of the species include, but are not limited to:

1. Long-term population viability and longevity of individuals

2. Identify effective pollinators; study pollinator biology, including other host species, timing of pollination, life cycles, etc.

3. Determine whether self-pollination is possible, or whether any reproductive barriers are present (e.g. self-incompatibility, inbreeding depression)

4. Determine presence of soil preferences or limitations; conduct a common garden experiment utilizing soil derived from carbonate, granodiorite, gneiss, and monzogranite parent materials

5. Study physiological response to various rainfall patterns (amount/timing of rains, monsoonal rains), as well as changing environmental conditions such as shifting seasons or higher/lower temperature extremes

6. Determine germination rates after fire (smoke treatment on seeds), as well as the ability to resprout after fire

7. Test for changing environmental conditions, for example, the effect of extended periods of drought or increased competition from non-native species on survivorship

8. Determine rates of survivorship for seedlings, juveniles, adults; and determine meaningful demographic size classes.

9. Test germination rates under a variety of stratification methods to test for physiological limits.

10. Estimate seed production and viability rates per individual and which, if any, environmental or biological factors contribute to reproductive success as measured by seed production.

Park Management

Field Surveys and Habitat Modeling

Continued efforts to locate new populations utilizing the habitat model should remain a priority, as well as improving upon the habitat model. Field surveys should focus on high probability areas according to the maps produced by the current model (see Appendix C). Because the model is meant to be iterative, any new data points should be uploaded immediately, and the model updated before another field survey takes place. According to the current habitat model, geospatial data should be taken for each individual more than 15 m apart. Future habitat models should consider the idea of utilizing absence points, as well as providing a means to weight the parameters differently.

As part of the field survey efforts, population status for all known occurrences should be recorded on a regular basis. For small populations (less than 50 individuals) we recommend doing population counts every five years, at a minimum. Finally, an effort should be made to better map and estimate the number of individuals located in the vicinity of Quail Mountain and Johnny Lang Canyon.

Annual Monitoring

It is highly recommended that annual monitoring at the four permanent plots occur for a minimum of five years, following the protocol presented in Appendix F. The frequency of monitoring could be reassessed after this time. It is also recommended that monitoring continue for the 52 individuals tagged in 2009. With consistent annual data collection, results from statistical analyses on demographics and reproductive biology for this species will be much more effective at predicting any correlative relationships. In particular, long-term viability of the *E. parishii* populations in JOTR, as well as longevity of individuals, will be addressed. Finally, there are a number of recommendations presented in Appendix E pertinent to annual monitoring that should be followed or addressed.

Protection

Complete and total protection should be afforded to all individuals and occupied habitat of *E. parishii*, in accordance with the Endangered Species Act (USFWS 2014). Collecting of specimens should only be allowed for the purpose of research or recovery efforts and must be approved by USFWS.

Areas within JOTR with known populations or individuals should be designated as a strict "no disturbance" zone, which would exclude any kind of ground disturbance, vegetation pulling, trimming, or removal. In particular, fire suppression activities (e.g. hand lines) should not be allowed in and around the known populations. Any newly proposed trails or access routes through occupied habitat should be redirected to a new area. Any proposed trail work on the Johnny Lang canyon trail should be scrutinized for necessity as part of the NEPA compliance process.

Finally, as a measure to protect the genetic diversity found within JOTR, an effort should be made to collect seeds from all populations and place them in long-term storage. All seed collection, viability testing, and seed processing should follow ethical and current protocols, such as those described in the Seeds of Success (2012) technical report.

Appendix A: Germination Study

By Naomi Fraga, Michael Wall and Evan Meyer, Rancho Santa Ana Botanic Garden

Initial germination tests were conducted on 0.5% agar solution on clear plastic examination plates maintained at 11 hrs. light at 20° C and 13 hrs. dark at 12° C. In general, seeds were not subjected to any pre-treatment because relatively high germination rates (above 75%) had previously been recorded for *E. parishii* seeds with no pre-treatment. A cold-stratification treatment yielded 80% germination rate and germination rates for no treatment ranged from 75% to 100%. Test results indicate that plants have a high germination rate and do not require special treatment to break dormancy (Table A1). Additionally, test results indicate that germination rates have not declined in seeds that have been in storage for 25 years (see accession 15781, Table A1). Germination trials conducted in 1991 for accession 15781 at RSABG showed low germination rates (30%) due to a poor quality seed lot that had not been screened for viability prior to testing (Table A1). This seed lot was reprocessed in 2013 to remove the sterile seed, and follow-up germination tests showed 100% germination. Considering RSABG accession 15781 is over 25 years old (collected in 1988), these results demonstrate that traditional means for seed storage (cold storage and low relative humidity (ca. 13%) is an effective long-term conservation strategy for securing germplasm of *E. parishii*.

Table A1. Germination trials of *E. parishii* from seed bank holdings at RSABG. NT = No treatment; SBD = San Bernardino.

Acc. #	County	Collection Date	Test date	Treatment	Number Tested	Total Germ.	% Germ.	Location	Land Manager
15781	SBD	21-Jun-88	16-Dec-99	NT	99	75	76	White Ridge-White Knob	SBNF/BLM
15781	SBD	21-Jun-88	12-Mar-90	NT	100	45	45	White Ridge-White Knob	SBNF/BLM
15781	SBD	21-Jun-88	15-Feb-90	NT	100	45	45	White Ridge-White Knob	SBNF/BLM
15781	SBD	21-Jun-88	18-Sep-91	NT	50	23	46	White Ridge-White Knob	SBNF/BLM
15781	SBD	21-Jun-88	18-Sep-91	NT	100	30	30	White Ridge-White Knob	SBNF/BLM
15781	SBD	21-Jun-88	21-Oct-91	NT	392	218	56	White Ridge-White Knob	SBNF/BLM
15781	SBD	21-Jun-88	1-Oct-13	NT	100	100	100	White Ridge-White Knob	SBNF/BLM
18515	SBD	13-Sep-94	29-May-01	NT	100	78	78	RSABG, (F1)	RSABG Ex:15781
20332	SBD	23-Jun-99	9-Nov-99	NT	100	94	94	Marble Cyn, Mitsubishi Cement Property	Private
20332	SBD	23-Jun-99	22-Nov-99	Cold Strat. 2 weeks	100	89	89	Marble Cyn, Mitsubishi Cement Property	Private
20332	SBD	23-Jun-99	27-Feb-07	NT	100	100	100	Marble Cyn, Mitsubishi Cement Property	Private
21888	SBD	22-Jun_06	5-Sep-06	NT	47	45	95	Long Canyon	JOTR
23220	SBD	08-Jul-10	2-Nov-10	NT	50	50	100	NE of Monarch Flat	BLM
23220	SBD	08-Jul-10	1-May-12	NT	45	42	93	NE of Monarch Flat	BLM
23300	SBD	27-Jul-10	9-Feb-11	NT	20	15	75	Cactus Flats	SBNF
23437	RIV	17-Jun-11	2-Aug-11	NT	50	45	90	Johnny Lang Canyon	JOTR
23437	RIV	29-Jun-11	5-Apr-13	NT	50	46	92	Johnny Lang Canyon	JOTR
23485	SBD	29-Jun-11	28-Feb-12	NT	30	29	97	Cactus Flats	SBNF
15781	SBD	21-Jun-88	1-Nov-13	NT	50	50	100	White Ridge-White Knob	SBNF/BLM

Appendix B: Genetic study

By Linda Prince and Naomi Fraga, Rancho Santa Ana Botanic Garden

Summary

Two populations of *Erigeron parishii* from JOTR (Quail Mountain and Long Canyon) and one population from the San Bernardino Mountains near Monarch Flat within San Bernardino National Forest (SBNF) were sampled for the genetic study using ISSR (inter simple sequence repeat) data. Individual populations were generally cohesive; however, the populations did not form reciprocally monophyletic population groups. This suggests either historic or contemporary gene flow between all three populations sampled. The two JOTR populations have lower genetic diversity than the population from SBNF, and are each characterized by a number of unique ISSR bands not found in the SBNF population sampled. The SBNF population had 35 unique fragments, whereas the JOTR Quail Mountain population had 12 unique fragments and the Long Canyon population had 8 unique fragments.

Introduction

At least one prior genetic study has been conducted on *E. parishii* (Neel and Ellstrand 2001), however that study focused on more westerly populations located at higher elevations and almost exclusively on calcareous substrates. The objective of the Neel and Ellstrand study was to assess intra and inter population genetic structure in the context of population fragmentation due to limestone mining. The objective of the current study is to evaluate genetic diversity of populations located within JOTR (on gneissic and granitic soils), relative to plants that occur outside of JOTR in the San Bernardino Mountains, where the majority of known populations occur. This exploratory study of relative genetic diversity was undertaken using ISSR (inter simple sequence repeat) data. The data generated in this study were compared and contrasted to the allozyme study by Neel and Ellstrand (2001). While the two data sets are not directly comparable and cannot be combined, qualitative comparisons can be made. In general, allozymes consist of fewer bands, providing a coarser assessment of genetic diversity than ISSRs. Numerous studies have compared the variability of data generated by allozymes and that of repeat based markers (AFLPs, RAPDs, and ISSRs in particular), showing that higher genetic diversity can be detected by repeat based markers, especially within populations (see the recent reviews by Nybom & Bartish 2000, and Nybom 2004). Still, fragment-based methods such as ISSRs do have some limitations relative to allozymes. Because ISSRs are primarily dominant data, it is not possible to determine heterozygosity, thus the statistical tests that may be applied are somewhat limited. The results of data analyses reported here include the percentage of polymorphic loci (P), Φ_{ST} (an analog of F_{ST} based on genetic distance), genetic distance (GD), and Shannon's information index (I) (Culley 2005).

Experimental Design

Three populations of *E. parishii* were sampled, two from JOTR (Quail Mountain and Long Canyon) and a single population from the San Bernardino Mountains on the SBNF (NE of Monarch Flat). Localities of populations sampled are shown in Figure 2 of the main report and location coordinates provided in Table B1. For each population, two to four leaves from a minimum of 30 individuals were collected and immediately placed in silica gel desiccant for preservation. In June of 2011, plants were sampled haphazardly, including extreme edges of the population. Sampled individuals were also geo-referenced using hand-held GPS units accurate to approximately 3 m. Voucher specimens for all populations are housed in the herbarium collection of RSABG. All laboratory work was conducted in the Laboratory of Molecular Evolution and Systematics at RSABG. Any remaining leaf material was saved and stored in the molecular lab at RSABG.

DNA was extracted following a minor modification of the Doyle and Doyle (1987) method (inclusion of a 50ºC incubation with Proteinase K (Life Technologies, Grand Island, New York, U.S.A.) for 20 min prior to the 65ºC incubation step). DNA was re-suspended in 100µL 1X TE buffer (10 mM Tris, 1 mM EDTA, pH 7.5). No secondary cleaning methods were employed. Quantification was carried out using 2µL of the stock DNA extraction with a NanoVue spectrophotometer (GE Healthcare Biosciences, Pittsburgh, Pennsylvania, U.S.A.). DNAs were diluted in water, to a working concentration of 10 ng/µL. Remaining DNAs are stored in the minus-80ºC freezer collection of the molecular lab at RSABG.

Data collection

DNA for three to four individuals per population were selected, based upon quantity of DNA available, for ISSR marker screening. Approximately 30 different fluorescently tagged ISSR primers were amplified using Phusion high fidelity polymerase (with the 5X GC Buffer; New England Biolabs, Ipswich, Massachusetts, U.S.A.). Because ISSR primers are anchored microsatellite primers, polymerase stutter or slipping was expected to be a problem. The use of Phusion polymerase minimized the likelihood of these fragments. Annealing temperature varied based upon primer composition, as indicated in Table B2. Fluorescently tagged fragments (1-3 µL) were diluted in 10 µL Hi-Di formamide and co-loaded with 0.5-0.75µL Liz 1200 internal size standard, electrophoresed and visualized on an Applied Biosystems Inc. (Carlsbad, CA, U.S.A.) 3130xl Genetic Analyzer (50 cm array, POP7 polymer) following the manufacturer's directions. Applied Biosystem's GeneMapper v. 4.0 software was used to score the data using the built-in AFLP module, with automatic binning.

Data were reviewed for each sample and the number and variability of bands per sample per primer noted. A number of primers either failed to produce any fragments or were virtually invariant across the samples tested. The results of the initial screening are summarized in Table B2. From the primers screened, the three primers with the most variability and larger number of fragments were selected for population wide analysis (813FAM, 815VIC, 880VIC). Only peaks with heights greater than 100 in at least one individual were scored, and only peaks with height >50 were scored as present. All samples were amplified and run in triplicate. Only peaks that appeared in all replicates (as described above) were analyzed. A data matrix of scored peaks (values = 0, 1, or ?) was generated and analyzed under several different criteria. In the first set, all loci and all samples were analyzed, including 14 samples with large amounts of missing data (due to single primer failure OR no scoreable fragments). Missing data were scored as "?". In the second set, 14 samples that contained large amounts of missing data had the missing data treated as absent bands (changed from "?" to "0"). The third set excluded those 14 samples from the analyses. These different analyses were conducted to assess the impact of missing data on the overall population diversity and structure estimates. The complete data matrix includes presence/absence data for 123 distinct bands. Only eight of those bands were "common" in the species, present in > 60% of the individuals per population.

The phylogenetic software package PAUP*4.0 (test version a129, Swofford 2002) was used to create a pairwise distance matrix under the "RFLP/AFLP" option [Nei-Li (fragments); L=17]. Distance dendrograms were also generated, using both Neighbor Joining (NJ) and the unweighted pair group method with arithmetic mean (UPGMA; under both average distance and total distance). Both NJ and UPGMA are simple agglomerative or bottom-up data clustering methods used in bioinformatics for the creation of phylogenetic trees. Branch support was estimated using 1000 bootstrap replicates (NJ or UPGMA as appropriate).

The number of different alleles (Na), number of effective alleles (Ne), Shannon's information index (*I*, Lewontin 1972), Nei's (1973) gene diversity (h) and unbiased gene diversity (uh), and percentage polymorphic loci (%P) were calculated in GenAlEx v. 6.5 (Peakall and Smouse 2006). Estimates of genetic diversity (h) and genetic structure (θ^{I}, an F_{ST} analog; and θ^{II}, an estimate most similar to Nei's G_{st}, and $G_{st}B$, a Bayesian estimate of G_{st}) were estimated in HICKORY v. 1.1 (Holsinger and Lewis 2007). HICKORY values were estimated using the "f-free" model since estimates of *f* from dominant data can be unreliable (Holsinger et al. 2002). Each HICKORY analysis was run in triplicate to ensure the Bayesian estimation had reached stationarity. Genetic diversity measures were estimated in two different programs as the numbers differ slightly, with HICKORY consistently providing lower estimates of diversity. A genetic distance matrix was generated in GenAlEx [for use in Principal Coordinates Analyses (PCoA or PCO) also conducted in GenAlEx] to identify groups of samples with the highest allelic similarity. Plots (based on the first two axes) for each analysis are provided in Figures B1-3.

Table B1. Location information of sampled populations of *Erigeron parishii*.

EO#	Location information	Latitude	Longitude	Elevation
6	NE of Monarch Flat, San Bernardino National Forest	34.35246	-116.83954	4300–4400 ft.
47	Quail Mountain, Joshua Tree National Park	34.02350	-116.21779	4000–4100 ft.
42	Long Canyon, Joshua Tree National Park	34.03967	-116.43621,	4000–4100 ft.

Table B2. ISSR primers screened for population genetic analysis of *Erigeron parishii* including annealing temperature employed, and approximate number of major bands observed. Bold type face indicates primers used for population wide study.

Primer Number	Base Composition	Dye	Anneal Temp.	Number of Bands
807	AGA GAG AGA GAG AGA GT	FAM	50.0	3-9
808	AGA GAG AGA GAG AGA GC	VIC	52.0	2
809	AGA GAG AGA GAG AGA GG	FAM	52.0	3+
811	GAG AGA GAG AGA GAG AC	VIC	52.0	6
812	GAG AGA GAG AGA GAG AA	VIC	50.0	0
813	**CTC TCT CTC TCT CTC TT**	**FAM**	**50.0**	**>18**
814	CTC TCT CTC TCT CTC TA	NED	50.0	0
815	**CTC TCT CTC TCT CTC TG**	**FAM**	**52.0**	**>16**
817	CAC ACA CAC ACA CAC AA	VIC	50.0	0
818	CAC ACA CAC ACA CAC AG	FAM	52.0	0
820	GTG TGT GTG TGT GTG TC	VIC	52.0	0
821	GTG TGT GTG TGT GTG TT	PET	50.0	0
822	TCT CTC TCT CTC TCT CA	VIC	50.0	0
823	TCT CTC TCT CTC TCT CC	NED	50.0	0
825	ACA CAC ACA CAC ACA CT	VIC	50.0	1
826	ACA CAC ACA CAC ACA CC	PET	54.0	0
828	TGT GTG TGT GTG TGT GA	FAM	50.0	0
830	TGT GTG TGT GTG TGT GG	VIC	54.0	0
861	ACC ACC ACC ACC ACC ACC	FAM	60.0	0
863	AGT AGT AGT AGT AGT AGT	FAM	48.0	2
866	CTC CTC CTC CTC CTC CTC	FAM	60.0	>15
868	GAA GAA GAA GAA GAA GAA	VIC	48.0	3
869	GTT GTT GTT GTT GTT GTT	PET	48.0	0
873	GAC AGA CAG ACA GAC A	NED	48.0	>10
874	CCC TCC CTC CCT CCC T	FAM	54.0	>12
880	**GGA GAG GAG AGG AGA**	**VIC**	**50.0**	**>15**
881	GGG TGG GGT GGG GTG	VIC	54.0	0

Tables B3-B5. Various population statistics and descriptors, under Bayesian allele frequency (BAFP; Lynch & Milligan 1994) criteria for *E. parishii* based on ISSR data. Results based on GenAlEx analyses. Highest values are in bold typeface, lowest values underlined. Number of individuals (SS), number of alleles (Na), number of effective alleles (Ne), Shannon's Information Index (I), Nei's gene diversity (h), Nei's unbiased gene diversity (uh), percentage polymorphic loci (%P). h*1-3 are values of h from three, independent HICKORY analyses.

B3. Analysis #1 with missing data scored as ?.

	SS		Na	Ne	I	h	h*1	h*2	h*3	uh	%P
(SBNF) **1**	**31**	**Mean**	**1.667**	1.218	**0.251**	0.147	**0.140**	**0.140**	**0.140**	0.152	**82.93**
		SE	0.067	0.025	0.018	0.013	0.009	0.009	0.009	0.014	
(JOTR-Q) **2**	**31**	**Mean**	1.220	**1.243**	0.239	**0.151**	0.131	0.131	0.131	**0.156**	60.98
		SE	0.088	0.029	0.022	0.016	0.012	0.012	0.012	0.016	
(JOTR-L) **3**	**28**	**Mean**	<u>0.780</u>	<u>1.184</u>	<u>0.173</u>	<u>0.112</u>	<u>0.110</u>	<u>0.111</u>	<u>0.110</u>	<u>0.117</u>	<u>39.02</u>
		SE	0.088	0.028	0.022	0.015	0.008	0.008	0.007	0.016	
Total		**Mean**	1.222	1.215	0.221	0.137	0.127	0.127	0.127	0.142	60.98
		SE	0.051	0.016	0.012	0.009	0.008	0.008	0.008	0.009	12.67

B4. Analysis #2 with missing data scored as 0.

	SS		Na	Ne	I	h	h*1	h*2	h*3	uh	%P
(SBNF) **1**	**31**	**Mean**	**1.675**	1.222	**0.255**	**0.150**	**0.142**	**0.142**	**0.145**	**0.155**	**83.74**
		SE	0.067	0.025	0.018	0.013	0.009	0.008	0.008	0.013	
(JOTR-Q) **2**	**31**	**Mean**	1.220	**1.232**	0.232	0.146	0.125	0.125	0.125	0.150	60.98
		SE	0.088	0.029	0.022	0.015	0.012	0.012	0.012	0.016	
(JOTR-L) **3**	**28**	**Mean**	<u>0.780</u>	<u>1.182</u>	<u>0.172</u>	<u>0.111</u>	<u>0.105</u>	<u>0.105</u>	<u>0.105</u>	<u>0.115</u>	<u>39.02</u>
		SE	0.088	0.027	0.022	0.015	0.008	0.008	0.008	0.016	
Total		**Mean**	1.225	1.212	0.220	0.136	0.124	0.124	0.124	0.140	61.25
		SE	0.051	0.016	0.012	0.008	0.009	0.009	0.009	0.009	12.91

B5. Analysis #3 with taxa (for which large amounts of data are missing) excluded from the analyses.

	SS		Na	Ne	I	h	h*1	h*2	h*3	uh	%P
(SBNF) **1**	**30**	**Mean**	**1.667**	1.217	**0.250**	0.147	**0.141**	**0.141**	**0.142**	0.152	**82.93**
		SE	0.067	0.024	0.018	0.013	0.009	0.009	0.009	0.014	
(JOTR-Q) **2**	**26**	**Mean**	1.187	**1.247**	0.240	**0.152**	0.134	0.134	0.134	**0.158**	59.35
		SE	0.089	0.030	0.023	0.016	0.012	0.012	0.012	0.017	
(JOTR-L) **3**	**20**	**Mean**	<u>0.732</u>	<u>1.173</u>	<u>0.163</u>	<u>0.105</u>	<u>0.109</u>	<u>0.109</u>	<u>0.109</u>	<u>0.111</u>	<u>36.59</u>
		SE	0.087	0.027	0.022	0.015	0.007	0.007	0.007	0.016	
Total		**Mean**	1.195	1.212	0.218	0.135	0.128	0.128	0.128	0.140	59.62
		SE	0.051	0.016	0.012	0.009	0.008	0.008	0.008	0.009	13.38

Results

Effect of missing data

Population 1, from SBNF, had the highest population descriptor values for the number of different alleles (Na), Shannon's Information Index (I) and the percentage of polymorphic loci (%P) regardless of how missing data were treated (see Tables B3-B5). The SBNF population also had the highest values for the number of effective alleles (Ne), except when missing data are scored as 0, or when those taxa were excluded from the analyses, in which case the number of effective alleles (Ne) was higher for the JOTR-Quail Mtn. population (population 2). As stated above, the program HICKORY always provided lower estimates of diversity (h) than did GenAlEx. HICKORY also indicated that the SBNF population was more diverse than either JOTR population. This is in contrast to the diversity values obtained in GenAlEx, in which the JOTR-Quail Mtn. population had higher diversity values, depending upon how missing data were treated. In all analyses, the JOTR-Long Canyon population (population 3) had the lowest population descriptor values. The most diverse population (SNBF) also had the highest number of unique bands (35), followed by JOTR-Quail Mtn. (12), then JOTR-Long Canyon (7).

Population genetic distance (see Table B6) and genetic structure (see Tables B7-9), as measured by θ^{I} (an F_{ST} analog), θ^{II} (an estimate most similar to Nei's G_{st}), and $G_{ST}B$ (a Bayesian estimate of G_{ST}) were all similar, although treating missing data as "0" resulted in slightly lower values across all measures. Populations from JOTR were always more similar to each other than either was to the population from SBNF. Finally, similar topology was found for NJ and UPGMA analyses (see Figures B4-6 for UPGMA dendrograms) regardless of the treatment of missing data. The effect of missing data was most obvious in the PCO graph of Analysis 1 (Figure B1). Individuals with large amounts of missing data (scored as "?") formed two outlying clusters, each cluster corresponding to samples with missing data for one of the two markers.

Population Diversity

The SBNF population had the largest number of unique fragments (35), with each of the JOTR populations having fewer (Quail Mountain w/ 12 unique fragments, Long Canyon w/ 8 unique fragments). Each population was genetically distinct, with varying numbers of population-specific fragments. The population from Quail Mountain had diversity values more similar to the population from SBNF, but was genetically more similar to the second JOTR population (GenAlEx: Nei's genetic distance = 0.049 to 0.64 depending upon analysis method versus 0.069-0.073 and 0.086-0.093 respectively for either population compared to SBNF). The Long Canyon population from JOTR was less diverse than either of the other two, based on all available measures of diversity (number of alleles, number of effective alleles, Shannon's Information Index, Nei's diversity, Nei's unbiased diversity, and percentage polymorphic loci).

Population Structure

Individual populations were generally cohesive, with the majority of samples from each population forming a clade (see Figures B4–6), regardless of how missing data were treated. The populations did not form reciprocally monophyletic population groups, suggesting either historic or contemporary gene flow between all three populations sampled. Principal Coordinates Analysis showed a similar pattern (Figures B1–3), with the bulk of the samples from any given population clustering together, with small areas of overlap between and among the populations. As noted above, this pattern was obscured when individual samples with large amounts of missing data were included in the analysis, as shown in Figure B3. The two outlying clusters correspond to sample data from either marker ISSR-813 or ISSR-815. A variety of measures of population structure (θ^{I}, θ^{II}, and $G_{ST}B$) were examined to assess the amount of population structure within *E. parishii*. The Bayesian estimate of G_{ST} ($G_{ST}B$) was always the most conservative measure, followed by θ^{II}, and then θ^{I}. Values, based on three independent Bayesian runs, ranged from 0.175-0.195 for $G_{ST}B$, 0.245-0.275 for θ^{II}, and 0.272-0.306 for θ^{I}. This finding is consistent with the analysis of similar values reviewed by Nybom (2004). The lowest values were obtained from Analysis 2 (missing data scored as “0”) and the highest values for Analysis 3 (taxa with large amounts of missing data omitted from the data matrix).

Discussion

Erigeron parishii occurs primarily on calcareous soils in the San Bernardino Mountains. Several populations occur on soils derived from gneiss and a few on granodiorite; these populations generally occur southeast of the center of the range. An earlier allozyme study of 22 populations of the species found lower genetic diversity (and greater inbreeding) in the one population that occurred off calcareous soils and on granitic soils, as compared to those populations on carbonate soils. Our data are consistent with that finding. Both the Long Canyon and the Quail Mountain populations have lower genetic diversity than the population located in SBNF based on analyses of ISSR data. Geographically, the Long Canyon population is located on the southern edge of the known range for the species. This population had the lowest genetic diversity of the three populations studied. Peripheral populations often have lower genetic diversity than populations closer to the center of the distribution. This phenomenon has been called the central-marginal hypothesis (proposed by da Cunha and Dobzhansky in 1954; reviews and examples: Franks et al. 2004, Eckert et al. 2008, Vakkari et al. 2009, Moeller et al. 2011, Pouget et al. 2013). Potential causes of the phenomenon are diverse, including lower habitat quality (fewer ecological niches), reduced gene flow, founder effects, or higher rates of extinction, etc.

The Bayesian estimates of population structure fall within the expected range for rare plant species. Specifically, based on the analysis and review of Nybom (2004), with values of $G_{ST}B$=0.175-0.195, θ^{II}=0.245-0.275, and θ^{I}=0.272-0.306, we could predict that *E. parishii* was a moderate-lived perennial of limited geographic range (endemic to narrow distribution), outcrossing, wind-dispersed, and a late successional species. This prediction corresponds well to what is currently known about the species.

Although the two JOTR populations of *E. parishii* sampled for this study have lower genetic diversity than the population from SBNF, there is evidence for past or contemporary gene flow among all three populations. Additionally, the populations in JOTR are each characterized by a number of unique ISSR bands not found in the SBNF population sampled.

Table B6. Pairwise population genetic distances for *E. parishii* based on analyses of ISSR data. Analysis 1: missing data = ?; analysis 2: missing data = 0; analysis 3: taxa with large amounts of missing data excluded. Highest values are in bold typeface, lowest values underlined. NeiP = Nei's genetic distance; uNeiP = Nei's unbiased genetic distance. Pop1=SBNF, Pop2=JOTR-Quail Mtn, Pop3=JOTR-Long Canyon.

Pairwise Comparison	Analysis 1		Analysis 2		Analysis 3	
	NeiP	uNeiP	NeiP	uNeiP	NeiP	uNeiP
Pop1-Pop2	0.073	0.067	0.069	0.063	0.072	0.065
Pop1-Pop3	**0.093**	**0.088**	**0.086**	**0.081**	**0.093**	**0.087**
Pop2-Pop3	<u>0.060</u>	<u>0.054</u>	<u>0.049</u>	<u>0.044</u>	<u>0.064</u>	<u>0.057</u>

Tables B7-B9. *E. parishii* estimates of population genetic structure based on HICKORY analysis results of ISSR data analyses. θ^{I} is an F_{ST} analog, θ^{II} is an estimate most similar to Nei's G_{st}, and $G_{ST}B$ is a Bayesian estimate of G_{ST}.

B7. Analysis #1 with missing data scored as ?.

	Run 1			Run 2			Run 3		
	θ^{I}	θ^{II}	$G_{st}B$	θ^{I}	θ^{II}	$G_{st}B$	θ^{I}	θ^{II}	$G_{st}B$
Mean	0.300	0.269	0.192	0.300	0.269	0.192	0.300	0.269	0.192
SE	0.026	0.030	0.017	0.026	0.30	0.017	0.026	0.030	0.017

B8. Analysis #2 with missing data scored as 0.

	Run 1			Run 2			Run 3		
	θ^{I}	θ^{II}	$G_{st}B$	θ^{I}	θ^{II}	$G_{st}B$	θ^{I}	θ^{II}	$G_{st}B$
Mean	0.272	0.245	0.175	0.273	0.246	0.175	0.273	0.246	0.175
SE	0.024	0.028	0.018	0.025	0.028	0.018	0.025	0.028	0.018

B9. Analysis #3 with taxa (for which large amounts of data are missing) excluded from the analyses.

	Run 1			Run 2			Run 3		
	θ^{I}	θ^{II}	$G_{st}B$	θ^{I}	θ^{II}	$G_{st}B$	θ^{I}	θ^{II}	$G_{st}B$
Mean	0.306	0.275	0.195	0.306	0.274	0.195	0.305	0.273	0.195
SE	0.026	0.030	0.017	0.026	0.031	0.018	0.026	0.030	0.017

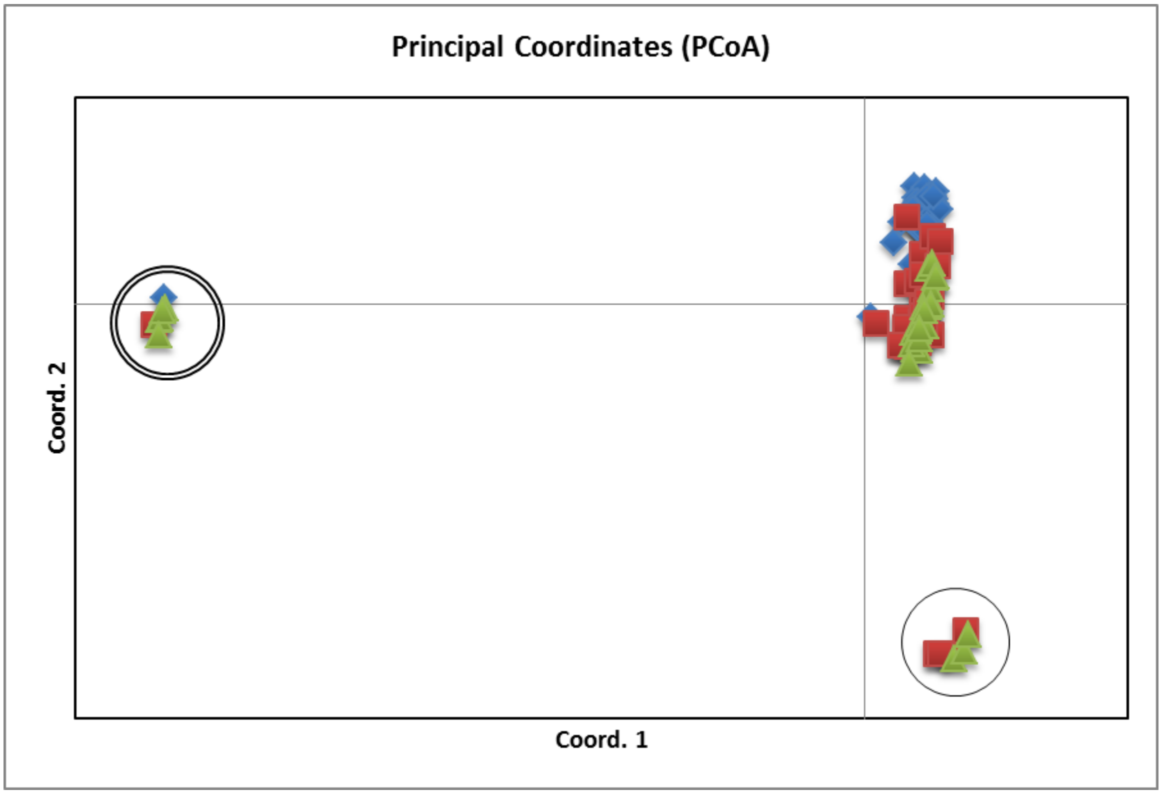

Figure B1. Principal coordinates analysis of ISSR data for *E. parishii* (analysis 1: missing data = ?). Coordinates 1 + 2 explain 66% of the variation. Populations color coding: JOTR Quail Mountain (green), JOTR Long Canyon (blue), San Bernardino National Forest (red). Note the two, circled, outlying clusters. These are samples with large amounts of missing data. Single circle = missing data for marker ISSR-813; double circle = missing data for marker ISSR-815.

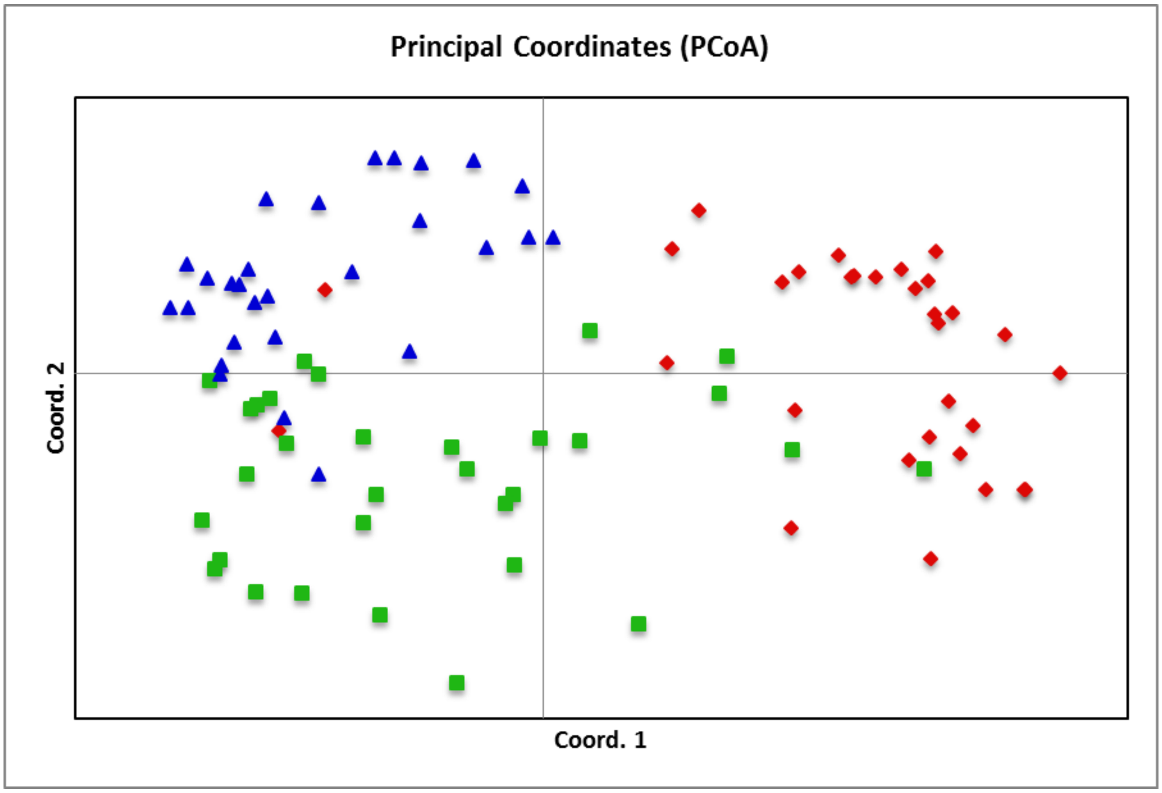

Figure B2. Principal coordinates analysis of ISSR data for *Erigeron parishii* (missing data = 0). Coordinates 1 + 2 explain 57% of the variation. Populations color coding: JOTR Quail Mountain (green), JOTR Long Canyon (blue), San Bernardino National Forest (red).

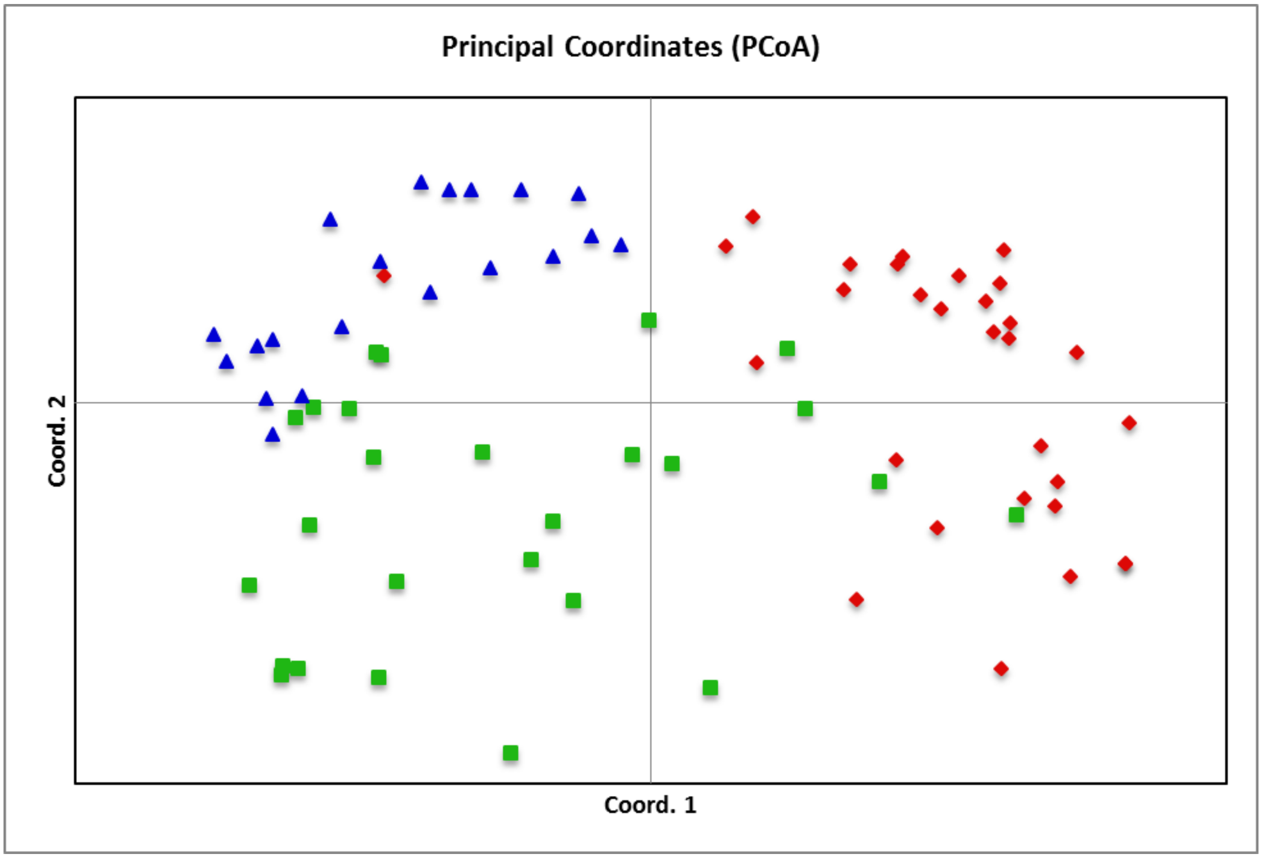

Figure B3. Principal coordinates analysis of ISSR data for *Erigeron parishii* (excluding taxa with missing data). Coordinates 1 + 2 explain 57% of the variation. Populations color coding: JOTR Quail Mountain (green), JOTR Long Canyon (blue), San Bernardino National Forest (red).

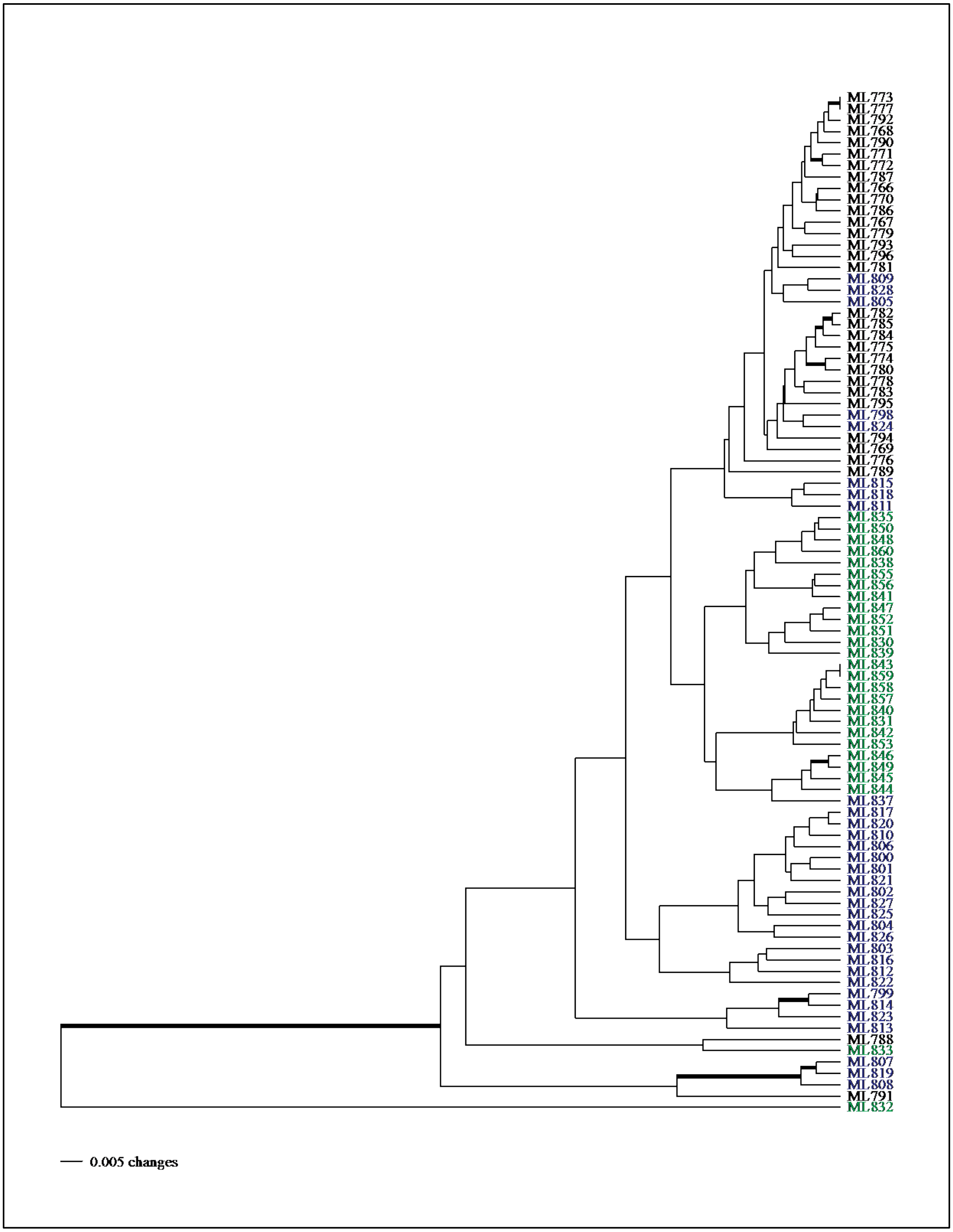

Figure B4. UPGMA analysis of ISSR data for *Erigeron parishii* (analysis 1: missing data = ?). Population color code: JOTR Quail Mountain (blue), JOTR Long Canyon (green), San Bernardino National Forest (black). Bold lines indicate branches with bootstrap support ≥50%.

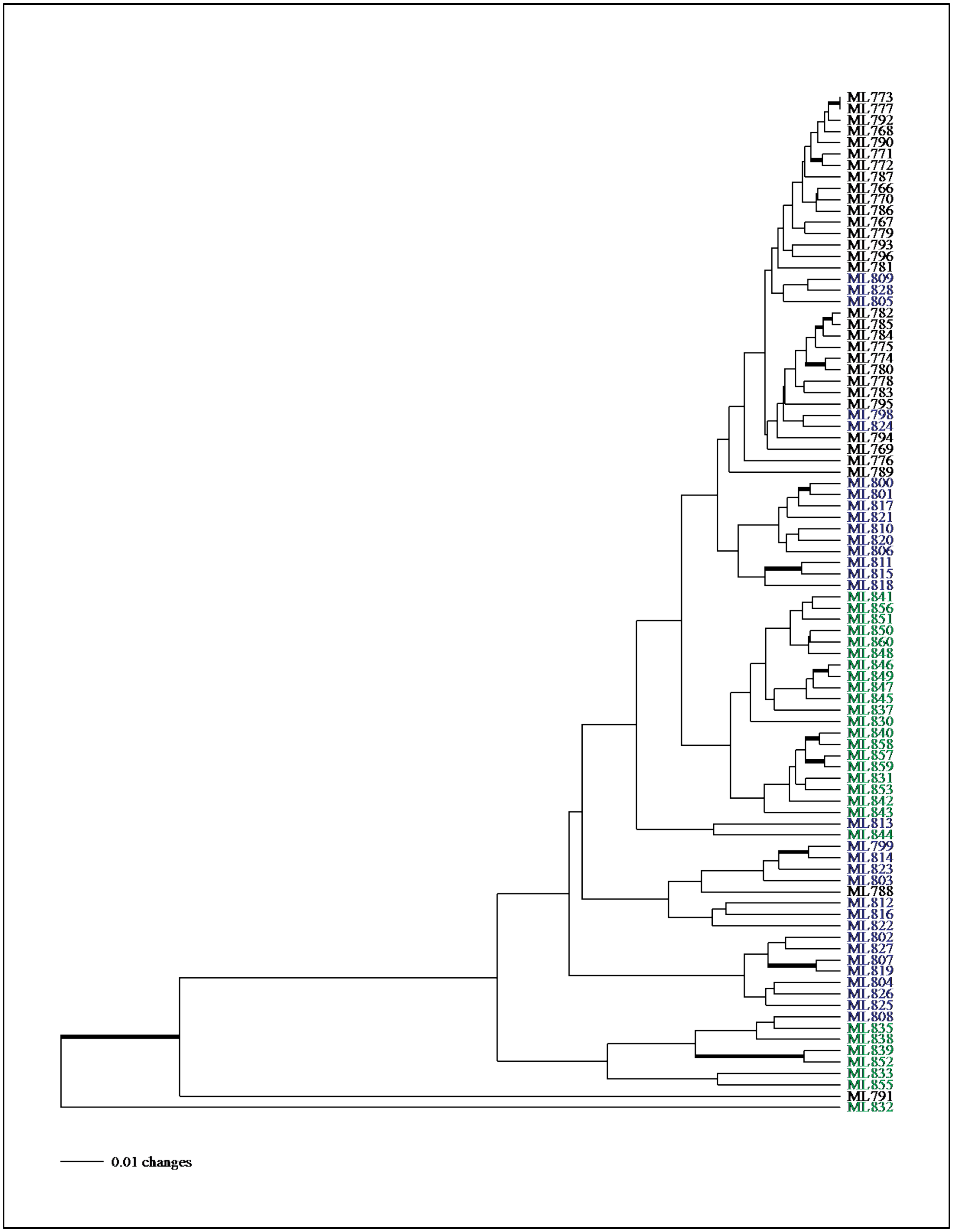

Figure B5. UPGMA analysis of ISSR data for *Erigeron parishii* (analysis 2: missing data = 0). Populations color coded: JOTR Quail Mountain (blue), JOTR Long Canyon (green), San Bernardino National Forest (black). Bold lines indicate branches with bootstrap support ≥50%.

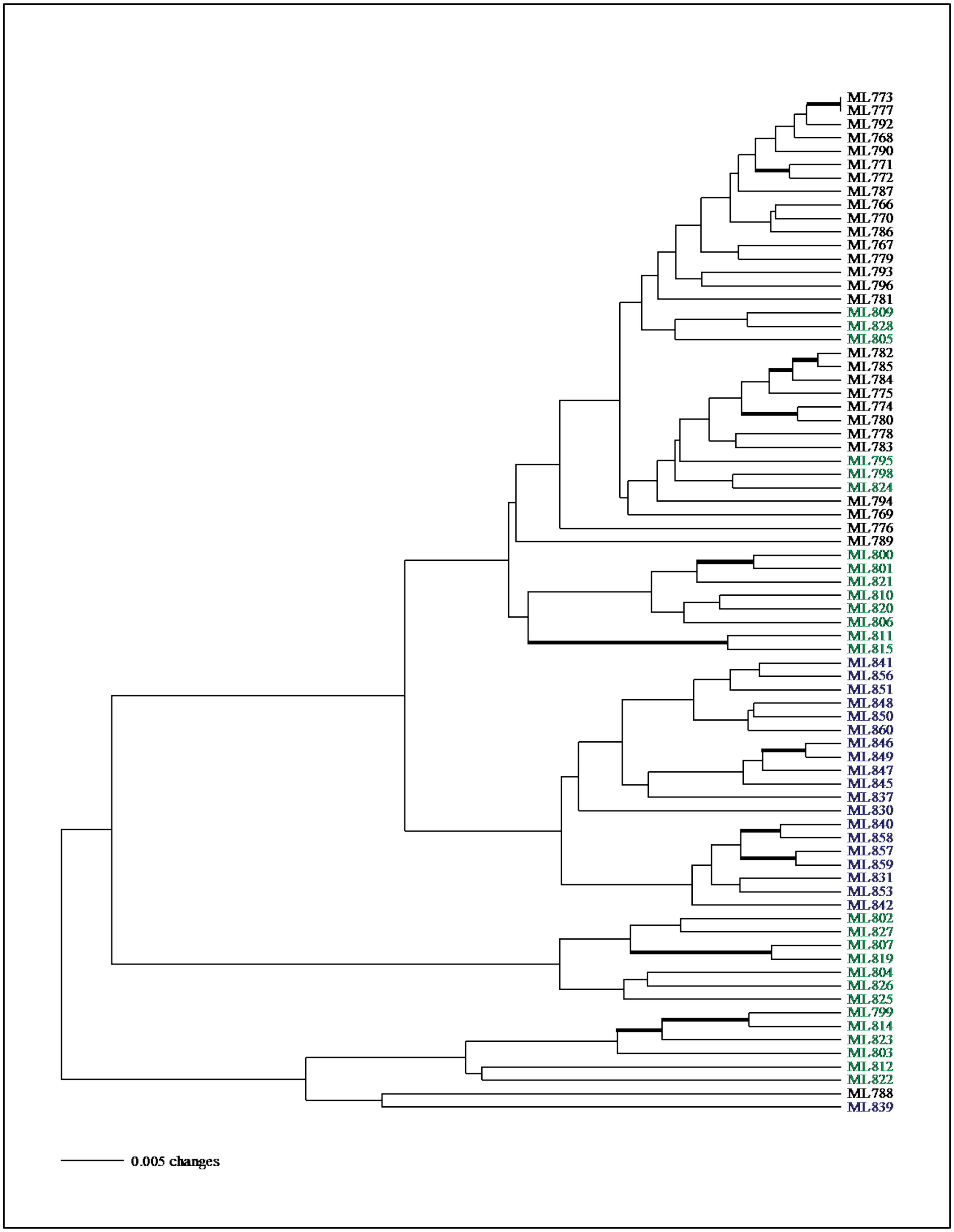

Figure B6. UPGMA analysis of ISSR data for *Erigeron parishii* (analysis 3: excluding taxa with missing data). Populations color coded: JOTR Quail Mountain (blue), JOTR Long Canyon (green), San Bernardino National Forest (black). Bold lines indicate branches with bootstrap support ≥50%.

Appendix C: GIS habitat model for *Erigeron parishii*

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Summary

A habitat model was developed to identify potential habitat for *Erigeron parishii.* The model is designed to highlight probable habitat based on environmental parameters that are associated with known localities. Parameters used in developing the probabilities include: slope, aspect, elevation, soil type, and vegetation type. Known localities are based on voucher specimens, field surveys, and CNDDB occurrence data. After a preliminary model was developed, high probability areas lacking presence points were targeted for a ground truthing exercise. The final model can be accessed as an ArcGIS Toolbox, labeled "Rare Plant Model" and is available on the JOTR GIS Resources share drive.

Methods

The habitat model was developed in a python environment using Python v2.6 (© Copyright 1990-2014, Python Software Foundation) because the tools available in ArcToolbox and capabilities in ModelBuilder (ArcGIS v10.1) were not sufficient to complete the task. The python script provided the flexibility to look at raster files, query properties of those raster files, and then implement dynamic statistics based on those properties. A script tool interface was created in ArcGIS Desktop, an environment familiar to GIS users, for the user to specify input parameters. The script can run one, selected, or all of the following parameters based on user preferences: elevation, slope, aspect, soil type, and/or vegetation type. A "presence point buffer" shapefile was produced in ArcGIS by creating circular polygons centered on each known locality with a 15 m radius. The area within each polygon is then used to collect data for each of the parameters (e.g. averages, minimum/maximum). Also, the script was developed with the idea that it would be implemented iteratively with a ground truthing process, as it is based on presence of known localities. Absence points were not informative due, in part, to the large area being tested (the entire Park) and the lack of data for the majority of that area. Therefore, absence points are not incorporated into the script. (Note: that the script requires an ArcInfo level of licensing for ArcGIS desktop and the Spatial Analyst extension.)

A preliminary model was produced in ArcGIS by manually performing the functions now automated by the Rare Plant Habitat Model script. Range limits were manually calculated for each parameter using the presence point buffer layer. The ranges of values were then used to create limited rasters for each parameter. Finally, we performed a weighted overlay of those limited rasters to create the final habitat model. The range of values used in creating the intermediate rasters were determined subjectively by narrowing the range for each parameter to include a minimum of 70% of the known area within the presence point buffer layer. This process was done using our best judgment to create range limits that best captured our understanding of the known habitat for the species, more specifically:

1. Four vegetation types were included in the first model: Red brome — Mediterranean grass (*Bromus rubens — Schismus* (*arabicus, barbatus*)) Semi-Natural Herbaceous Stands, Single-

leaf Pinyon Pine / Muller's Oak (*Pinus monophylla / Quercus cornelius-mulleri)* Woodland Association, California Juniper / Blackbush (*Juniperus californica / Coleogyne ramosissima)* Association, Muller Oak — California buckwheat — Narrowleaf goldenbush (*Quercus cornelius-mulleri — Eriogonum fasciculatum — Ericameria linearifolia*) Association. These vegetation types accounted for 93.2% of the area within the presence point buffer layer.

2. Two soil types were used for the calculations, Pinecity gravelly loamy sand and Xeric Torriorthents-Bigbernie Association. These two soil types account for 92.3% of the area within the presence point buffer layer.

3. Elevation range was limited to 1245–1445 m (4084–4740 ft), which accounted for 70.1% of the area in the presence point buffer layer.

4. Slope range was limited to 6°–34°, which accounted for 97.4% of the area in the presence point buffer layer.

5. Aspect range was limited to 0°–90° and 310°–360°, which accounted for 83% of the area in the presence point buffer layer.

The output from this model was then used to prioritize areas for ground truthing surveys, which yielded one new occurrence for the species (see Figure C1). Originally, we had thought that using absence points would be helpful in producing the model, however, this proved not to be the case. It is possible that absence points could be useful in a model that focuses on a narrower range of field values for the various parameters (i.e. limit the analysis to one watershed). The first model was informative for the development of a more user-friendly and automated script that is less time-intensive and reduces user error.

The final model is set up so that the user is not required to manually establish the range limits for the various parameters, as this method is tedious and inconsistent. The user only needs to select the various source data layers to be used in the analysis through a user-friendly interface, after which the model will perform calculations according to the specific scripts for each parameter (read below for details). Essentially the model will create range limits for raster data such as slope, aspect, and elevation, capturing 95% of the area within the presence point buffer layer. For vector data such as soil and vegetation types, only the type that represents the most area within the presence point buffer layer will be selected for. These limitations can be overcome either by adjusting the script (only to be done by advanced GIS/modeling specialists) or by creating source data layers that somehow combine relevant data. For example, by assigning a common code to all vegetation types represented by the presence point buffer layer, the analysis could better represent the range of vegetation types associated with the occurrence of the species. This type of manipulation to the source data layers can also offset any bias associated with an unequal number of data points in any given area. Because the model is based on weighted averages it will always be prone to bias the results according to the habitat associated with the highest number of presence points. While this type of limitation may be appropriate for narrow habitat specialists, it can be misleading for plants that can occur in a variety of habitats. For this reason, it may be reasonable to exclude certain presence points, if they represent anomalous habitat types (for example, a waif found in the wash below the main population on the slope). Conversely, it is important to continue to add points to the presence point buffer layer, as each additional point will hopefully increase the accuracy of the output. In particular, it is important to make sure that GPS points are recorded in the field for each individual plant, or a group of plants isolated by a 15 m radius.

The model is meant to be iterative. In other words, the output of each model will guide future field surveys to target high probability habitat, then as new populations/individuals are added to the database, the model will increase in accuracy. Also, since a date field is collected with each point, users can select data in a date range and rerun the model based on the subset. Doing so will allow the user to see how the model accuracy changes over time as the amount of presence points are increased.

Scripts

Elevation: When the user selects elevation as an analysis parameter and specifies a digital elevation model to use in the analysis, the script applies the corresponding elevation statistic calculations. First, it extracts elevation values that are within the presence point buffer. Second, it calculates the standard deviation (S.D.) and average (Avg.) of the extracted values. Third, it assigns a 95% confidence limit for an elevational range (Avg. ± 2 S.D.), which is then applied to the original digital elevation model and selects the elevation values within the 95% confidence limits to create a new raster. This raster is used in the last step of the script during the weighted overlay.

Slope: When the user selects slope as an analysis parameter and specifies a slope surface analysis product to use in the analysis, the script applies the corresponding slope statistic calculations. First, it extracts slope values that are within the presence point buffer. Second, it calculates the standard deviation (S.D.) and average (Avg.) of the extracted values. Third, it assigns a 95% confidence limit for an elevational range (Avg. ± 2 S.D.), which is then applied to the original slope raster and selects the slope values within the 95% confidence limits to create a new raster. This raster is used in the last step of the script during the weighted overlay.

Aspect: When the user selects aspect as an analysis parameter and specifies an aspect surface analysis product to use in the analysis, the script applies the corresponding aspect statistic calculations. Aspect values are cyclic values, meaning 0 degrees and 360 degrees are the same value, and not a range that starts with a low value and stops at the high value. Because aspect values are cyclic, a few more steps needed to be incorporated into the script. First, it extracts aspect values that are within the presence point buffer. Second, it isolates the values ranging from zero to 180 degrees by setting values less than one and greater than 180 to null. Third, it calculates the aspect standard deviation and average extracted values subset. Fourth, it assigns a 95% confidence limit for an aspect range (Avg. ± 2 S.D.). Next, the third and fourth step are repeated for aspect values ranging from 180 to 360 degrees – a subset is created, average and standard deviation are calculated, and the low and high value in the standard deviation range are calculated. Based on the standard deviation range, the script's last step takes the original aspect raster and selects the aspect values within both standard deviation ranges and creates a new raster. This raster is used in the last step of the script during the weighted overlay.

Soil: When the user selects soil as an analysis parameter and specifies soil polygons to use in the analysis, the script applies the corresponding soil statistic calculations. First, it clips soil types to the presence point buffer. Second, it calculates coverage area for each soil type. Third, it sorts through the area totals and isolates the soil type with the most coverage (the maximum). Lastly, the maximum soil type is selected out from the original soil polygons and converted into a raster format. This raster is used in the last step of the script during the weighted overlay.

Vegetation: When the user selects vegetation as an analysis parameter and specifies vegetation polygons to use in the analysis, the script applies the corresponding vegetation statistic calculations. First, it clips vegetation association types to the presence point buffer. Second, it calculates coverage area for each vegetation type. Third, it sorts through the area totals and isolates the vegetation type with the most coverage (the maximum). Lastly, the maximum vegetation type is selected out from the original vegetation polygons and converted into a raster format. This raster is used in the last step of the script during the weighted overlay.

Weighted Overlay: The last part of the script takes the five parameters, or less if a parameter was excluded from the analysis, and overlays them using the weighted overlay tool. The tool was set to give each parameter equal weight. The result is an overlay that has values ranging from zero to five, or zero to the number of parameters being analyzed; five representing where the habitat is most likely located and zero representing where the habitat is least likely located.

Results and Discussion

The final model can be accessed as an ArcGIS Toolbox, labeled "Rare Plant Model" and is available on the JOTR GIS Resources share drive. The model can be used for any species, provided you have geospatial data layers with known locations and at least one of the corresponding parameters.

Below are two examples of the model output. The first model (Figure C2) utilized all five data layers (elevation, aspect, slope, vegetation, and soil) and we did not modify fields of the source data in any way. Therefore, the highest probability habitat is biased toward the habitat (vegetation association and soil type) found around the Quail Mountain population because this population has the highest number of points. However, habitat associated with the populations further west in the Little San Bernardino Mountains (i.e. above Long Canyon) also have viable habitat, so we decided to modify the vegetation and soil source data layers for a second version of the model. This second version (Figure C3) also utilized all five parameters, but with the following modifications:

1. There are four vegetation associations represented by the presence point buffer layer. These were discussed above and were used to develop the preliminary habitat model. In order to capture and equally weight these vegetation associations, we decided to combine three of them into one common name and code, therefore forcing the script to recognize them all as one vegetation type. One of the four associations, Red brome — Mediterranean grass (*Bromus rubens — Schismus* (*arabicus, barbatus*)) Semi-Natural Herbaceous Stands, was not included in this exercise because it is poorly described and represents a post-fire seral stage in much of JOTR. Therefore, we decided to exclude it from this analysis as it doesn't necessarily represent optimal habitat.

2. We re-coded the two most common soil types found within the presence point buffer layer, so that both would be included in the final overlay. Both of these soil types were discussed above and were included in the preliminary model.

The second version (Figure C3) seems to reflect probable habitat more accurately, according to the authors experience and present knowledge. The population of *E. parishii* on Quail Mountain is distributed over a large area, supports hundreds of individuals, and has been the focus of a much more detailed field survey by JOTR (i.e. a majority of the individuals have been assigned GPS points). For these reasons, version 1 of the habitat model favors the soil and vegetation types most represented by these points (notice the lack of deep red along the western ridgelines in Figure C2, as compared to Figure C3). In contrast, many of the known locations further to the west in the Little San Bernardino Mountains (i.e. above Long Canyon) represent several individuals spanning an area greater than that incorporated by the 15 m radius of our presence point buffer polygons. In other words, there has not been effort to record individual plants in this area, rather one point was taken to represent the entire population. Many of the known locations in this region are along narrow ridgelines or on steep slopes, where the available land surface with suitable habitat is much smaller. This could explain the smaller population sizes found in the area.

Future Suggestions

Future efforts should focus on the following items.

1. Field efforts to locate new populations should focus on high probability areas according to the map produced by version 2 of the current model.

2. Geospatial data should be taken for each individual, unless there are multiple individuals within a 15 m radius of the point.

3. New data should be added immediately to the presence point buffer layer. Then the model should be updated.

4. Future models should consider the idea of utilizing absence points, as well as providing a means to weight the parameters differently.

5. Additional trials should be done with the current model, to see if other modifications to the available data sources increase the accuracy of the output.

6. Collaboration with San Bernardino National Forest is encouraged for future efforts in modeling. According to Scott Eliason (pers. comm.) a habitat model exists for SBNF

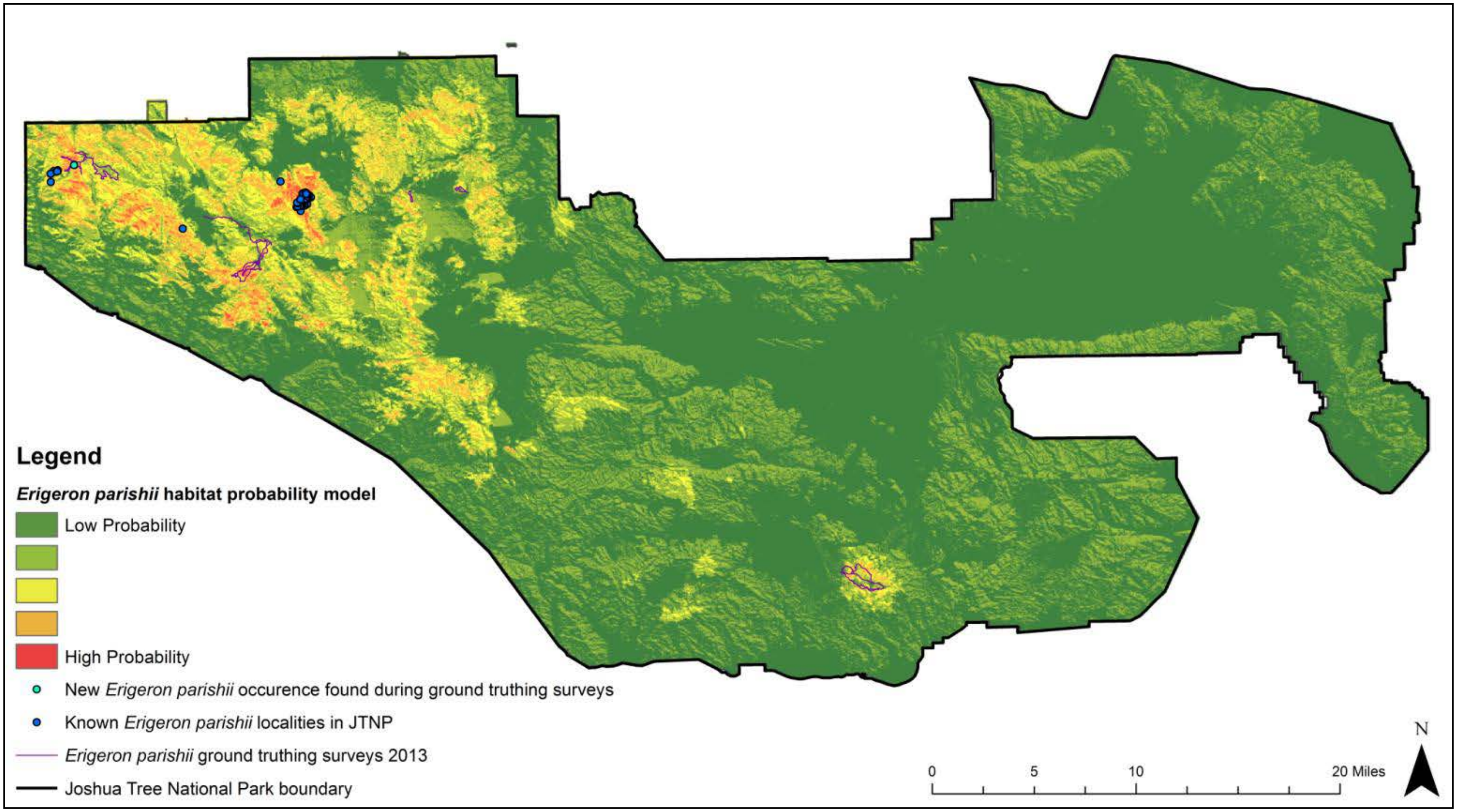


Figure C1. Preliminary *Erigeron parishii* habitat probability model. The model reflects a weighted overlay of a manually defined range of values for elevation, slope, aspect, soil type, and vegetation types that are most commonly associated with the known *Erigeron parishii* localities within Joshua Tree National Park. Dark green represents the lowest probability habitat, while red represents areas of highest probability habitat. Ground truthing surveys were performed in spring and summer of 2013, yielding one new occurrence; a population of approximately 30 individuals east of Long Canyon.

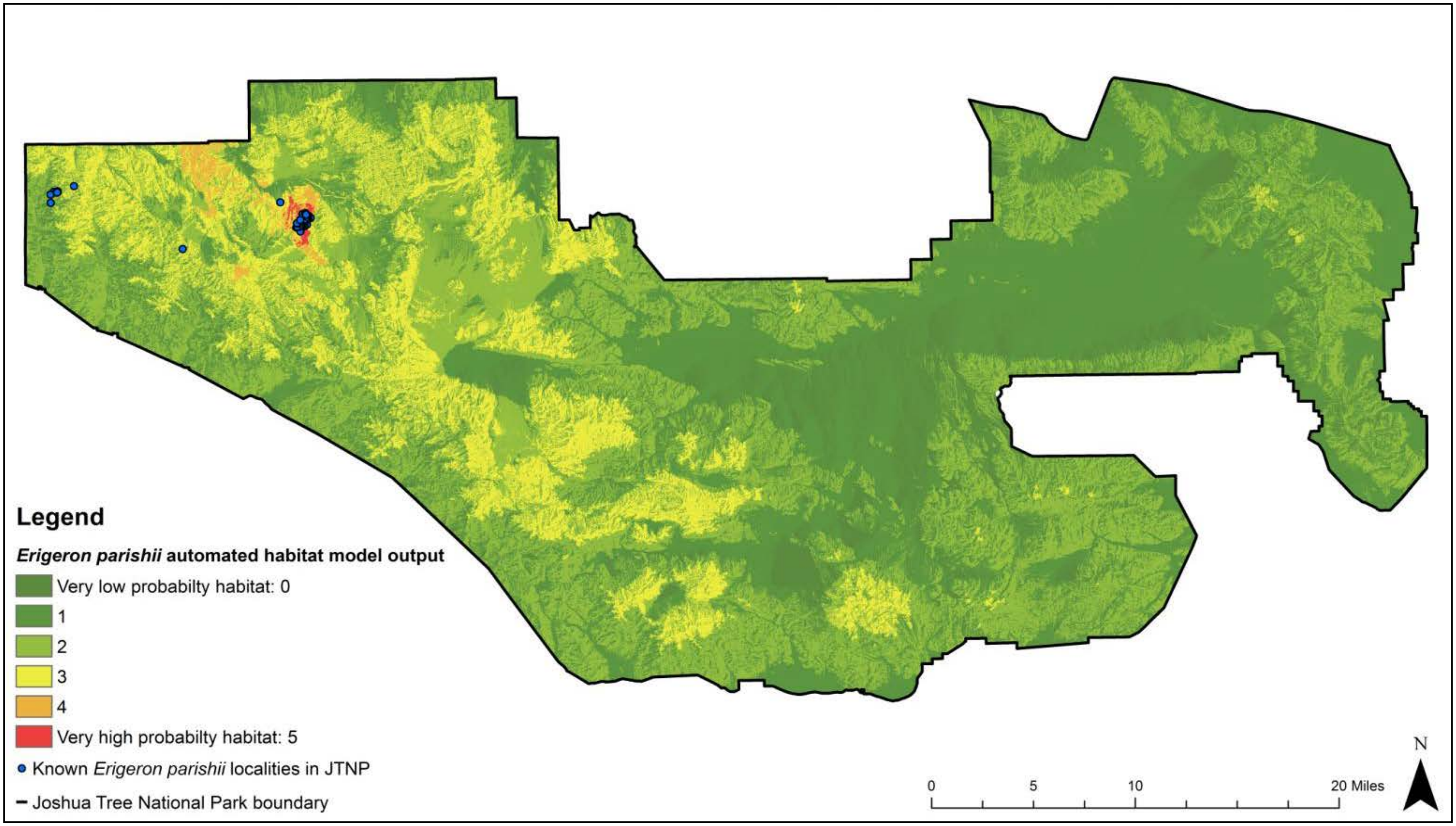


Figure C2. *Erigeron parishii* habitat probability model output produced using the ArcGIS Toolbox automated script, Rare Plant Model. The model output reflects a weighted overlay of a statistically defined range of values for elevation, slope, and aspect representing values associated with 95% of the area in which the species occurs in Joshua Tree National Park. Soil types and vegetation types were restricted to the one type of each containing the highest frequency of occurrences. Areas falling within the target ranges of each parameter are assigned a value of “1”, and areas falling beyond the range limitations are assigned a value of “0”. Overlapping ranges are summed accordingly; five representing where the habitat is most likely located, and zero representing where the habitat is least likely located.

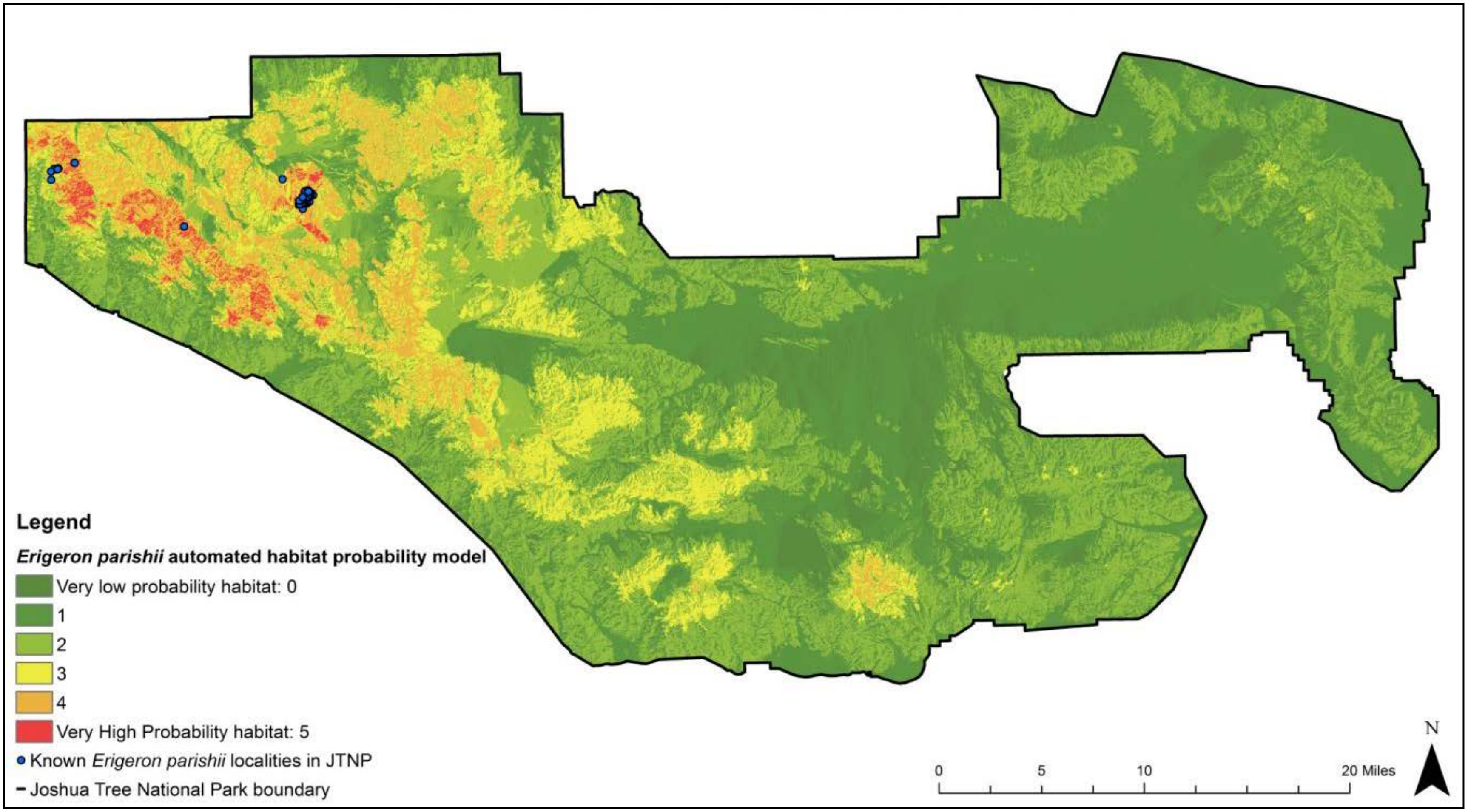


Figure C3. *Erigeron parishii* habitat probability model output produced using the ArcGIS Toolbox automated script, Rare Plant Model. The model output reflects a weighted overlay of a statistically defined range of values for elevation, slope, and aspect representing values associated with 95% of the area in which the species occurs in Joshua Tree National Park. Soil types and vegetation type source data were edited to combine all types which contain occurrences of the species, resulting in 3 vegetation types and 2 soil types included in the analysis. Areas falling within the target ranges of each parameter are assigned a value of “1”, and areas falling beyond the range limitations are assigned a value of “0”. Overlapping ranges are summed accordingly; five representing where the habitat is most likely located, and zero representing where the habitat is least likely located.

Appendix D: Known occurrences for *Erigeron parishii*

Table D1. List of 41 known occurrences of *Erigeron parishii*. Sources CNDDB, RSABG survey information 2013, CCH 2014, JOTR. EO = Element Occurrence; ElmDate = Year last visited; County = Riverside (RIV), San Bernardino (SBD).

EO	ElmDate	County	Quad	Elev (FT)	Location	Population Information
2	1992	SBD	Big Bear City	4080	Just NW of Cushenbury Springs, N of Baldwin Lake, SBD Mountains	NE-most polygon had ~25 plants in 1987. The remaining polygon had ~300 plants in 1987and ~200 plants in1988. Includes former EO #1.
3	2006	SBD	Big Bear City	5800	Cactus Flat, SBD Mountains	Based on 1926 Jones collection. Area south of Hwy 18 surveyed in 1988, no plants observed. A 2006 Hartley photo from "Cactus Flats is attributed to this site. Needs Field Work.
4	1988	SBD	Big Bear City	6400	Canyon Spring, Nelson Ridge, NE of Baldwin Lake, SBD Mountains	75-100 plants between this site and EO #26 IN 1979 & 1988.
5	2010	SBD	Big Bear City	6000	Just S of and E of spring, north end of Lone Valley, SBD Mountains	300 plants observed in 1979, 500+ plants observed in 1987; Barrows estimated 1300-1700 in 1988; ~50 plants in new colonies observed in 1992. "scarce" in N 1/2 SEC 32 in 1998. Includes former EO #12.
6	2011	SBD	Big Bear City	4320	Along Cushenbury Canyon from Cushenbury Springs to Whiskey Springs including N-facing slope N of Monarch Flat, SBD Mountains	~3100 plants estimated in 1979. Thousands of plants in 1986 & 1988. 1366 plants on 160 acres in sec 24 in 1993. Small portions of populations have been reported on many occasions. Includes former EO's #7, 8, 9, & 23.
10	2988	SBD	Big Bear City	5400	N of Silver Peak along W slope of Blackhawk Canyon, SBD Mountains	NW-most polygon had ~725 plants counted (1500-2000 plants estimated) in 1988. Includes former EO #28.
11	2010	SBD	Big Bear City	4900	Slope E of Horsetheif Flat near Arrastre Creek, SBD Mountains	80 plants observed in 1979 in S most polygon. 150 scattered plants observed (200-300 estimated) in N most polygon in 1988. Plants described as uncommon in creek in 2010.
13	2012	SBD	Big Bear City	4520	Terrace Spring, south of Round Mountain, SBD Mountains	Population numbers are for portions of occurrence: ~1600 Plants estimated in 1979, <1000 plants seen in 1987, ~820 plants counted in (1700-2400 plants estimated) in 1988, ~100 plants seen in 1992, 63 seen in 2011, and 3 seen in 2012.
14	2996	SBD	Fawnskin	4500	Lower Furnace Canyon, Bousic Canyon, and Canyon E of Bousic Canyon, SBD Mountains	In 1988: 2617 seen (3000+ EST) in Furnace Canyon, ~250 est in Bousic Cyn, 1488 seen (2000-2500 EST) in canyon E of Bousic Cyn. 100 along ridge W of Furnace Cyn in 1991. 100S in sec 8 in 1992. ~1800 in Furnace Cyn in 1996. Includes EO's # 15 & 16.
17	1996	SBD	Fawnskin	5200	Lower Arctic Canyon near outwash fan, SBD Mountains	Large SE-most polygon: seen in 1979, 175 plants observed (200-250 plants estimated) in 1988, about 2000 plants observed in the NW 1/4 of sec 16 in 1996. Small NW most polygon based on 2008 USFS digital data.

EO	ElmDate	County	Quad	Elev (FT)	Location	Population Information
19	2005	SBD	Yucca Valley South	3450	E Fork of Long Canyon, ~2.5 air mi SSE of Rattlesnake Spring, Little SBD Mountains	3 plants observed in 2005. Survey of the slope and ridgeline in area did not reveal any other individuals in 2005. A 1975 Leary Collection attributed here.
22	2003	SBD	Yucca Valley North	4200	S of Skyline Ranch Road, NW of Yucca Valley	150-200+ plants estimated in 1988. Mentioned as "scarce" IN 2003. A 1973 Clarke Collection from "UC Burns Pinyon Reserve" also attributed to this site.
24	2010	SBD	Big Bear City	5400	Vicinity of Marble Canyon and Marble Canyon Pit, SBD Mountains	~125 seen (~200 plants estimated) in N most Polygon in 1988. Also observed in 1982, 1994, 1996, 1998, AND 2010. Collectors described the population as occasional to scarce. Includes former EO #34.
25	1988	SBD	Fawnskin	5400	Canyon between Arctic and Marble Canyon, SBD Mountains	~50 plants seen (100-150 plants estimated) in middle polygon in 1988. The other two polygons are based on 2008 USFS digital data with no attribute table information.
26	2998	SBD	Big Bear City	6000	Vicinity of Squirrel Spring, N side of Nelson Ridge at the S end of Lone Valley, SBD Mountains	<100 plants seen in the W-most polygon in 1988. 10 plants seen in the E-most polygon in 1992. 400 plants seen in center polygon in 1995. "frequent" in wash and adjacent slopes in center of section 4 in 1998. Includes former EO #40.
27	2988	SBD	Yucca Valley North	4100	N side of Skyline Ranch Rd, 1.75 mi E of Pioneertown, NW of Yucca Valley	In 1988, 95 plants were seen in the east polygon and 12 plants were seen in the west polygon. May extend further W.
29	2012	SBD	Butler Peak	5400	NE slope of White Mountains, ca. 1 air mi E of North Peak, SBD Mountains	Seen in NW-most polygon in 1988. Seen in SE-most polygon in 2002. Greater than 9 plants total in NE-most polygon in 2012; Some may have been planted.
30	2005	SBD	Big Bear City	6100	Between Squirrel Spring and Granite Spring, S end of Lone Valley, SBD Mountains	2000 plants in 1991.
31	1992	SBD	Onyx Peak	6000	NE slope of Mineral Mountain, SE of Blue Cut, SBD Mountains	Fewer than 50 plants observed in 1992. Extent of population is unknown; Needs field work.
32	1991	SBD	Fawnskin	5500	About 0.7 mi (1 km) W of Furnace Canyon, SBD Mountains	10 plants observed in 1991.
33	1992	SBD	Fawnskin	6200	Wildrose Canyon; just NW of spring at head of the canyon, SBD Mountains	Two plants observed in 1992 in NW-most polygon. Only source of information for SE-most polygon is 2008 USFS digital data.
35	1995	SBD	Big Bear City	4700	NE slope of Blackhawk Mountain ca. 0.5 mi E of Blackhawk Canyon, SBD Mountains	500 plants observed in 1995.
36	1995	SBD	Big Bear City	4200	N OF Blackhawk Mountain, ca 0.6 mi NNW of mouth of Blackhawk Mountain, SBD Mountains	50 plants observed in 1995. G

EO	ElmDate	County	Quad	Elev (FT)	Location	Population Information
37	1995	SBD	Cougar Buttes	3800	NNW of Blackhawk Mountain ca. 1.75 mi ENE of Hwy 18 at Camp Rock Rd, SBD Mountains	20 plants observed in 1995.
38	1995	SBD	Cougar Buttes	3840	NW of Blackhawk Mountain, ca. 0.6 mi NE of Hwy 18 at Camp Rock Rd., SBD Mountains	50 plants observed in 1995.
39	1992	SBD	Big Bear City	6120	E of Smart's Ranch RD on ridge above Lone Valley, ca. 1 mi SE of Top Spring, SBD Mountains	Fewer than 10 plants observed in 1992.
41	2011	SBD	Rattlesnake Canyon	5700	SE of Rattlesnake Canyon, ca. 1.3 air mi NNE if Mound Spring, SBD Mountains	200 plants observed in S polygon in 2000. 3 plants observed in N polygon in 2011.
42	2011	SBD	Yucca Valley South	4030	Above Long canyon, ~2.3 air mi SSE of Rattlesnake Spring, Little SBD Mountains	36 plants observed in 2006. Two 1939 Jaeger Collections also attributed to this site. Revisited in 2011, ~60 individuals estimated.
43	XXXX	SBD	Big Bear City	4500	Just NW of Round Mountain, SBD Mountains	Only source of information for this site is 2008 USFS digital data. "occurrence unconfirmed" according to attribute table
44	XXXX	SBD	Fawnskin	4600	Near Junction of Arctic Canyon and Cushenbury RD, W of Cushenbury Springs , SBD Mountains	Only source of information at this site is 2008 USFS digital data. "occurrence unconfirmed" according to attribute table. Needs Fieldwork.
45	2012	SBD	Onyx Peak	6100	Just E of Mineral Mountain; ca. 2 air mi SE of Tip Top Mountain, SBD Mountains	Unknown number of plants seen in N polygon in 2008; Only source of information is 2008 USFS digital data. 11 Plants observed in S polygon in 2012.
46	2011	SBD	Bighorn Canyon	4900	3 mi W of Ruby Mountain; 0.5 mi N OF New Dixie Mine RD, Bighorn Mountains	Only one plants observed here in 2011 during a limited survey.
47	2013	RIV	Indian Cove	4668	NE of Quail Mountain, just W of Johnny Lang Mine, Little SBD Mountains	Most plants found on previously burned loose, rocky, gravelly slopes, as well as in drainages. This occurrence represents a large population estimated at 1000 individuals, covering an area of ~100 hectares. Visited several times since 2008.
48	2011	RIV | SBD	Indian Cove	3923	N facing slopes of Quail Mountain, ca. 1.8 mi NNE of peak	2 plants observed in 2011. Only source of information is a 2011 La Doux et al. collection.
49	2009	RIV	Joshua Tree South	4611	Upper Reaches of East Wide canyon, just below upper Covington Flats, Little SSBD Mountains	One plant found in 2009. Only source of information is a 2009 La Doux & Clifton collection.
NA	2013	SBD	Rimrock	5934	About 1 air mile E of Black Mountain, Bighorn Mountain Wilderness	5 plants found by Duncan Bell in 2013
NA	2013	SBD	Bighorn Canyon	5401	Head of Bighorn Canyon, west of Ruby Canyon, Bighorn Mountains	12 plants found by Duncan Bell in 2013

EO	ElmDate	County	Quad	Elev (FT)	Location	Population Information
NA	2013	SBD	Rattlesnake Canyon	5227	Small drainage west of Rattlesnake Canyon, Bighorn Mountain Wilderness	7 plants found by Duncan Bell in 2013
NA	2013	SBD	Rattlesnake Canyon	4628	Small unnamed drainage E of Rattlesnake Canyon, Bighorn Mountains	1 dry plant found by Naomi Fraga in 2013, needs additional surveys
NA	2013	SBD	Bighorn Canyon	5325	Slopes between Ruby Canyon and Bighorn Canyon, Bighorn Mountains	20 plants found by Naomi Fraga in 2013
NA	2013	SBD	Yucca Valley South	4640	Slopes between Long Canyon and Black Rock Canyon, approximately 1.3 air miles SW of Black Rock Spring.	Counted 25 individuals in June 2013, plants found on steep (30 degree) loose cobble slope, with large gneiss outcrops and Pine/Oak litter.

Appendix E: Pilot demographic and reproductive biology study for *Erigeron parishii* in Joshua Tree National Park

By Tasha La Doux and Mitzi Harding, Joshua Tree National Park

Summary

In May of 2009, preliminary studies were initiated on 62 plants in Johnny Lang Canyon, located at the base of Quail Mountain. The intention of this study was to learn more about life history and reproductive biology for *Erigeron parishii,* as well as establish a long-term monitoring protocol for assessing the age structure of populations and expected survivorship of various size classes. Ten seedlings and 52 reproductively mature ("adult") plants were tagged and measured in 2009, then resurveyed in 2013. Presumably none of the seedlings (<50 cm^3) surveyed in 2009 survived, as they were not relocated in 2013. No plants smaller than 500 cm^3 flowered in 2009. Approximately 92% of the plants in size class 3 and 4 (501-6500 cm^3, 6501-25000 cm^3, respectively) either stayed within the same size class or grew into a larger size class category. Plants >25000 cm^3 (size class 5) had a 55% chance of dying or declining to a smaller size category. The mean number of flowering heads ranged between 19 and 25 during a 4-week survey in May 2009. The maximum number of flowering heads observed was 311. A positive relationship between total plant volume and number of flowering heads is strongly supported (Spearman's Rho = 0.914, 51 d.f., p=1.31e-21) based on the measurement data collected in May of 2009. This positive relationship was moderately to strongly supported in 2013 and 2009 using the following size class categories for the number of flowering heads: 0, <10, 11–100, >100 (Spearman's rho=0.561, 63 d.f., p=1.15e-6; Spearman's rho=0.870, 51 d.f., p=2.90e-17, respectively). Four permanent plots were established in May 2013; data was collected following the protocol provided in Appendix F.

Introduction and Methods

The study site is located in the Little San Bernardino Mountains near the west entrance of Joshua Tree National Park (JOTR). Plants were found on decomposing gneiss and monzogranite, between 1210–1280 m (3975–4200 ft), and the UTM (NAD83) coordinates for the approximate center of the area are: E 572216 and N 3765037 (Figure E1). Each of the 52 adult plants were tagged with a permanent metal tag bearing a unique number. Data was recorded for each individual including tag number, date, observers, UTM coordinates, elevation, height (cm), two widths (cm), phenology (see below for details), pollinators observed, habitat, soil, slope, aspect, weather, time of day, associated species and any additional relevant notes. Permanent plots were not used due to the low density of plants throughout the area, which made it difficult to establish a plot with greater than 10 individuals in it. However, after a number of failed attempts over the years to relocate the plants in this study, as well as the time required to search for them, it was decided that permanent plots (Figure E1) were going to be necessary for long-term viability of the study. Results from the permanent plots established in May 2013 are not discussed here.

Twenty-six plants were tagged on May 1, 2009, then revisited on May 15 and 28, 2009. An additional 26 plants were tagged on May 15, 2009, and then revisited on May 28, 2009. Ten seedlings (<25 cm^3) were identified and recorded on May 1, 2009.

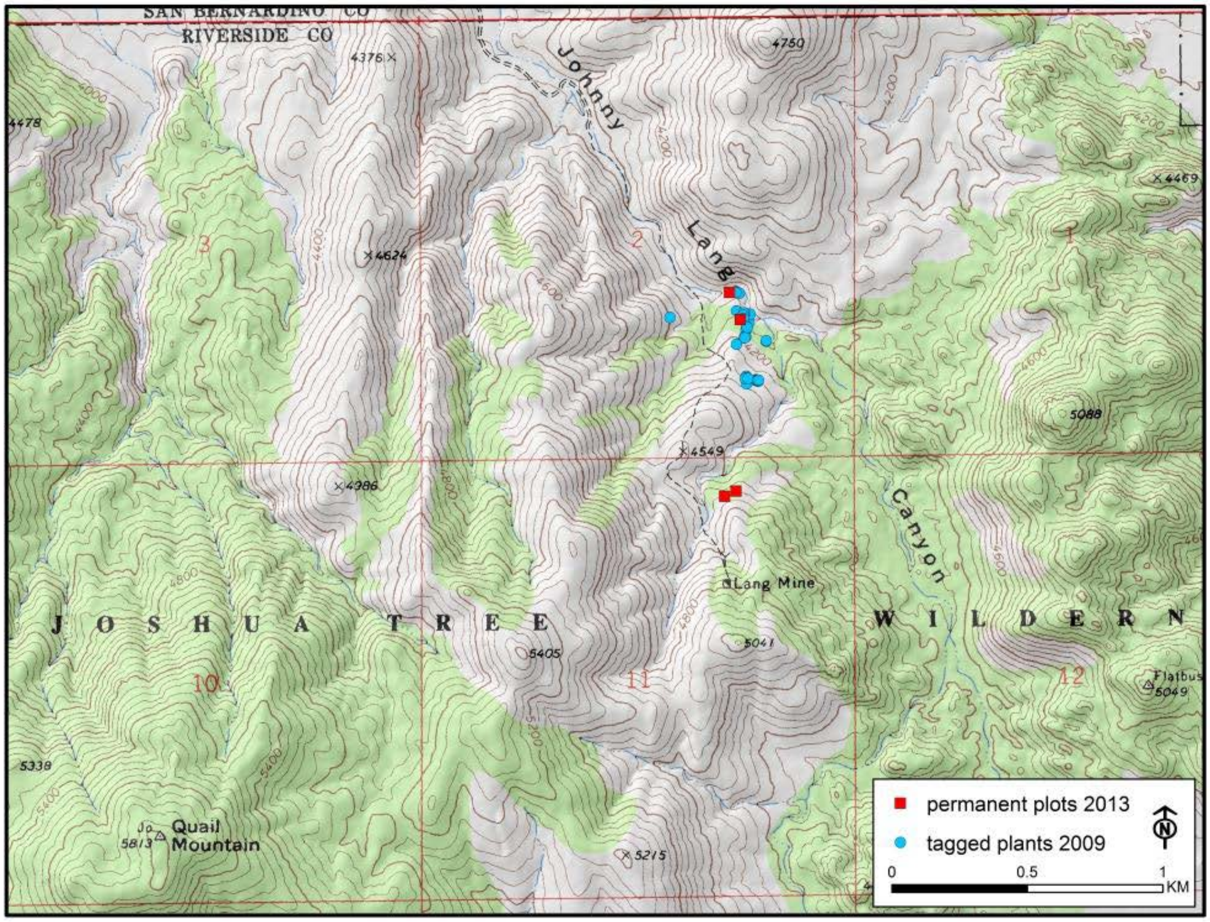


Figure E1. Map showing Johnny Lang Canyon on the northeast side of Quail Mountain and the locations for the 52 adult plants (blue circles) tagged and monitored between 2009-2013, as well as the four permanent plots (red squares) established in 2013.

Height was measured perpendicular to the slope of the ground. The longest axis of any plant material was recorded (dead or alive). During this season, new growth consistently exceeded the old growth. The width measurements were taken parallel to the slope. The longest axis was measured first, then the second axis was measured perpendicular to the first axis (refer to Figures F3 and F4 in Appendix F).

The purpose of the revisits was to track flowering phenology for each individual. Characteristics recorded included the total number of flowering heads and their flowering stage. Flowering stage was broken into four categories: buds, early flowers, late flowers, and seeding. Each category was defined as follows:

- Bud = No open flowers, head with green phyllaries and/or fresh buds
- Early Flowering = Flowers are open, no open flowers are senescing
- Late Flowering = some or all flowers are senescing or going to fruit
- Seeding = fruit/seed development with no open flowers

In June 2013, repeat monitoring was conducted. Of the 52 tagged, adult individuals, eight were found to be dead, whereas four individuals could not be positively identified due to missing tags. None of the ten seedlings were found alive. The monitoring protocol, diagrams, and datasheets can be found in Appendix F.

There were three differences in data collection methods between 2009 and 2013. First, during the repeat monitoring in 2013 we measured height and the two widths for both dead material (total cover) and new growth only. These two measurements were noticeably different in 2013 compared to 2009, presumably due to lower precipitation totals during the months preceding data collection (May 1, 2009 versus June 6, 2013). Total precipitation recorded at the Lost Horse weather station (approximately 2 km east of the site) was 7.62 cm (3.99 in) from July 1, 2008, to April 30, 2009, versus 7.47 cm (2.94 in) from July 1, 2012, to June 5, 2013. Secondly, instead of enumerating the number of heads and their flowering stages in 2013 (as was done in 2009), we categorized the number of heads as 0, 1-10, 11-100, or >100. This was done as a time saving method, but also because our previous data led us to believe that these categories would be meaningful (see Results section). Finally, the phenological stage was recorded as vegetative (did not flower), buds only, flowering, flowering & fruiting, fruiting only, and post-fruiting. The last category was created in 2013 because the timing of our surveys missed the bulk of the reproductive season and we wanted to record the difference between a plant that did not flower during the current season versus one that had flowered but was already past the seed dispersal stage.

Potential pollinator activity was recorded if any insect was found in and around the open flowers during the 2009 monitoring. A total of five insects were captured after observing them on *E. parishii* flowers. It appears that these five insects represent three different taxa across two orders (Diptera and Coleoptera). Specimens are available at the JOTR Resource Division, and further identification is recommended.

The Natural Resource Conservation Survey was contracted by the NPS to produce a soil map of JOTR in 2009. During their survey efforts, we asked them to provide a more detailed assessment of the soil properties associated with the study site (see Appendix G). The soils are slightly alkaline and mostly consist of gravelly loamy sand weathered from gneiss parent material (USDA et al. 2013). More details are discussed in the Habitat section of the main report.

Results and Discussion

During the 2009 field season, timing of the monitoring efforts captured flowering phenology fairly well (see Figures E2 and E3). Based on the 26 individuals tagged on May 1, 2009, 96% had buds, 50% were beginning to flower, and none of them were in late flowering or seeding stage. By May 15, 2009, those same 26 plants showed an obvious shift toward late flowering, with only 69% with buds, 73% with early flowers, 58% with late flowers, and 12% seeding. By May 28, 2009, none of the plants showed buds, only 19% had early flowers, 81% had late flowers, and 77% were seeding. Based on the data collected during that season, a 4-week survey period captures the majority of the reproductive season. The maximum number of flowering heads at any given time was 311; the median and average values also varied throughout the season as shown in Figure E4.

Size classes were created to best capture demographic changes observed in the 2009 season (Table E1). These categories are not of equal size; they represent a best guess by the authors. The size class categories should be reconsidered when more data is available. Nine of the 62 plants were removed from this analysis because they lacked complete datasets. None of the plants under 50 cm^3 (size class 1) were relocated in 2013 and were therefore considered dead. Previous work done by Mistretta and White (2001) also found that seedlings have a high mortality rate (87%). Of the six plants in size class 2 (51-500 cm^3), five did not flower during the 2009 field season; the one plant that did flower only produced 2 inflorescences. It is possible that these individuals were seedlings, however at initial tagging the observer did not feel confident in calling it a first year seedling. All plants >500 cm^3 produced flowers during the 2009 season.

Approximately 92% of the plants in size class 3 and 4 (501-6500 cm^3, 6501-25000 cm^3, respectively) either stayed within the same size class or grew into a larger size class category. Plants >25000 cm^3 (size class 5) had a 55% chance of dying or declining to a smaller size category (see Figure E5). Based on this preliminary dataset, it appears that survivorship increases once plants reach a certain size (500 cm3), and senescence rates appear to increase after the plants become >25000 cm^3. Whether these trends are associated with age classes will be an interesting question to address over the coming years. As reported by Mistretta and White (2001), these data support the observation that *E. parishii* has high survival and reproductive rates once a certain size and/or age class is reached, though more data is needed to determine statistically significant trends for survivorship and reproductive rates associated with size and/or age class demographics.

Using raw data (volume x number of heads), a strong positive relationship (Figure E6) between number of flowering heads and total plant volume (cm^3) is strongly supported (Spearman's rho=0.914, N=53, 51 d.f., p=1.31e-21), and more so when two outliers are removed (Spearman's rho=0.946 (N=51, 49 d.f., p=1.30e-25). In an effort to reduce the amount of time required to survey the plants (counting heads is very time consuming), we ran the same analysis using the following categories for total number of heads: 0, 1-10, 11-100, >100. The positive relationship is still strong, though slightly less: Spearman's rho=0.870 (N=53, 51 d.f., p=2.90e-17) with the two outliers versus 0.894 (N=51, 49 d.f., p=9.86e-19) without the two outliers (Figure E6).

Table E1. Size class categories created for *Erigeron parishii* demographic study.

Size Class	1	2	3	4	5
Volume (cm3)	<50	51-500	501-6500	6501-25000	>25000
# of plants (N)	11	6	14	11	11

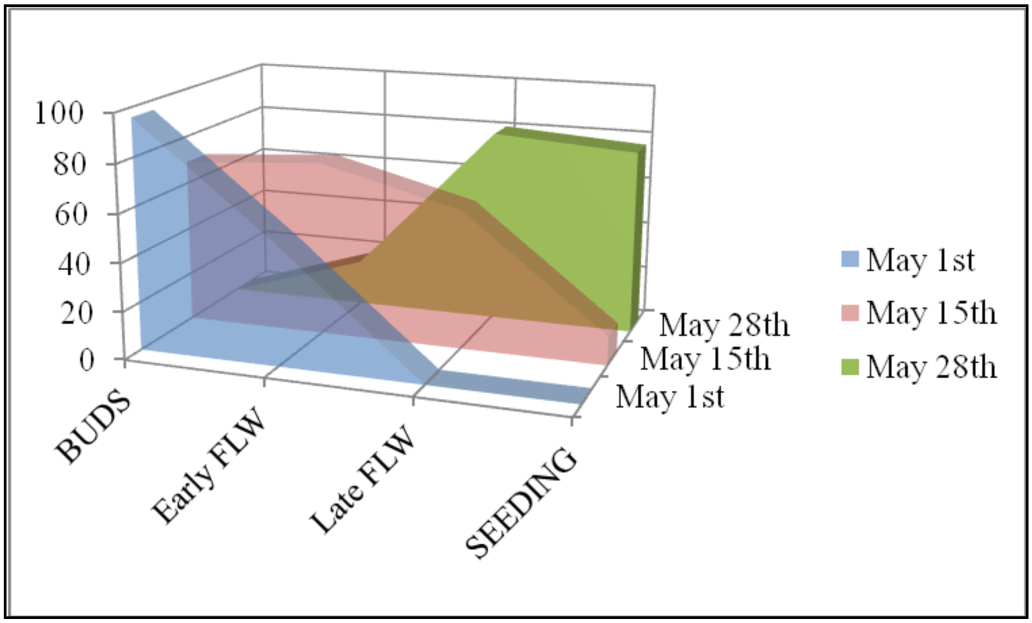


Figure E2. *Erigeron parishii* reproductive phenology during May 2009. Y-axis represents percentage of plants with heads at a given reproductive stage over the 4-week survey period, May 1–28, 2009. n=26.

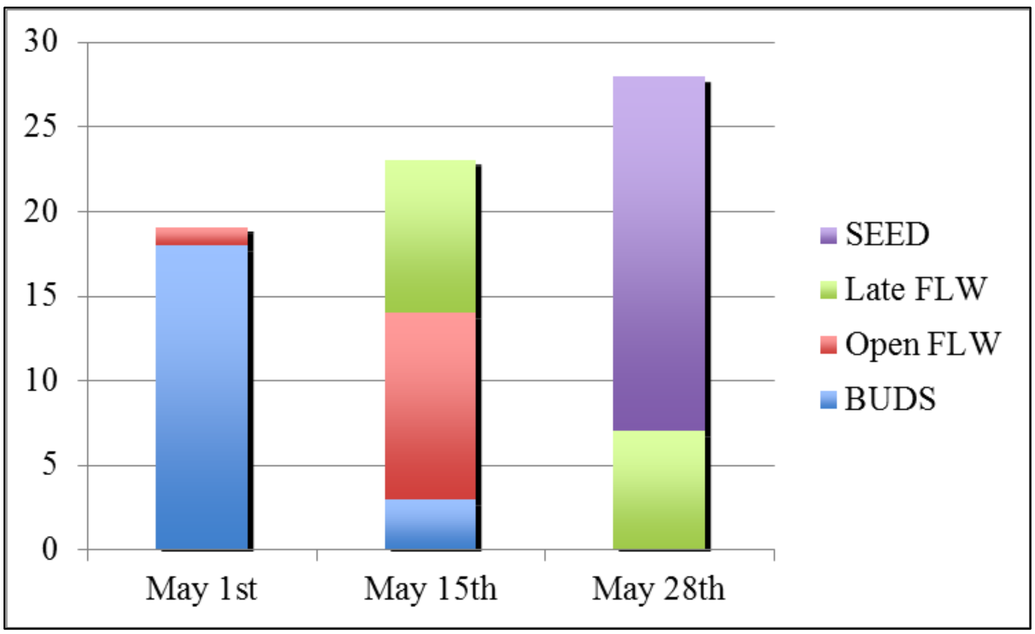


Figure E3. *Erigeron parishii* reproductive phenology during May 2009. Median values for total number of heads in each reproductive stage over the 4-week survey period, May 1–28, 2009. n=26

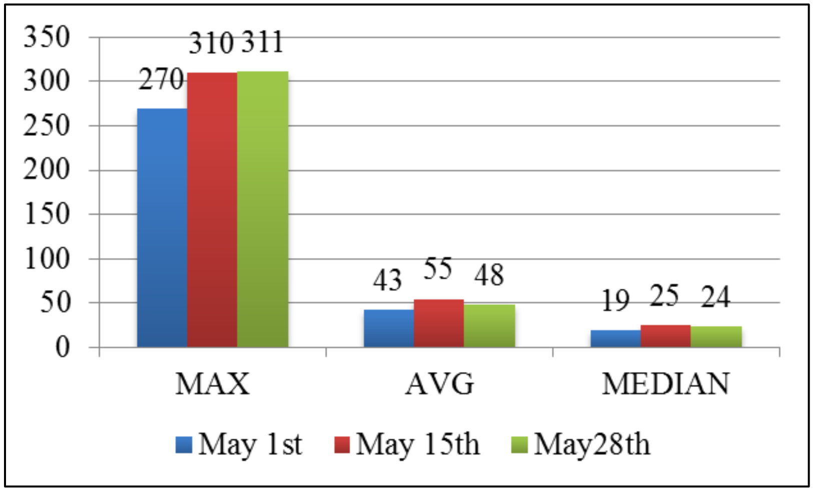


Figure E4. Maximum, Average, and Median number of flowering heads per plant on May 1st, 15th, and 28th during the 2009 *Erigeron parishii* monitoring (n=52) in Johnny Lang Canyon.

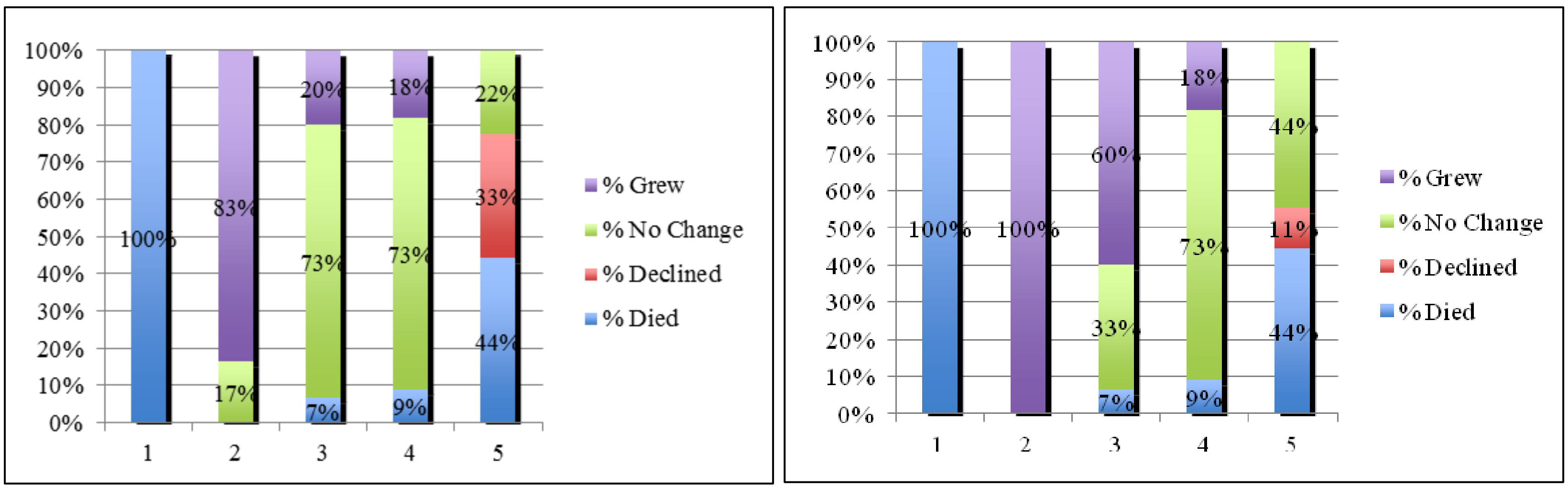


Figure E5. Based on the size classes presented in Table E1, the percentage of plants that died, declined, did not change, or grew between 2009 and 2013 is shown. Size class is based on volume (cm^3) calculated as HxWxW. The left chart is based on new (green) growth only, whereas the right chart is based on total volume (including dead material).

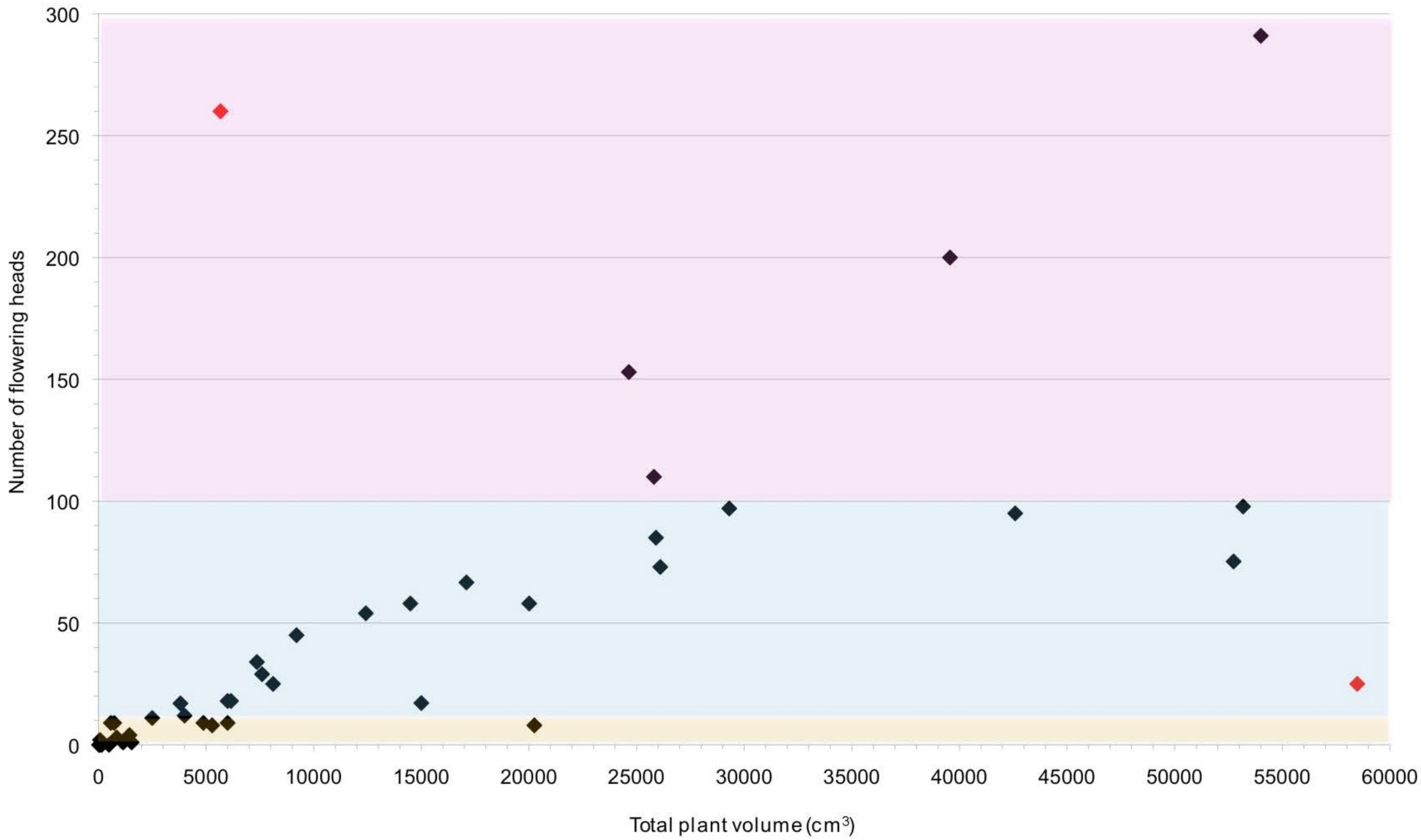


Figure E6. Results from *Erigeron parishii* monitoring in May 2009 showing a positive relationship between total number of flowering heads and total plant volume (cm^3). Spearman's rho=0.914 (N=53, 51 d.f., p=1.31e-21) including the two outliers (marked in red), however without the two outliers Spearman's rho=0.946 (N=51, 49 d.f., p=1.30e-25). The positive relationship is still fairly strong when the total number of flowering heads is categorized as follows: 0, 1-10 (yellow shading), 11-100 (blue shading), >100 (purple shading). Spearman's rho=0.870 (N=53, 51 d.f., p=2.90e-17) with two outliers (marked in red), and without the outliers rho=0.894 (N=51, 49 d.f., p=9.86e-19).

Future monitoring

In order to aid in future monitoring efforts, four permanent plots containing a total of 65 individuals were established in 2013 (see Figure E1). Plot size and shape varies among plots based on the best configuration for capturing the most plants; the goal, however, was to keep the survey area within each plot to ~225 m^2 and capture a minimum of ten individuals. The protocol presented in Appendix F was used for collecting data, with one exception. As mentioned before, instead of enumerating the number of heads and their flowering stages (as was done in 2009), we categorized the number of heads as 0, 1–10, 11–100, or >100. After analyzing data from the 2013 permanent plots, we realized that the categories used for number of flowering heads may not be optimal, as the relationship between total plant volume and categorized flowering heads was not as strong (Table E2). In retrospect, it would have been better to count the total number of heads in 2013 despite the additional time required to do so. Future monitoring should record the total number of flowering heads rather than categorizing them in the field.

Table E2. Spearman's Rho values for various analyses using the 2009 and 2013 monitoring data. Total volume (cm^3) represents HxWxW of all plant material (dead and new growth), New growth represents the volume of new (green) material only, Flw head categories are as follows: 0, 1–10, 11–100, >100.

	Year	Spearman's Rho	N	d.f.	p
Total volume x Total flowering heads	2009	0.914	53	51	1.31e-21
Total volume x Flw head categories	2009	0.870	53	51	2.90e-17
Total volume x Flw head categories	2013	0.560	65	62	1.54e-6
New growth x Flw head categories	2013	0.133	65	62	0.2947

In addition, measurements for new growth versus total volume (including dead material) should continue in years where the total volume exceeds new growth, though it appears from the 2013 data that total volume is the better parameter to use. Based on the 2013 data, measurements for total volume support a moderate positive relationship between plant size and reproductive output, however when the measurements for new growth (green branches only) were used the relationship was no longer supported (see Table E2).

Relocating plants in 2013 was extremely difficult and time-consuming, in addition, the tags did not always stay in the ground. The notes and photos from the previous monitoring season were helpful in trying to positively identify some plants. For this reason, we recommend taking photos and including as much detail in the monitoring notes as time permits.

Finally, in order to develop a better understanding of the relationship between size, age, and rates of survival and reproduction, we needed to confine the monitoring area to a small enough area that surveying for new seedlings could be achieved. The four permanent plots will allow for better tracking of seedling cohorts as long as annual visits are made. With time, we will be able to assign survival and reproductive rates to age classes and develop a better understanding for the demographic and life-history traits for this species.

Recommendations

- Conducting annual surveys is essential for building a robust long-term dataset that will allow meaningful conclusions about reproductive output and demographic trends. We recommend following the monitoring protocol provided in Appendix F annually for a minimum of 5 years, on the four permanent plots as well as the other tagged individuals.

- Determine rates of survivorship and reproductive output for seedlings, juveniles, adults; and determine meaningful demographic age and size classes.

- Conduct analyses on how weather conditions affect demographics (survival rates for age/size classes) and reproductive biology (flowering period, seed production/viability) over time. Suggestions for important climate variables include: the amount and timing of rainfall, minimum precipitation per event or season, effect of summer rainfall, temperature extremes, and number of days below freezing.

- There were a number of individuals that appeared to be dead with young seedlings growing up from the center of the plant. It is unclear whether these "new" plants truly represent new individuals that germinated from seed or whether they are resprouts from the previous larger plant. By conducting annual surveys, as well as photo monitoring of each plant, the answer to this question might be addressed. In addition, one could excavate the plant, tease apart the root system, and see if the two plants (new and old) are in fact connected.

- Tracking the same 25 inflorescences (five heads per individual) with the goal of capturing the very beginning of flowering (buds) to when the plant has gone completely to seed will establish an expected duration for each reproductive stage.

- Testing whether the individuals (i.e. waifs) found at the bottom of canyons on non-typical habitat such as alluvium benches and low-grade washes are contributing to the long-term viability of the species. Assessing differences between waifs and core individuals found on typical habitat (loose upland slopes) may reveal a distinction of "source" versus "sink" populations; parameters to address might include mortality rates, reproductive capacity, size of individuals, and/or variability in population size.

Appendix F: *Erigeron parishii* monitoring protocol

By Tasha La Doux and Mitzi Harding, Joshua Tree National Park

Four permanent plots have been established in Johnny Lang Canyon, on the northeast side of Quail Mountain (see Figure E1 in Appendix E). Each plot varies in size and bearing (Table F1); however the goal was to keep the survey area within each plot to ~225 m^2 and capture a minimum of ten individuals. There are three rectangular plots: ERPA-1, 2 and 3, as well as one belt transect ERPA-4 (Figures F1 and F2). Plots ERPA-1 and ERPA-2 are oriented so the origin is the southwest corner. The origin for ERPA-3 is the west corner. ERPA-4 is a belt transect, with the origin on the west end. All four corners for each rectangular plot, as well as the two endpoints for the belt transect, are permanently marked with steel markers. All measurements should be metric.

Table F1. Location and orientation of the four permanent *Erigeron parishii* monitoring plots located in Johnny Lang Canyon (Quail Mountain). All GPS data is recorded in NAD83 UTM, and bearings are recorded with a 12° east declination. There are 3 rectangular plots (ERPA 1-3) and one belt transect (ERPA 4).

	Origin Location			Plot Size and Orientation	
Plot ID		**UTM E**	**UTM N**	**X-axis**	**Y-axis**
ERPA 1	SW corner	572135	3764476	11m @ 74°	25m @ 344°
ERPA 2	SW corner	572177	3764495	10m @ 58°	25m @ 328°
ERPA 3	W corner	572193	3765125	15m @ 114°	15m @ 24°
ERPA 4	W end (belt)	572153	3765224	40m @ 65°	±5m on either side of line

Rectangular Plots (ERPA 1, 2, and 3):

1. Establish plot by laying down measuring tape along two axes. Be sure to use the bearings to maintain a 90° angle at the corner. Begin at the origin (0,0) and run one tape along the x-axis, the other along the y-axis. Use pin flags to mark each meter along both tapes (Figure F2).

2. One person will be the recorder, and walk along the y-axis outside the plot. This person should have a compass so they can ensure a 90° angle for determining the y-axis reading. The other person will be the observer, and will call out data for the recorder.

3. At each plant, the following information should be recorded/verified at each visit:

    - Location of plant within plot. The location should be to the nearest meter along the axes, determined by the southwest corner of the 1m^2 subplot the plant is located within (see Figure F2).
    - Plant ID (metal tag should be in ground next to plant, or attached to plant)
    - Height1, width1, width2 of the new growth or live material only (see Figures F3 and F4).
    - Height2, width3, width4 of total cover, including old or dead material, if greater than the above measurements (see Figures F3 and F4).

- o Number of inflorescences
- o Reproductive status
- o Tag location
- o Notes

4. If the tag is missing, attempt to use the past coordinates to deduce the plant ID. Write down the old ID number in the notes and make sure this information stays on the datasheet. Assign a new ID and attach new tag to the plant or stake it to the ground (preferred). Always record the location of the tag on the datasheet.

5. Be sure to look for and record any new seedlings or juveniles that were not previously recorded. Assign a new ID and tag, accordingly.

Belt transect (ERPA 4):

1. The belt transect is 40 meters in length (X-axis) and 10 meters wide (Y-axis). The X-axis runs down the center of the belt creating a north and south side (Figure F1).

2. Establish transect by laying down one measuring tape starting from the origin (west endpoint) to the 40m mark (east endpoint). This will serve as the "X-axis" of the belt transect. The Y-axis is defined by the distance of a plant away from the X-axis, at a perpendicular angle, in both the north and south directions within 5 meters.

3. One person will be the recorder, and a second person will be the observer calling out data for the recorder.

4. At each plant, the following information should be recorded/verified at each visit:

    - o Location of plant within transect. The location should represent the center of the plant, to the nearest 0.1 m. The Y coordinate should be accompanied by "N" or "S" indicating which side of the X-axis the plant is located (Figure F1).
    - o Plant ID (metal tag should be in ground next to plant, or attached to plant)
    - o Height1, width1, width2 of the new growth or live material only (see Figures F3 and F4).
    - o Height2, width3, width4 of total cover, including old or dead material, if greater than the above measurements. (see Figures F3 and F4).
    - o Number of inflorescences
    - o Reproductive status
    - o Tag location
    - o Notes

5. If the tag is missing, attempt to use the past coordinates to deduce the plant ID. Write down the old ID number in the notes and make sure this information stays on the datasheet. Assign a new ID and attach new tag to the plant or stake it to the ground (preferred). Always record the location of the tag on the datasheet.

6. Be sure to look for and record any new seedlings or juvenile plants that were not previously recorded. Assign a new ID and tag, accordingly.

Explanation of Fields:

Height: measure perpendicular to ground, from base of plant to highest point (see Figure F3)

Width1 or 3: measure longest distance, parallel to ground (see Figures F3 and F4)

Width2 or 4: measure longest distance perpendicular to width 1 or 3 (see Figures F3 and F4)

Number of inflorescences: count the number of inflorescences from current season only.

Reproductive Status: If there are no inflorescences from this season then call it vegetative (VEG), otherwise categorize as buds only (BUD), flowering (FLW), flowering and fruiting (FLW/FRT), fruiting (FRT), or post-fruiting (POST). Be sure to base this on the current season inflorescences only.

# of heads: Count the total number of inflorescences from the current season only, regardless of their reproductive status.

Tag location: Describe where the tag is located relative to the center of the plant, as well as whether it is attached to the plant or staked into the ground (e.g. on plant, SW)

Notes: Indicate anything about the plant that may be helpful or useful. For example, if it appears to be a juvenile or dying, location of the plant relative to other landmark, herbivory, etc.

Important Notes:

- All plant measurements should be to the nearest cm.
- Never leave a field blank (except in Notes).
- Timing of monitoring should target when the plants are flowering/fruiting, to ensure that we are capturing the vegetative growth and reproductive output at its maximum.
- It is very important to minimize your impact to the area. For this reason, only one person should walk around inside the plot. Avoid stepping near, under, or above the base of the plant.
- Bring a copy of the previous years' data with you to ensure all individuals are revisited. This will ensure that any new seedlings or juveniles are recognized. Data can be found in the Botany Program folder within the JOTR Resources' share drive.
- Blank datasheets (Figure F5) can also be found in the Botany Program folder within the JOTR Resources' share drive. Be sure to print out several copies for each field day.
- Data should be transcribed into an electronic version within a week of data collection. Hard copies of the datasheets should be archived.

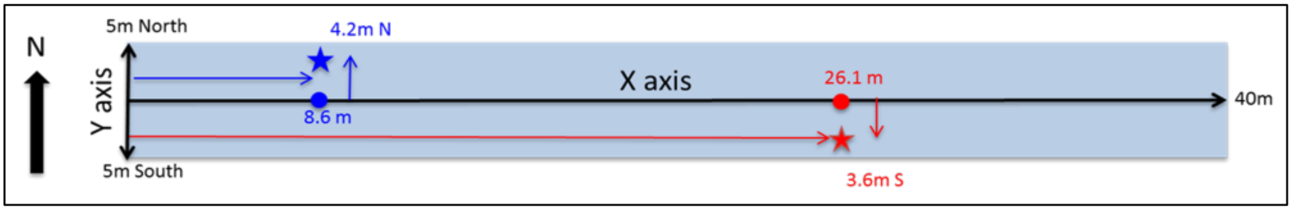


Figure F1. Plot diagram for belt transect (ERPA-4), showing two examples of how to measure the x-, y-axis readings for the location of a plant within the plot. Measurements are taken to the nearest 0.1 m. The y-axis reading is given as the distance from the x-axis with a cardinal direction (e.g. north or south) from the x-axis. Blue star location: x-axis = 8.6 m, y-axis = 4.2 m North. Red Star location: x-axis = 26.1 m, y-axis = 3.6 m South.

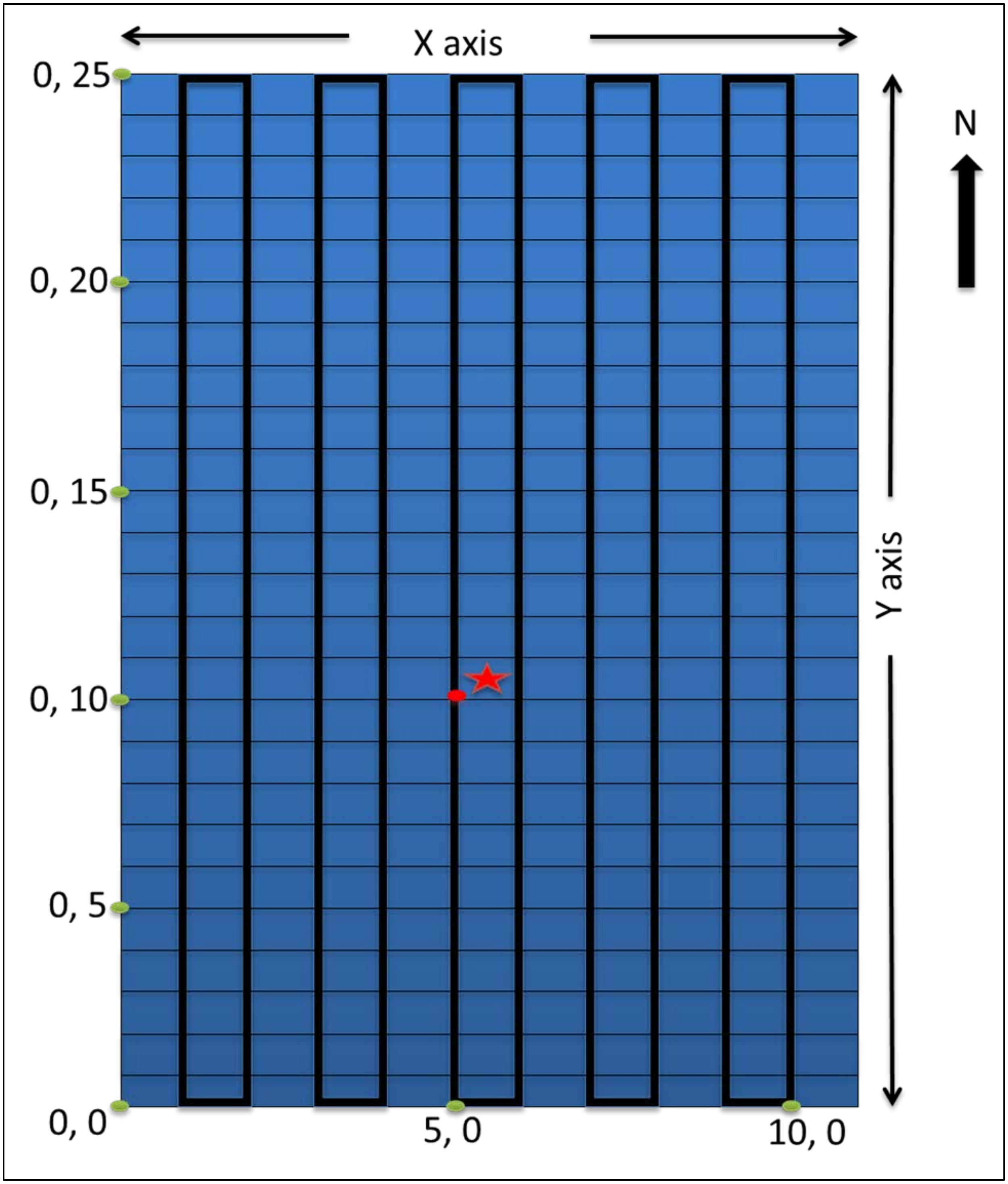


Figure F2. Diagram of rectangular plots (ERPA-1, -2, and -3) showing gridlines with the origin (0, 0) at the southwest corner. The (x, y) coordinate of the southwest corner of each 1m x 1m subplot is used to record the location of the plant. For example, the (x, y) reading for the red star is (5, 10).

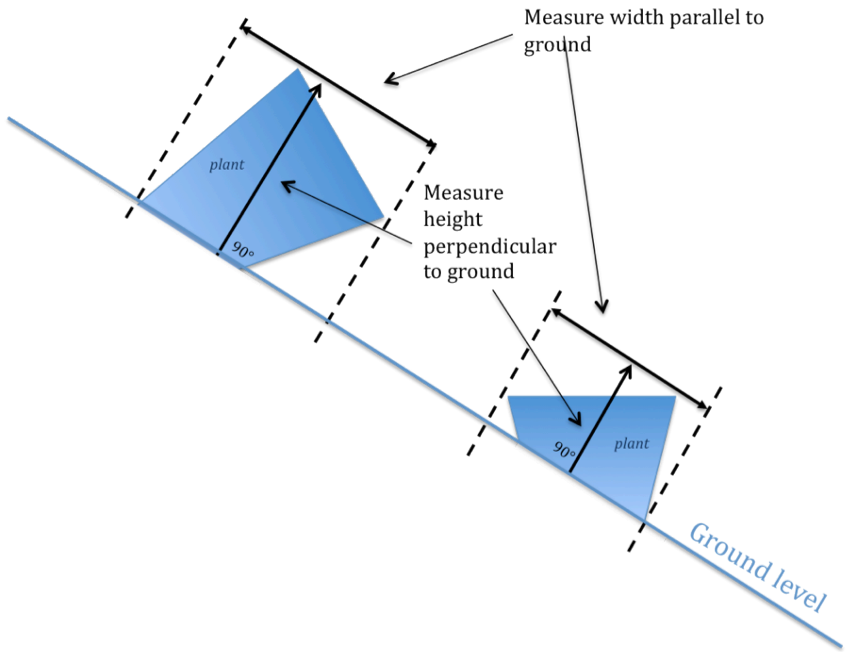


Figure F3. Side view of a hill slope with two plants. Solid black lines demonstrate proper method for measuring width and height.

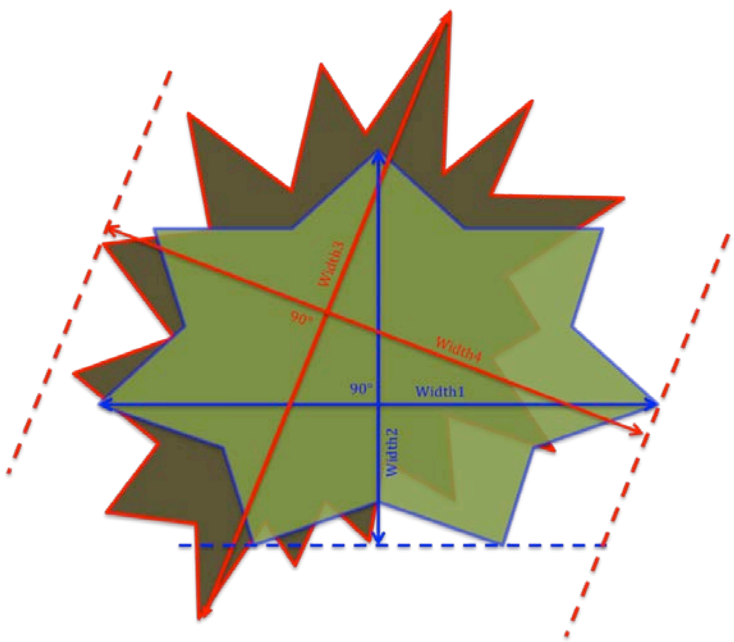


Figure F4. An aerial view of a plant; solid lines demonstrate where to take proper width measurements. Old or dead plant material is shown in brown with red outline, whereas new growth or live material is represented by green with blue outline. Width 1 and 2 represent live (green) material only (blue lines); width 3 and 4 represent total cover (red lines), which includes dead and live material. Width 1 and 3 represent the longest axis, width 2 and 4 are always perpendicular (90°) to their respective axis.

***ERIGERON PARISHII* MONITORING**	Date:
Observer(s):	Bearings:
Plot Location:	Aspect:
GPS for 0/0:	Slope:
Datum:	Elev:

			(Live matierial)			Total cover (+old material)			**#**	**Repr.**	**Tag**	
Plant ID	**X**	**Y**	**H1**	**W1**	**W2**	**H2**	**W3**	**W4**	**heads**	**Status**	**location**	**Notes**

Categories for Repr status: vegetative, buds only, flw, flw/frt, frt, post-fruiting stage. Notes should include info about health, age, herbivory, pollinators, etc. Tag location inlcudes where the tag is located relative to the center of the plant, as well as whether it is attached to the plant or staked into the ground (ex. plant SW)

Plot Description (Soil, Habitat, Associated Species):

Figure F5. Example datasheet for *Erigeron parishii* monitoring.

Appendix G: Soil Analysis for Quail Mountain population

Report provided by Paul Rindfleisch 5/28/2009, Senior Soil Scientist for the Natural Resource Conservation Survey. Text below has not been modified from the original document provided.

Erigeron parishii Soil Investigation

Purpose: Assistance was requested by Joshua Tree National Park Service Staff (Alice Miller) in identifying soil properties associated with endangered plant species *Erigeron Parishii*.

Methods: 5 partial soil descriptions (see attached map and descriptions) were done in soil map unit TC4: Pinecity gravelly loamy sand, 30 to 50% slope (see attached map unit description). Color and soil consistence were not recorded, as neither property seemed to be relevant to *Erigeron Parishii* distribution. pH, texture, rock fragments, effervescence, presence or absence of structure and ped and void features (e.g. clay films, secondary carbonates) and depth to bedrock were recorded at each stop. Samples from the surface horizon of each pedon were also collected for possible soil organic carbon determination.

Results: The apparent preferred habitat for *Erigeron Parishii* is areas with very shallow to shallow soils; in some places, the plants were growing directly out of cracks in the bedrock, in other cases, the plants were growing directly next to or under outcrops of granitic or gneissic bedrock. In all cases, the plants were found on north aspects. Landforms were primarily low hills with slopes up to 35%, although two pits were in areas associated with inselbergs that had negligible slopes. All soils were less than 50 cm to a paralithic contact. With one exception (ERPA-2), the soils were dominantly sandy loams with moderate amounts of coarse fragments. ERPA-2 had a sandy-skeletal particle size control section and is similar to the dominant component in the map unit, Pinecity. Pedons ERPA-1 and ERPA-3 classify as loamy, mixed, superactive, thermic, shallow typic haplargids, similar to the series Desertqueen. Pedon ERPA-4 classifies as a loamy- skeletal, mixed, superactive, thermic, shallow typic torriorthent. Both of these soils are recognized as minor components in the map unit description. Pedon ERPA-5 classifies as a loamy, mixed, superactive, thermic, shallow typic haplocambid, which will interpret similarly to pedons ERPA-1 and -3. Most pedons did not show an effervescence reaction in any horizons, and pHs are neutral to slightly alkaline. Surface fragment quantities are typically high (~85%), and are dominated by gravel-sized fragments (2-75 mm). Available water holding capacity ranges from 0.12 in/in for sandier soils to 0.34 in/in for loamier soils. Saturated hydraulic conductivity (a measure of infiltration) ranges from moderately high (1-10 µm/s) for loamier horizons to high (10-100 µm) for sandier soils. Runoff, determined using slope and saturated hydraulic conductivity ranges from negligible on flatter sites to moderate on more sloping sites. Kw, a relative measure of susceptibility of the soil to rain drop erosion ranges from 0.02 to 0.28, with higher numbers indicating greater susceptibility. By comparison a soil with a silt loam texture, 15% clay and no rock fragments would have a Kw of 0.43. Generally, sandier soils and/or soils with large amounts of rock fragments have lower Kws.

TC4--Ironped gravelly loamy sand, 30 to 50 percent slopes

Map Unit Setting

General location: northwestern portion of Joshua Tree National Park, in the Joshua Tree Wilderness Area
Major uses: Recreation and wildlife habitat
MLRA: 30 - Mojave Desert
Map unit landscape: Mountains
Elevation: 3900 to 5215 feet (1190 to 1590 meters)
Mean annual precipitation: 4 to 7 inches (100 to 175 millimeters) Mean annual air temperature: ---
Frost-free period: 280 to 320 days

Map Unit Composition
**Pinecity gravelly loamy sand--80 percent
Minor components: 20 percent

Major Component Description

*Pinecity gravelly loamy sand and similar soils
Slope: 30 to 50 percent Aspect: None noted Landform: Backslope of hill
Parent material: Residuum weathered from gneiss
Typical vegetation: Nevada jointfir-obselete, other annual forbs, water jacket

Selected Properties and Qualities of Pinecity gravelly loamy sand

Surface pH: 7.4
Surface area covered by coarse fragments: 20 to 50 percent fine gravel, 5 to 10 percent coarse gravel, 0 to 5 percent cobbles
Depth to restrictive feature: Paralithic bedrock--2 to 14 inches
Slowest rate of saturated hydraulic conductivity: Low
Salinity: Not saline
Sodicity: Not sodic
Available water capacity to 60 inches: About 0.2 inches (Very low) Shrink-swell Potential:

Selected Hydrologic Properties of Pinecity gravelly loamy sand

Present annual flooding: None Present annual ponding: None Surface runoff: Very high
Current water table: None noted.
Natural drainage class: Excessively drained
Hydrologic Soil Group: D

California Land Use Interpretive Groups
Land capability nonirrigated: 8
Ecological site: Not Assigned

Typical Profile
**A--0 to 1 inches; gravelly loamy sand
**Bw--1 to 4 inches; gravelly loamy sand
**Cr--4 to 13 inches; soft bedrock

Minor Components

****Rock Outcrop
Composition: About 10 percent
Slope: --- Landform:
Ecological site: Not Assigned

****Typic Haplargids and similar soils
Composition: About 5 percent Slope: 30 to 50 percent Landform: Backslope of hill
Typical vegetation: big galleta, blackbrush, other annual forbs
Ecological site: Not Assigned

****Typic Torriorthents and similar soils
Composition: About 5 percent Slope: 30 to 50 percent Landform: Backslope of hill
Typical vegetation: Nevada jointfir-obselete, big galleta, water jacket
Ecological site: Not Assigned

E-mail correspondence from Paul Rindfleisch to Alice Miller (Vegetation Branch Chief for JOTR in 2009):

Hi Alice. Here are the descriptions I took the day that we were out together. Let me know if you have any questions on the notation used.

For taxonomic unit: lmy = loamy, s-skel = sandy-skeletal, l-skel = loamy-skeletal

mx = mixed mineralogy
sa = superactive cation exchange class
th = thermic temperature regime
sh = shallow soil depth class ($\leq$ 50 cm to a restrictive layer)

Don't hesitate to make further queries on things your aren't sure about. I will be in the field this week until friday, but then I will be in the office for next couple of weeks after that.

Paul

Paul Rindfleisch, Senior Soil Scientist
14393 Park Ave. Suite 200
Victorville, CA 92392-3302
Phone: 760-843-6882 x116
Fax: 760-843-9521

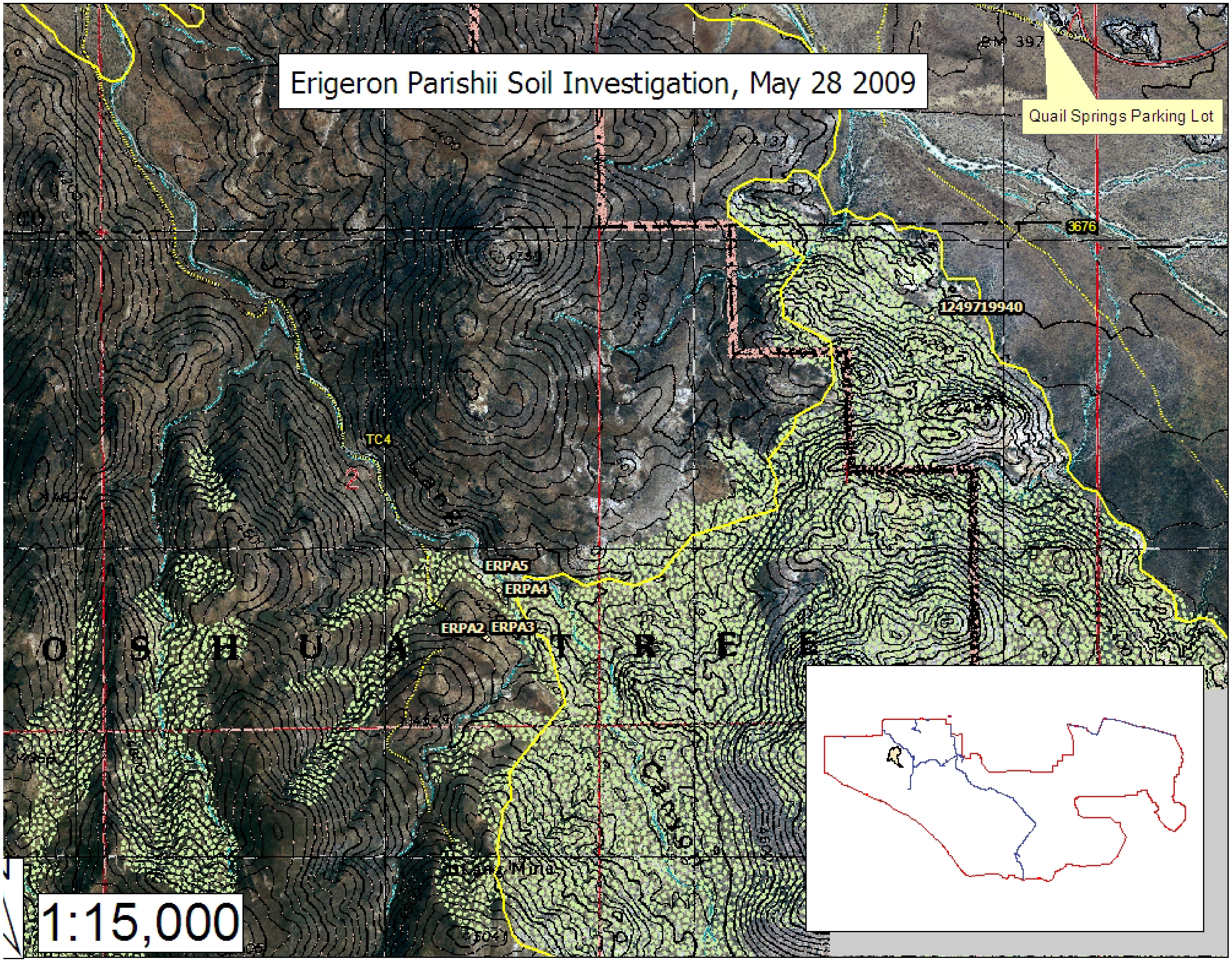
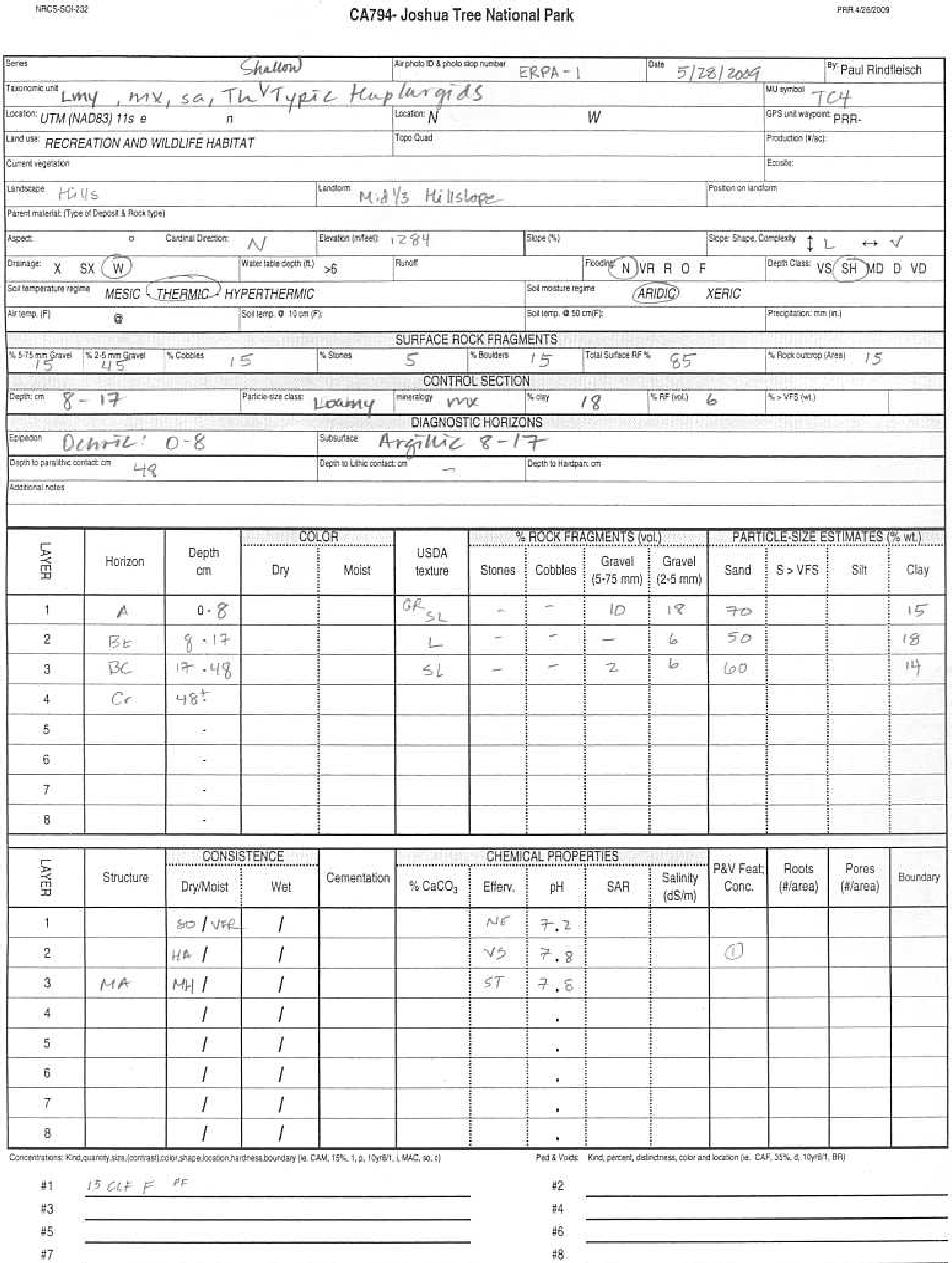


Figure G-1. Map provided by Paul Rindfleisch (NRCS) for *Erigeron parishii* soil survey conducted near Quail Mountain.



NRCS-SOI-232

CA794- Joshua Tree National Park

PRR 4/28/2009

Series: Shallow	Air photo ID & photo stop number: ERPA - 1	Date: 5/28/2009	By: Paul Rindfleisch
Taxonomic unit: Lmy, mx, sa, Th Vtypic Haplargids			MU symbol: TC4
Location: UTM (NAD83) 11s e n	Location: N	W	GPS unit waypoint: PRR-
Land use: RECREATION AND WILDLIFE HABITAT	Topo Quad		Production (#/ac):
Current vegetation			Ecosite:
Landscape: Hills	Landform: Mid 1/3 Hillslope		Position on landform
Parent material: (Type of Deposit & Rock type)			
Aspect: o; Cardinal Direction: N	Elevation (m/feet): 1284	Slope (%)	Slope Shape, Complexity: ↕ L ↔ √
Drainage: X SX (W)	Water table depth (ft.) >6; Runoff	Flooding: N VR R O F	Depth Class: VS (SH) MD D VD
Soil temperature regime: MESIC (THERMIC) HYPERTHERMIC		Soil moisture regime: (ARIDIC) XERIC	
Air temp. (F) @	Soil temp. @ 10 cm (F):	Soil temp. @ 50 cm(F):	Precipitation: mm (in.)

SURFACE ROCK FRAGMENTS

% 5-75 mm Gravel	% 2-5 mm Gravel	% Cobbles	% Stones	% Boulders	Total Surface RF %	% Rock outcrop (Area)
15	45	15	5	15	85	15

CONTROL SECTION

Depth: cm	Particle-size class	mineralogy	% clay	% RF (vol.)	% > VFS (wt.)
8 - 17	Loamy	mx	18	6	

DIAGNOSTIC HORIZONS

Epipedon: Ochric: 0-8	Subsurface: Argillic 8-17	
Depth to paralithic contact: cm 48	Depth to Lithic contact: cm —	Depth to Hardpan: cm

Additional notes

LAYER	Horizon	Depth cm	COLOR Dry	COLOR Moist	USDA texture	% ROCK FRAGMENTS (vol.) Stones	Cobbles	Gravel (5-75 mm)	Gravel (2-5 mm)	PARTICLE-SIZE ESTIMATES (% wt.) Sand	S > VFS	Silt	Clay
1	A	0-8			GR SL	–	–	10	18	70			15
2	Bt	8-17			L	–	–	—	6	50			18
3	BC	17-48			SL	–	–	2	6	60			14
4	Cr	48+											
5		-											
6		-											
7		-											
8		-											

LAYER	Structure	CONSISTENCE Dry/Moist	Wet	Cementation	% $CaCO_3$	CHEMICAL PROPERTIES Efferv.	pH	SAR	Salinity (dS/m)	P&V Feat; Conc.	Roots (#/area)	Pores (#/area)	Boundary
1		SO / VFR	/			NE	7.2						
2		HA /	/			VS	7.8			(1)			
3	MA	MH /	/			ST	7.8						
4		/	/				.						
5		/	/				.						
6		/	/				.						
7		/	/				.						
8		/	/				.						

Concentrations: Kind,quantity,size,(contrast),color,shape,location,hardness,boundary (ie. CAM, 15%, 1, p, 10yr8/1, i, MAC, so, c)

Ped & Voids: Kind, percent, distinctness, color and location (ie. CAF, 35%, d, 10yr8/1, BR)

#1 15 CLF F PF

#2

#3

#4

#5

#6

#7

#8

Figure G-2. Datasheet provided by Paul Rindfleisch (NRCS) for *Erigeron parishii* soil samples collected near Quail Mountain.

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