# Enhancing the Resilience of Edaphic Endemic Plants

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# Executive Summary

This study presents an approach for identifying and describing geographic areas that support edaphic endemic species and their habitat in a design that enhances resilience and provides opportunities for shifting distributions. We developed conceptual models to inform field studies and management, refined soils and vegetation attributes, and assessed regional population structure and threats. We used results to suggest prioritized locations for surveys, management, potential translocation, and additional conservation or acquisition. The U.S. Geological Survey (USGS) and San Diego Management and Monitoring Program (SDMMP) modeled suitable habitat for the target species under current and future climate scenarios; model results are in a separate report and referenced in this document, as appropriate. Target species include San Diego thornmint (*Acanthomintha ilicifolia*), thread-leaved brodiaea (*Brodiaea* filifolia), Otay tarplant (*Deinandra conjugens*), Dehesa nolina (*Nolina interrata*), and Parry's tetracoccus (*Tetracoccus dioicus*).

All target species occur on nutrient poor soils, and each species is associated with a unique suite of physical and chemical soil properties. San Diego thornmint is restricted to clay soils with low sand content and has a low tolerance to metals. Thread-leaved brodiaea occurs on clays in a narrow pH range, and is tolerant to high sodium soils but avoids alkaline soils. Otay tarplant has a positive relationship with clay, sodium, magnesium, and low fertility soils. Dehesa nolina prefers soils with high pH and calcium levels, and avoids sites with high copper levels. Parry's tetracoccus occurs on soils with higher metal concentrations than surrounding areas. We provide a range of variables for each species that can inform site selection for management and restoration. For example, testing soil before enhancing or augmenting small occurrences will allow us to locate suitable sites and eliminate or remediate unsuitable sites with remnant populations before investing management funds.

We used distribution data, habitat suitability models, genetic principles and information to develop regional population structures for each target species. We then identified populations or population groups important for long-term resilience and locations where conservation and management actions would be most beneficial.

We identified 17 population groups for San Diego thornmint, 6 for thread-leaved brodiaea, 13 for Otay tarplant, and 4 each for Dehesa nolina and Parry's tetracoccus. We also identified gaps in connectivity within and between population groups, and opportunities to restore habitat in those gaps and improve population resilience. Recommended actions vary by species:

- For San Diego thornmint, thread-leaved brodiaea, and Otay tarplant, conserve and survey additional habitat, but focus management primarily on enhancing existing occurrences, and expanding and/or augmenting selected small occurrences.
- For Dehesa nolina, survey and conserve high suitability habitat east of the current distribution.
- For Parry's tetracoccus, conserve known occurrences and survey for potential new ones between all population groups.

Habitat is predicted to decline in the future for all target species under various climate scenarios, although the amount of predicted habitat remaining varies among species. San Diego thornmint and Parry's tetracoccus have the largest amounts of predicted future suitable habitat, Dehesa nolina and thread-leaved brodiaea had small amounts of predicted future suitable habitat, and Otay tarplant had no predicted future suitable habitat. We recommend conserving future predicted suitable habitat within or beyond San Diego County, and experimentally translocating target species into this habitat as climatic conditions change if monitoring indicates further species declines.

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# 1 Introduction

The Southern California Natural Community Conservation Program (NCCP) conserves edaphic endemic plants that have declined over the last 100 years as a result of habitat loss and fragmentation from urban and agricultural development. Remaining populations face low genetic diversity from reduced population sizes, geographic isolation, and loss of pollinators. To enhance resilience of these species across their ranges, we must manage threats to increase population size, identify potential habitat to connect existing populations, find or restore new populations, and provide opportunities for shifting distributions due to changes in precipitation and temperature, particularly intensive and prolonged droughts.

This project addressed five edaphic endemic plant species that are restricted to San Diego County or also occur in neighboring counties or Baja California, Mexico: San Diego thornmint (*Acanthomintha ilicifolia*), thread-leaved brodiaea (*Brodiaea filifolia*), Otay tarplant (*Deinandra conjugens*), Dehesa nolina (*Nolina interrata*), and Parry's tetracoccus (*Tetracoccus dioicus*). The target species currently occur within several planning areas in San Diego County, including:

- San Diego Multiple Species Conservation Plan (MSCP)
- San Diego MSCP North County Subarea Plan area
- San Diego Multiple Habitat Conservation Plan (MHCP) area

All 5 species occur in the Management Strategic Planning Area (MSPA) for San Diego County and are priorities for management under the regional Management and Monitoring Strategic Plan for conserved lands in San Diego County (MSP Roadmap; San Diego Management and Monitoring Program [SDMMP] and The Nature Conservancy [TNC] 2017): Regional management goals include (1) maintaining or expanding occurrences to increase resilience to environmental stochasticity, (2) establishing new occurrences (if warranted), (3) maintaining genetic diversity, and (4) ensuring long-term persistence in native plant communities.

## Approach

We used a multi-scalar approach to identify and describe geographic areas that support these edaphic endemic plants and their habitats in a design that enhances population resilience and provides opportunities for shifting distributions. Locally, we refined soil and vegetation attributes. Regionally, we modeled suitable habitat under current and future climate scenarios and assessed regional population structure and threats. We used results to suggest locations for conservation, survey, management, or potential translocation opportunities. The refined understanding of plant-soil relationships may improve restoration and translocation outcomes. This work contributes to San Diego NCCP subarea plans in progress and other NCCPs.

We conducted this work under a Local Assistance Grant (LAG, P1582108-01) from the California Department of Fish and Wildlife (CDFW). Project partners include the San Diego Management and Monitoring Program (SDMMP). We have organized this report into the following sections:

- Biology, Distribution, and Threats
- Soil and Vegetation Characterization
- Habitat Suitability and Climate Change Modeling
- Regional Management
- Next Steps

We include supporting information in the following appendices:

- Target Species Biology, Distribution, and Status (Appendix A)
- Conceptual Models (Appendix B)
- Soil and Vegetation Characterization (Appendix C)

The SDMMP modeled habitat suitability for the five target species for this project, and produced a stand-alone report (Preston and Perkins in review). We provide a brief summary of findings in the Habitat Suitability and Climate Change Modeling section of this report and use current and future predicted habitat suitability models prepared by SDMMP in the regional management section of this report.

# 2 Target Species

We conducted a literature search for the five target species and SDMMP consolidated spatial data from a variety of sources, including the SDMMP Master Occurrence Matrix (MOM), California Natural Diversity Database (CNDDB), San Diego Natural History Museum (SDNHM) Plant Atlas and data from Baja, California, Consortium of Herbaria, regional rare plant Inspect and Manage (IMG) surveys, and data from Orange County, as appropriate. We used this information and spatial data to summarize species biology, threats, distribution, and estimated population sizes (Appendix A), develop or refine conceptual models (Appendix B), and guide field surveys to characterize soils and vegetation (Appendix C). SDMMP used these data to inform species-specific habitat suitability modeling under current and future climatic conditions (Preston and Perkins 2018).

In this section, we summarize biology, distribution, and threats for the target species. Refer to Appendix A for an expanded discussion. Figure 1 depicts species' distribution throughout the region, based on the compiled spatial dataset, which includes current and historic records. Table 1 lists regulatory status, covered species status, and MSP management category for the target species.

## *San Diego Thornmint*

San Diego thornmint is an annual species that is restricted to San Diego County and Baja California, Mexico (CNDDB 2013, Beauchamp 1986, SANDAG 2012). It occurs primarily on clay soils or clay lenses in chaparral, scrub, and grassland (Oberbauer and Vanderwier 1991, SANDAG 2012), although some occurrences are on gabbroic soils. There are a relatively large number of thornmint occurrences in San Diego County, particularly for a rare species, but many of these are small, fragmented, and threatened by invasive species. Appendix A lists MOM occurrences for San Diego thornmint in the county. Note that all MOM occurrences are on conserved lands.

San Diego thornmint

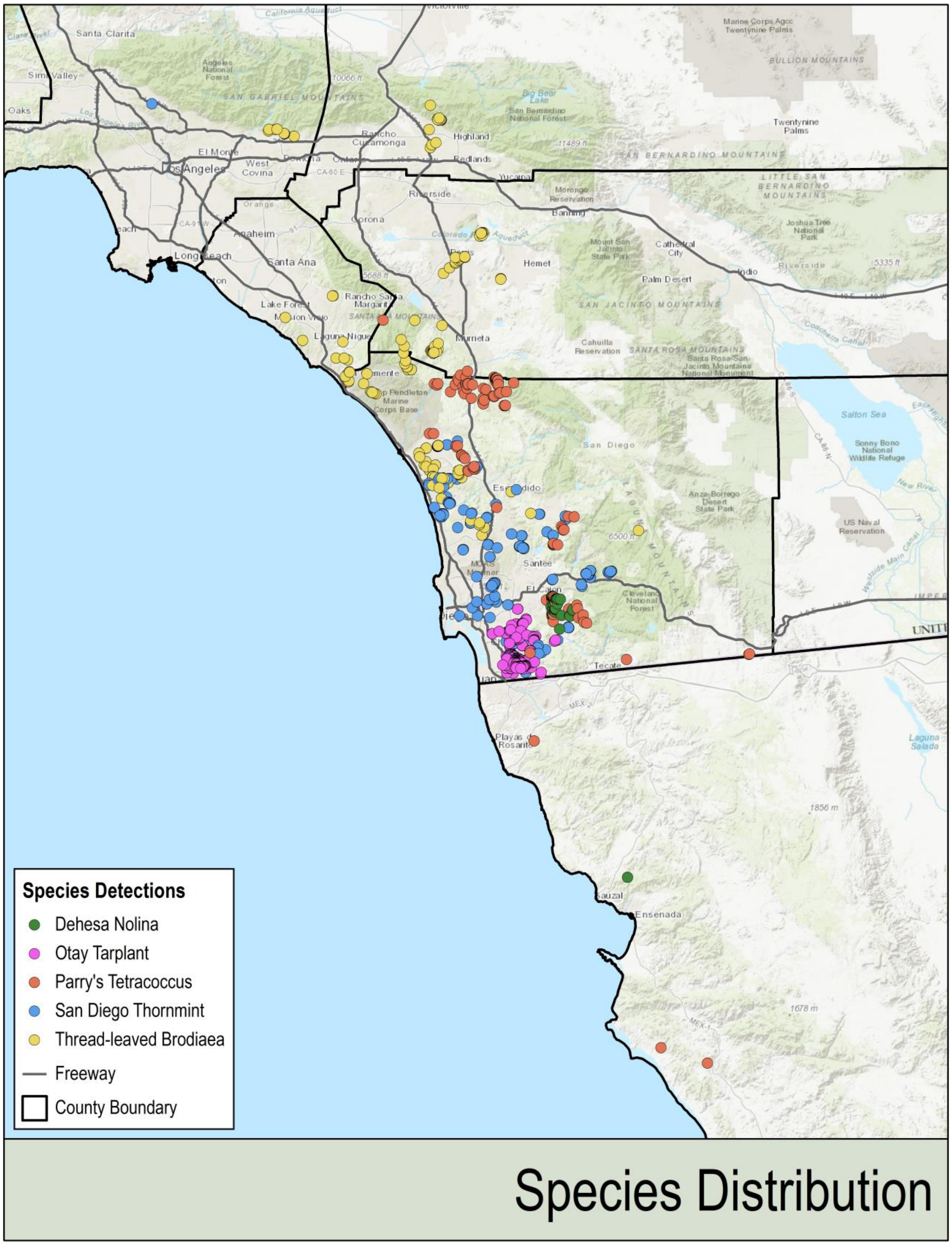


**Figure 1**. Distribution of Target Species.

**Table 1**. Target Species.

| Common Name | Scientific Name[1] | Regulatory Status[2] | NCCP[3] | MSP Management Category[4] |
|---|---|---|---|---|
| San Diego thornmint | *Acanthomintha ilicifolia* | FT/CE | MSCP<br>NCP | SO |
| Thread-leaved brodiaea | *Brodiaea filifolia* | FT/CE | MSCP<br>MHCP<br>MSHCP | SS |
| Otay tarplant | *Deinandra conjugens* | FT/CE | MSCP | SS |
| Dehesa nolina | *Nolina interrata* | ---/CE | MSCP | SO |
| Parry's tetracoccus | *Tetracoccus dioicus* | ---/--- | MSCP<br>MHCP<br>NCP | SS |

1 Plant species nomenclature generally follows Baldwin et al. 2012.
2 Regulatory Status: FT = federally threatened; CE = state endangered.
3 NCCP (Natural Community Conservation Plan): MSCP = City of San Diego Multiple Species Conservation Plan; MHCP = San Diego Multiple Habitat Conservation Plan; MSHCP = Western Riverside County MSHCP; NCP = proposed San Diego North County Plan (SDMMP and TNC 2017).
4 MSP Management Categories: SO = species with significant occurrence(s) at risk of loss from MSP area; SS = species stable but still requires species-specific management to persist in MSP area.

## *Thread-leaved Brodiaea*

Thread-leaved brodiaea is a perennial herb (geophyte) that is strongly associated with clay soils (although it occasionally occurs on non-clay alkaline soils), which restrict its potential distribution and suitable areas for restoration or transplantation (USFWS 1998, 2009, 2011). This species occurs in San Diego, Los Angeles, Orange, Riverside and San Bernardino counties.

Thread-leaved brodiaea

In San Diego County, thread-leaved brodiaea faces a number of threats, including invasive plants and habitat fragmentation, among others. Appendix A lists MOM occurrences for thread-leaved brodiaea in San Diego County.

## Otay Tarplant


Otay tarplant

Otay tarplant is a late-spring-blooming annual herb that occurs on clay soils and subsoils. This species occurs in southern San Diego County and northern Baja California. It experiences large population fluctuations based on climatic conditions (i.e., 'boom or bust' populations). Primary threats include invasive plants and habitat fragmentation. Habitat fragmentation that leads to loss of genetic diversity in the future would be of concern because Otay tarplant cannot cross-breed with genetically similar individuals. Appendix A lists MOM occurrences for Otay tarplant in San Diego County.

## Dehesa Nolina


Dehesa nolina

Dehesa nolina is a fire-adapted, clonal, perennial herb that is restricted to gabbroic or metavolcanic soils in chaparral or occasionally, coastal sage scrub or grassland habitats (Oberbauer 1979, Oberbauer and Vanderwier 1991, Beauchamp 1986, Rombouts 1996, CNPS 2012, CBI 2012, 2015, McNeal and Dice 2016). It occurs in San Diego County and northern Baja California, Mexico. Within San Diego County, this species is narrowly restricted and threatened by invasive plants (in some locations) and altered fire regimes. Appendix A lists MOM occurrences for Dehesa nolina in San Diego County.

## Parry's Tetracoccus


Parry's tetracoccus

Parry's tetracoccus is a deciduous shrub that occurs on gabbroic soils in chaparral and coastal sage scrub in Orange, Riverside, and San Diego counties, and Baja California, Mexico (CNPS 2012). In San Diego County, the species occurs sporadically in coastal foothills, but may be locally abundant (1954). We do not have complete distribution or threats data for this species, nor do we know much about the species' ecology. Appendix A lists MOM occurrences for Parry's tetracoccus in San Diego County.

# 3 Soils and Vegetation Characterization

The soils and vegetation characterization study focused on soil chemistry and physical properties of the five target species, as well as other attributes that might define occupied habitat, such as vegetation and microtopography. In this section, we provide a brief summary of the soils study; refer to Appendix C for the full soils report, which includes detailed discussions of methods, analyses, results, and recommendations, including future studies or experiments.

All five species occur on nutrient-poor soils. We recommend testing soils to identify site fertility and chemistry for variables with strong relationships to species presence before expanding, establishing, or translocating the species. Soil testing would also benefit projects to enhance or augment small occurrences by ensuring that soils are still suitable to support the target species; we could then eliminate or remediate unsuitable sites with remnant populations before investing management funds.

Field characteristics such as soil color, soil texture, microtopography, and vegetation were variable and sample sizes too small to analyze statistically. However, some patterns emerged that would help identify sites at a broad-scale for surveys or management, such as soil color and vegetation for gabbroic species.

The mechanisms underlying the patterns we present, while well informed, are nevertheless speculative. Thus, we recommend confirming causal links between soils and plants in follow-up studies. In Appendix C, we discuss species-specific studies or experiments that would further refine soil-plant relationships and test hypotheses implied by the observed patterns.

## *San Diego Thornmint*

Our study confirms that San Diego thornmint is restricted to clay soils but adds that these clays must be particularly low in sand (even relative to other clay-loving species). At a large scale, thornmint is found on clays with 60% less iron relative to the global average (all *far*[1] points across San Diego) and is much less tolerant of metals than the other clay obligates we studied. San Diego thornmint on gabbroic clays occurs in microsites with equally low metal content, even though gabbro is typically metal-rich. However, gabbro readily weathers into silt and clay (Medeiros et al. 2015). We conclude, therefore, that the occurrence of thornmint on gabbroic clays is due to the weathering properties of the parent material rather than its chemical content. Significant soil variables for thornmint include clay (42-52%), low sand (25-35%), and low metal content (3.5-6 ppm iron [Fe], 0.5-1.1 ppm copper [Cu], and 0.25-0.55 ppm zinc [Zn]).

1 At each species occurrence, we spatially matched three sampling locations (*in*, *near*, *far*) to compare soils within target species occurrences to soils nearby and far away without the target species.

Our study also concurs with reported descriptions of soil color on clay lenses but discovered that these colors were much more variable than the other species we evaluated. San Diego thornmint ranges across the largest number of colors and has the most variance in Red-Green-Blue (RGB) values compared to the other species. It has a strong association with "brown" soils.

A large proportion of thornmint observations were on fine silty clay, which has the highest clay content when measured in the laboratory. San Diego thornmint was always associated with soil cracks, but these occurred on adjacent habitat, as well. San Diego thornmint occurred most frequently in concave hollows rather than on undulating terrain. This could be because these landscape features fill up with fine grain sediment (e.g., clay) over time.

San Diego thornmint occurrences had the highest diversity of associated plants among our target species, but the lowest total (absolute) vegetation cover. The San Diego thornmint clay lenses were often smaller than the vegetation sampling area; thus, associated species included those found in and immediately adjacent to San Diego thornmint patches.

### *Thread-leaved Brodiaea*

Our data support thread-leaved brodiaea as a clay endemic and show that this species is tolerant to relatively high sodium (Na) content in clays, yet avoids alkaline soils. Instead, thread-leaved brodiaea stays within a relatively narrow pH range more typical of non-clay soils, even when more alkaline soils are available nearby. It therefore seems likely that those populations reported on "alkaline soils" (e.g., Riverside County) are actually on smaller patches of unmapped clay which, while salty, are not alkaline. If confirmed, this piece of information will dramatically improve our ability to select appropriate sites for thread-leaved brodiaea outplantings and restoration in the future.

Thread-leaved brodiaea occurred in a relatively narrow pH range that was much lower than the other clay species in this study. Soil pH controls many aspects of soil biology and chemistry, so this pattern could represent direct physiological effects of pH or various indirect effects not measured in this study. For example, pH can influence the dominant form of nitrogen (N) (ammonium vs. nitrate) and the availability of phosphorus (P) and various micronutrients, some of which are maximally available at intermediate pH levels. Significant soil variables for thread-leaved brodiaea include clay content (39-53%), pH (6.1-6.4), and Na (111-205 ppm).

Thread-leaved brodiaea occurs on a broad spectrum of colors described in the Munsell color chart, but has a strong tendency to occur on "brown" soils. It often occurs on fine clay soils. Soil cracks are always present but not independently a reliable predictor of habitat because they also occur on adjacent soils. Microtopography where this species occurs is generally undulating.

Thread-leaved brodiaea occurrences had the lowest number of associated plants among our target species. This is likely due to high nonnative grass cover, although the chemistry and texture of clays associated with thread-leaved brodiaea pose a challenge to some plants and may influence species diversity.

## *Otay Tarplant*

Prior to this study, specific adaptation of Otay tarplant to clay soils was not well-known, other than its general affinity for clay soils, subsoils, and lenses. Our data show that Otay tarplant correlates positively to clay as expected. It also has a positive relationship with Na and magnesium (Mg), which may be attributable to its preference for clay or possibly, tolerance to salt or preference for Na-smectite clay. Our data also show that Otay tarplant occurs on soils with relatively low fertility (as indicated by low levels of Zn and P) in comparison to the surrounding landscape. Drivers could be either clay's inherent properties or an ecological strategy of stress tolerance and competition avoidance.

We saw a much looser negative relationship to sand than the other clay species we examined. Further, the proportion of silt associated with Otay tarplant is less variable than it is elsewhere on the landscape. The importance and potential implications of this observation are unclear but point toward questions about physical characteristics of soils that we have not yet addressed. Significant soil variables for Otay tarplant include clay content (31-41%), Na (84-173 ppm), Zn (0.06-2.5 ppm), and P (0.06 ppm and 4-6.6 ppm as assayed by Weak Bray method).

Otay tarplant soils are variable in color, but the species has a strong tendency to occur on "brown" soils. Otay tarplant occurs primarily on fine sandy clay, which has the most sand relative to other clays. We detected cracks on the soil surface at 100% of Otay tarplant occurrences, but they also occur in a large proportion of adjacent habitat so are not independently a reliable predictor of potential habitat. Otay tarplant occurred most frequently on undulating terrain with fewer occurrences on flat or concave terrain.

The number of associated species and total cover of vegetation in Otay tarplant occurrences were intermediate between San Diego thornmint and thread-leaved brodiaea, and included both grassland and coastal sage scrub species.

## *Dehesa Nolina*

Dehesa nolina is generally restricted to gabbroic soils and clays within a small area of San Diego County and northern Baja California. Some populations occur on soil series where gabbro is not the primary parent material but an inclusion in other soil types. There are also a few populations on clay soils not derived from gabbro according to the SSURGO soils data set, which is spatially coarse and often inaccurate at finer scales relevant to plants. We sampled soils from parental material identified in SSURGO as both gabbroic and non-gabbroic.

Our data indicate that clay content does not significantly influence Dehesa nolina at the scale of our study. However, clay strongly influences pH and calcium (Ca), which were the two most significant factors associated with Dehesa nolina. The pH might drive the relatively high boron (B), high Ca, and low manganese (Mn) concentrations associated with this species (or vice versa). Logistic regression indicated that Ca was the strongest predictor of Dehesa nolina presence even when pH was included in the model. The gabbro sites in this study had relatively low Ca concentrations compared to a global average across all our *far* points, so the significantly higher Ca associated with Dehesa nolina could indicate selection for Ca-rich microsites within a generally Ca-depleted landscape.

Dehesa nolina also shows an interesting spatial relationship with Cu, occurring on soils with low Cu levels that appear embedded inside areas of locally high Cu. Gabbro soils are similar in some respects to serpentine soils, which select for endemic plant species by a combination of low fertility and high concentrations of toxic metals. Gabbro can be relatively rich in Cu (Medeiros et al. 2015), so this species may require microsites within gabbroic soils with low Cu levels. Alternatively, this species may remediate Cu levels by bioaccumulation, as some serpentine soil endemics hyper-accumulate nickel (Ni).

While these data do not clearly address the factors of gabbro soils that lead to endemism in Dehesa nolina, they do suggest local conditions that this species may require within this broader soil type. Significant soil variables for Dehesa nolina include pH (6.1-6.6), Ca (1200-1900 ppm), and Cu (0.4-1.1 ppm).

Dehesa nolina has a strong tendency to occur on “brown” soils, but also occurs on red or yellow soils and never on gray soils. It occurs most frequently on moderately fine sandy clay loam or fine sandy clay, and shows no association with cracks on the soil surface. We found this species on all topographies except flat microsites.

Shrub diversity and total vegetation cover was relatively high at Dehesa nolina occurrences. In fact, native shrub richness was the strongest predictor of Dehesa nolina, followed by the presence of Parry’s tetracoccus. Species associated with nolina and tetracoccus represent a distinct assemblage associated with gabbro soils in southern San Diego County.

## Parry's Tetracoccus

Parry's tetracoccus shares similar soil characteristics with Dehesa nolina, but its relationship to those characteristics is quite different. For example, while Dehesa nolina appears to "avoid" Cu, Parry's tetracoccus occurs on a wide range of Cu concentrations. Parry's tetracoccus also occurs on soils containing more Fe and Zn than the surrounding area. These patterns are subtle, and given their moderate concentrations, probably do not directly represent the importance of these elements as either nutrients or toxins. However, they may be indicators of other associated metals not measured in this study. Parry's tetracoccus may therefore be avoiding competition with other plants by tolerating metals in a metal-rich environment. Significant soil variables for Parry's tetracoccus include Fe (8-15 ppm), Zn (1.2-2.1 ppm), and Cu (0.4-0.7 ppm).

Parry's tetracoccus has a strong tendency to occur on "brown" soils, but also occurs on red or yellow soils and never on gray soils. It occurs most frequently on moderately fine sandy clay loam or fine sandy clay, and shows no association with cracks on the soil surface. We found this species on all topographies except flat microsites

Parry's tetracoccus occurrences had the highest total vegetation cover of the target species (average = 116%). This was substantially higher than cover at Dehesa nolina occurrences (76%) despite the close spatial association of these two species. In some areas, these two species occur within a few feet of each other. Associated shrub diversity was also relatively high. Parry's tetracoccus and Dehesa nolina often co-occur and are good predictors of one another where their ranges overlap.

# 4 Habitat Suitability and Climate Change Modeling

The United States Geological Survey (USGS) and San Diego Management and Monitoring Program (SDMMP) developed habitat suitability models for the five target species under current and future environmental conditions in southern California. They prepared a stand-alone report that includes a full discussion of modeling methods, results, and conclusions (Preston and Perkins in review).

A range of current condition habitat models were constructed for each species reflecting alternative hypotheses about habitat relationships based upon climate, topography, and soils. A single model was selected for each species to characterize currently occupied habitat (current conditions, 1981-2010). We used current conditions models to develop regional population structures (Section 5.0) and management recommendations under current conditions (Section 6.0). These models also provided the basis for predicting future suitable habitat based upon climate variables derived from a collection of global climate models. These global climate models predict future temperature and precipitation patterns for three time periods (2010-2039, 2040-2069, and 2070-2099) and different greenhouse gas emission scenarios (low, intermediate, high). We used the future conditions models to identify management recommendations under future conditions (Section 6.0).

Future conditions models showed that all five species declined in predicted suitable habitat under future climate scenarios, even though they currently occur in warmer and drier conditions within the study area (Preston and Perkins in review). We summarize results and present cumulative models maps for three timeframes, using the emissions scenario with the best results for each species.

## *San Diego Thornmint*

San Diego thornmint habitat suitability declines under all emission scenarios for all future time periods, although there are differences between models with respect to predictions (Preston and Perkins in review). For the high emission scenario (Representative Concentration Pathway [RCP] 8.5), 62% of current suitable habitat remains in 2010-2039, with large reductions in suitable habitat in the next two time periods.

For the high emissions scenario, predicted suitable habitat persists in San Diego County in coastal and inland valleys in 2010-2039, contracts in 2040-2069, and moves to higher elevations in the mountains in 2070-2099 (Figures 2a-c). Beyond San Diego County, existing habitat persists in Orange and Ventura counties in 2010-2039. It contracts in those areas in 2040-2069,

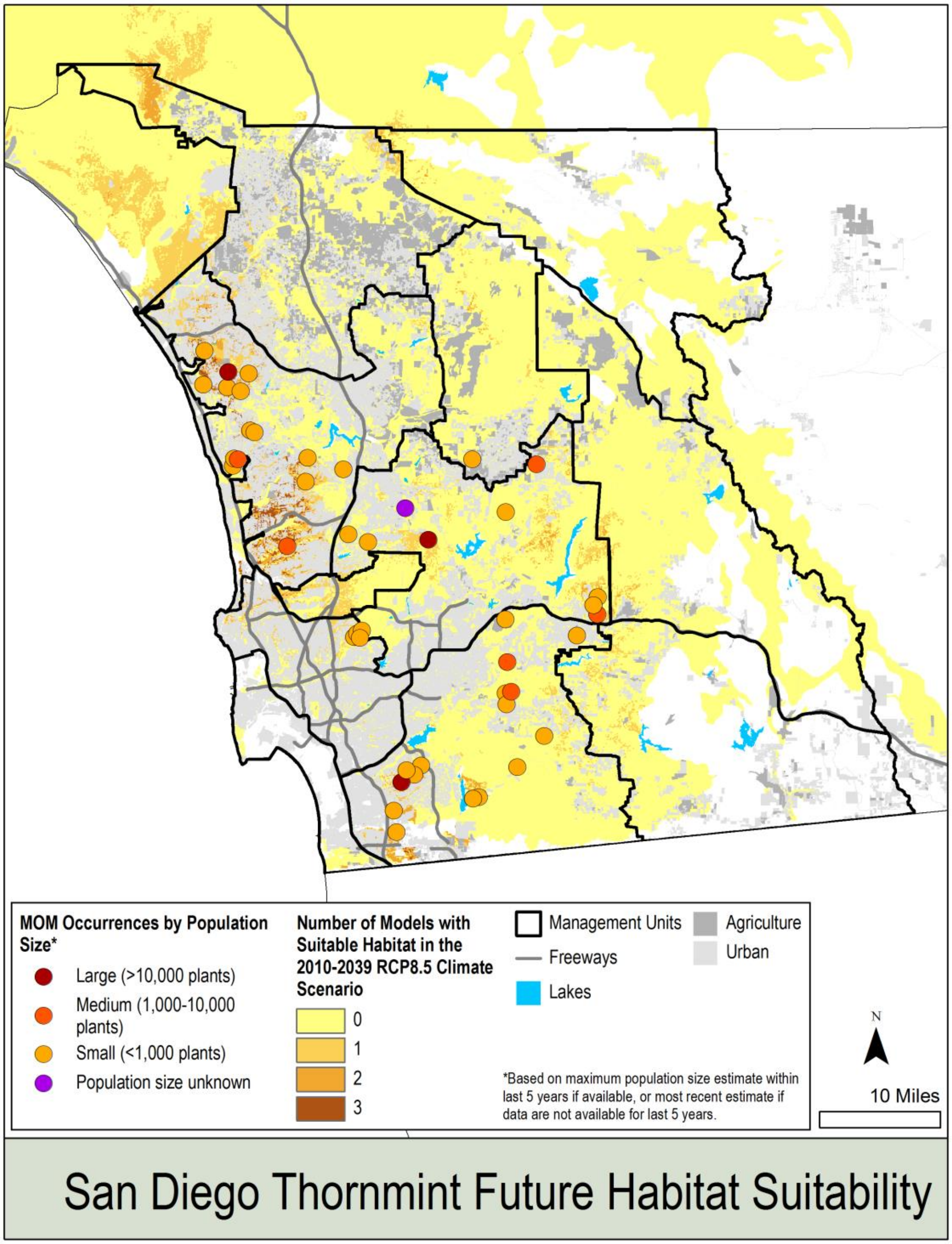


**Figure 2a**. San Diego Thornmint, Habitat Conditions under Future Climate Scenarios. Cumulative models maps, high emissions scenario (RCP 8.5), time period 2010-2039.

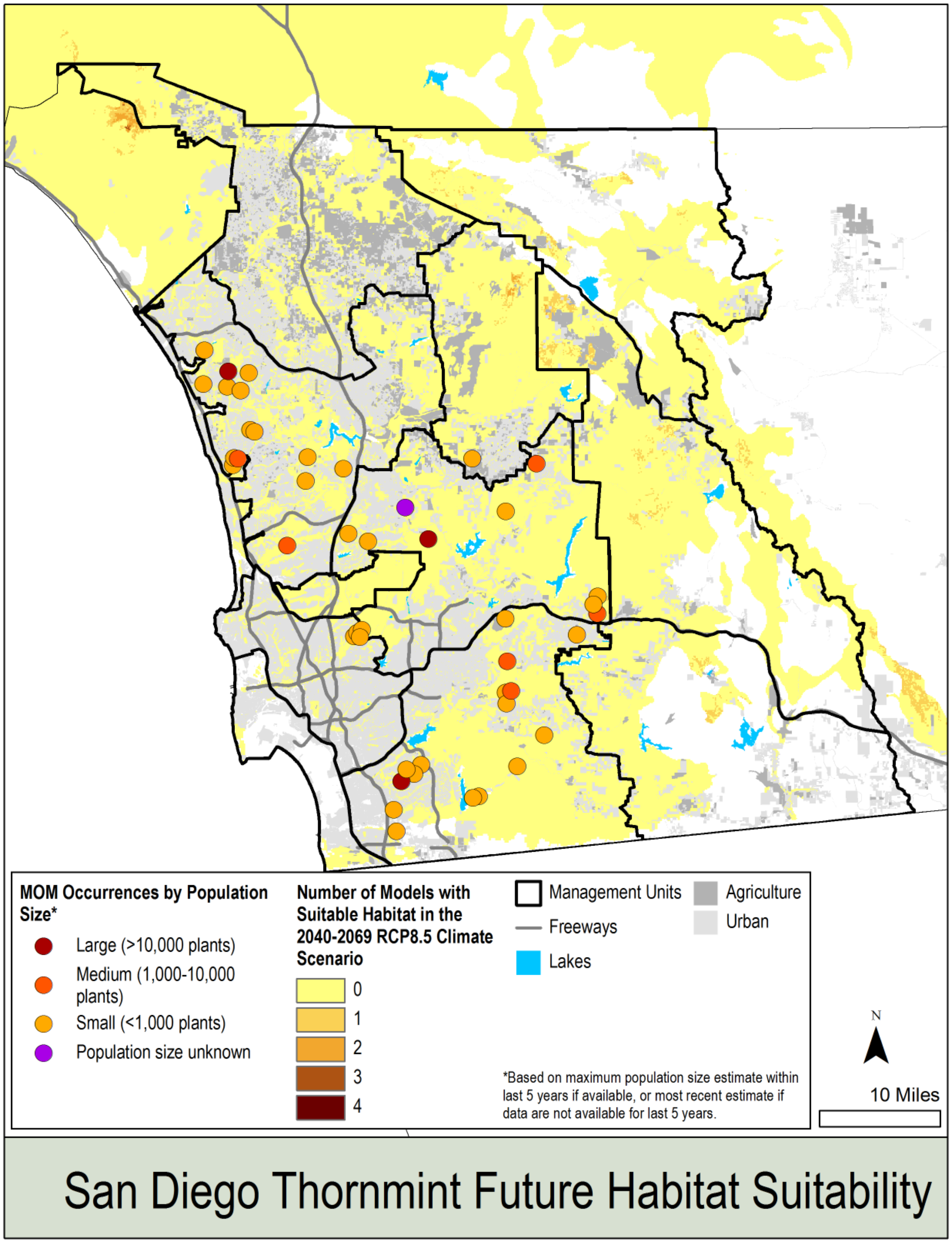


**Figure 2b**. San Diego Thornmint, Habitat Conditions under Future Climate Scenarios. Cumulative models maps, high emissions scenario (RCP 8.5, time period 2040-2069.

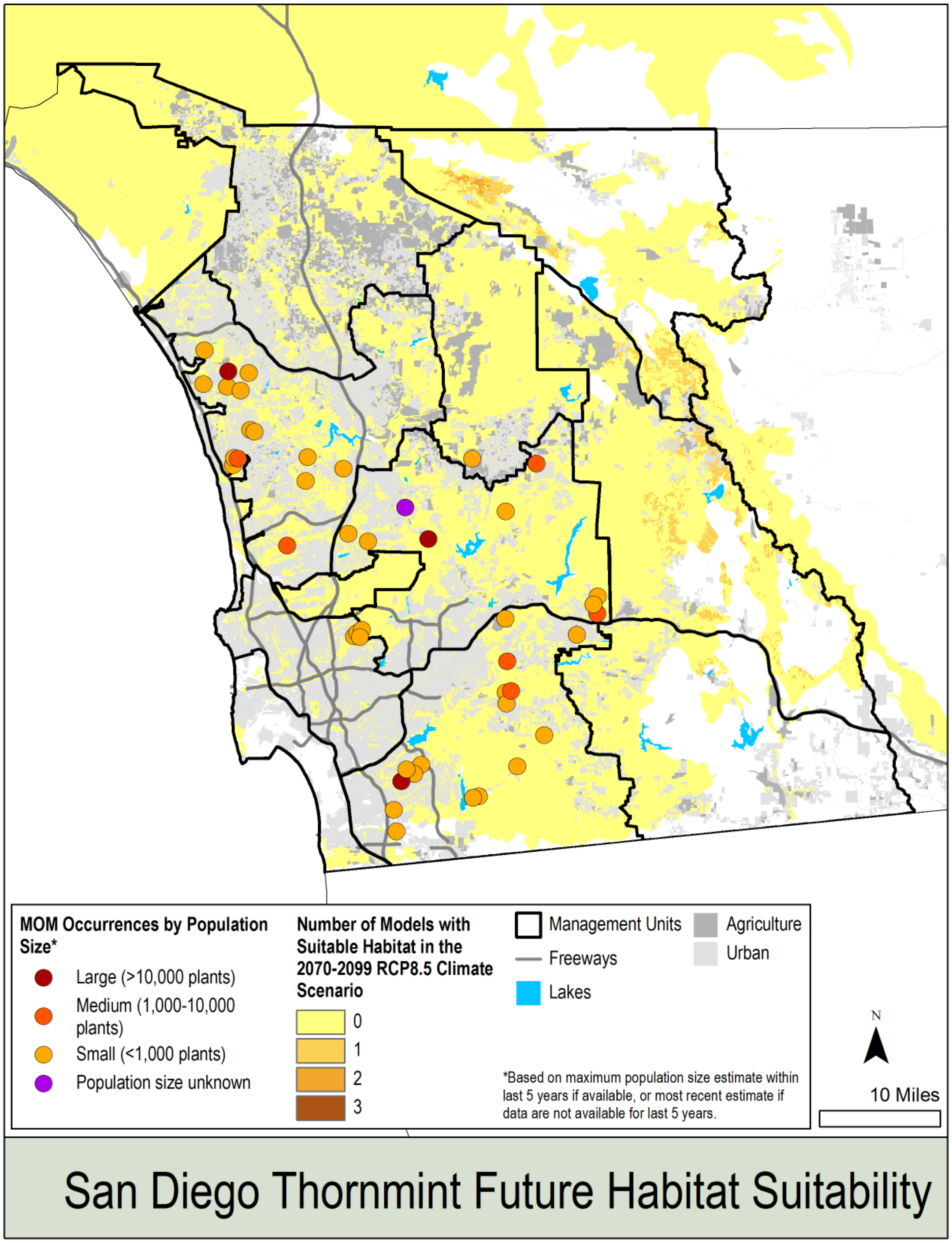


**Figure 2c**. San Diego Thornmint, Habitat Conditions under Future Climate Scenarios. Cumulative models maps, high emissions scenario (RCP 8.5), time period 2070-2099.

and expands along the Santa Barbara coastline and into the San Gabriel Mountains. In 2070-2099, small patches of suitable habitat persist in eastern Ventura County in 2070-2099, while new habitat occurs at higher elevations in the mountains northeast of Santa Barbara and into the San Gabriel Mountains (see Preston and Perkins in review).

## *Thread-leaved Brodiaea*

Thread-leaved brodiaea habitat predictions under future climate scenarios indicate no suitable habitat under medium and high emission scenarios in the future, and only a small amount of suitable habitat in the lowest emission scenario (RCP 2.6) for the last two time periods only (Preston and Perkins in review).

Under the low emissions scenario, there are small patches of habitat in Riverside County, but no suitable habitat in San Diego County in 2040-2069 (Figures 3a-b). For 2070-2099, there are very small patches of habitat in San Diego County (Carlsbad, southeast of San Vicente Reservoir, southwest of Capitan Grande Reservoir, and east of Jamul), and a small amount of habitat in Riverside County (see Preston and Perkins in review).

## *Otay Tarplant*

There is no suitable habitat predicted for Otay tarplant under any of the global climate models, emission scenarios, or time periods (Preston and Perkins in review). This underscores the need to build resilience into the current regional population structure.

## *Dehesa Nolina*

The amount of suitable habitat predicted for Dehesa nolina is small under both current and future climate scenarios. For future scenarios, the amount of habitat declines for the three emission scenarios over time. For the high emission scenario (RCP 8.5), the cumulative models map shows 89% of current suitable habitat remaining in 2010-2039, which decreases to 26% by 2070-2099 (Preston and Perkins in review).

For 2010-2039, the high emissions scenario predicts small areas of suitable habitat north, east, and even west of the current distribution in San Diego County. In 2040-2069, habitat contracts to mountain peaks to the east and far northern portion of the county and this pattern continues with some spatial differences in 2070-2099 (Figures 4a-c). Beyond San Diego County, the most consistent areas of suitable habitat include the southern Santa Ana Mountains and the northern San Gabriel Mountains in Orange and Los Angeles counties, respectively (see Preston and Perkins in review).

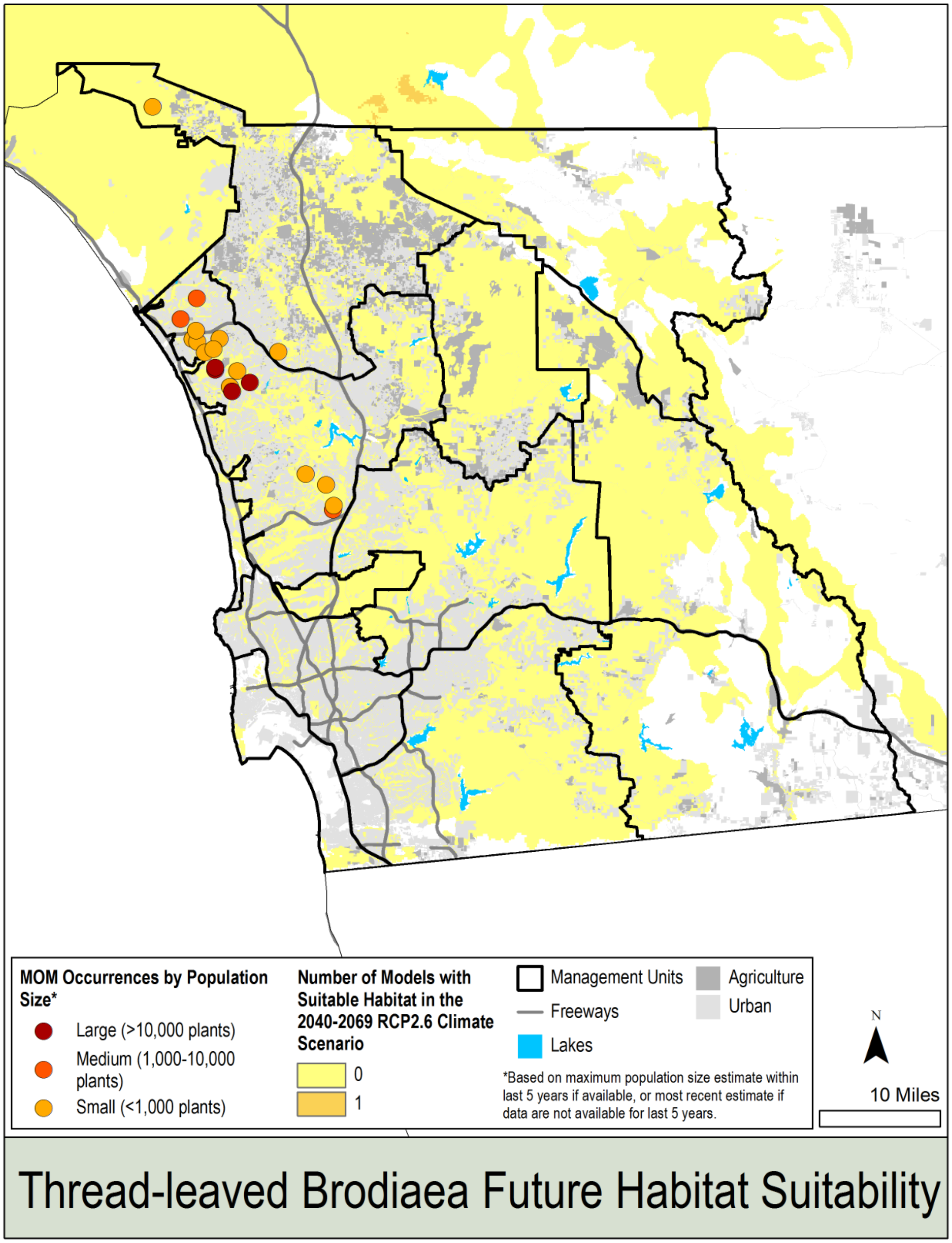


**Figure 3a**. Thread-leaved Brodiaea, Habitat Conditions under Future Climate Scenarios. Cumulative models maps, high emissions scenario (RCP 2.6), time period 2040-2069.

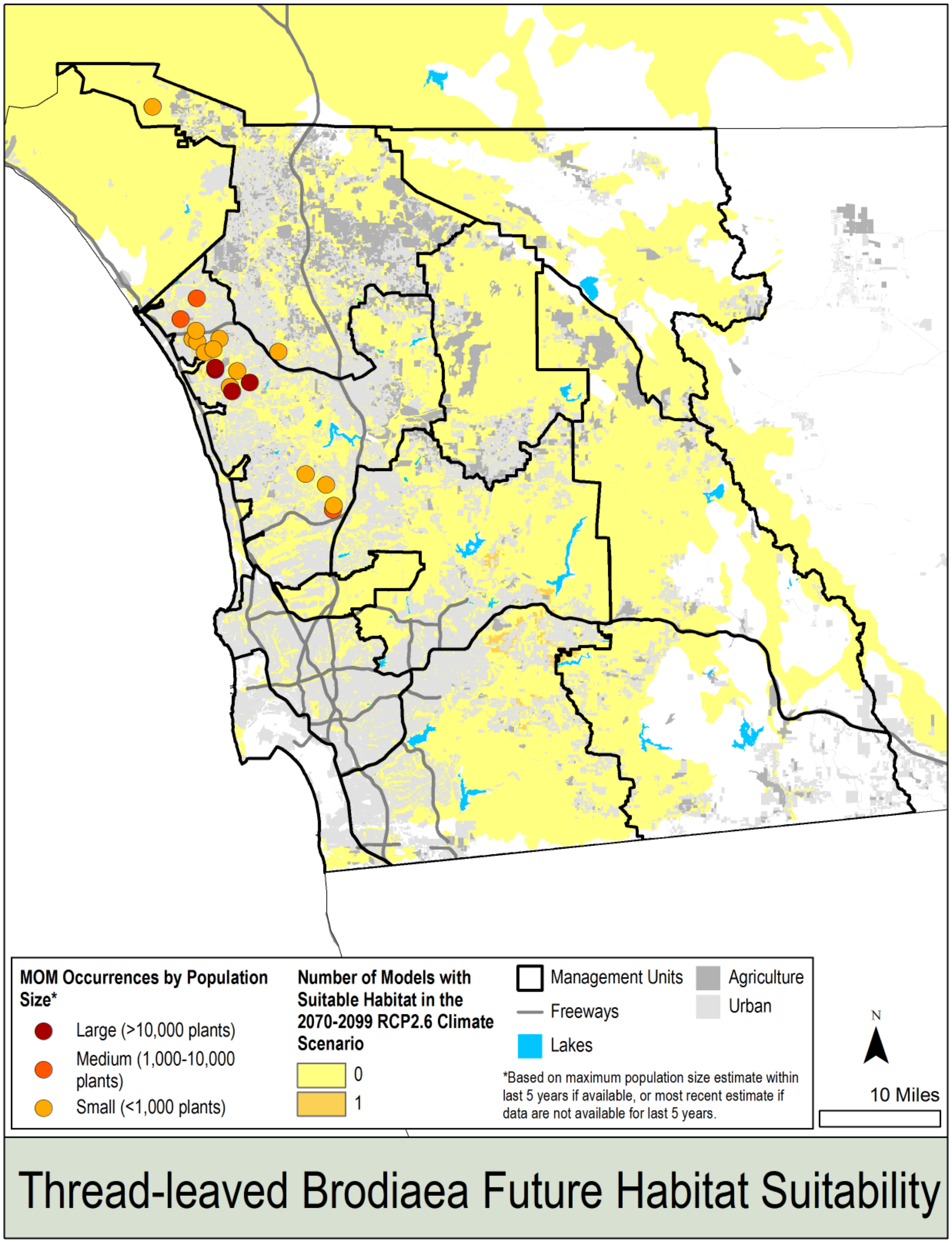


**Figure 3b**. Thread-leaved Brodiaea, Habitat Conditions under Future Climate Scenarios. Cumulative models maps, high emissions scenario (RCP 2.6), time period 2070-2099.

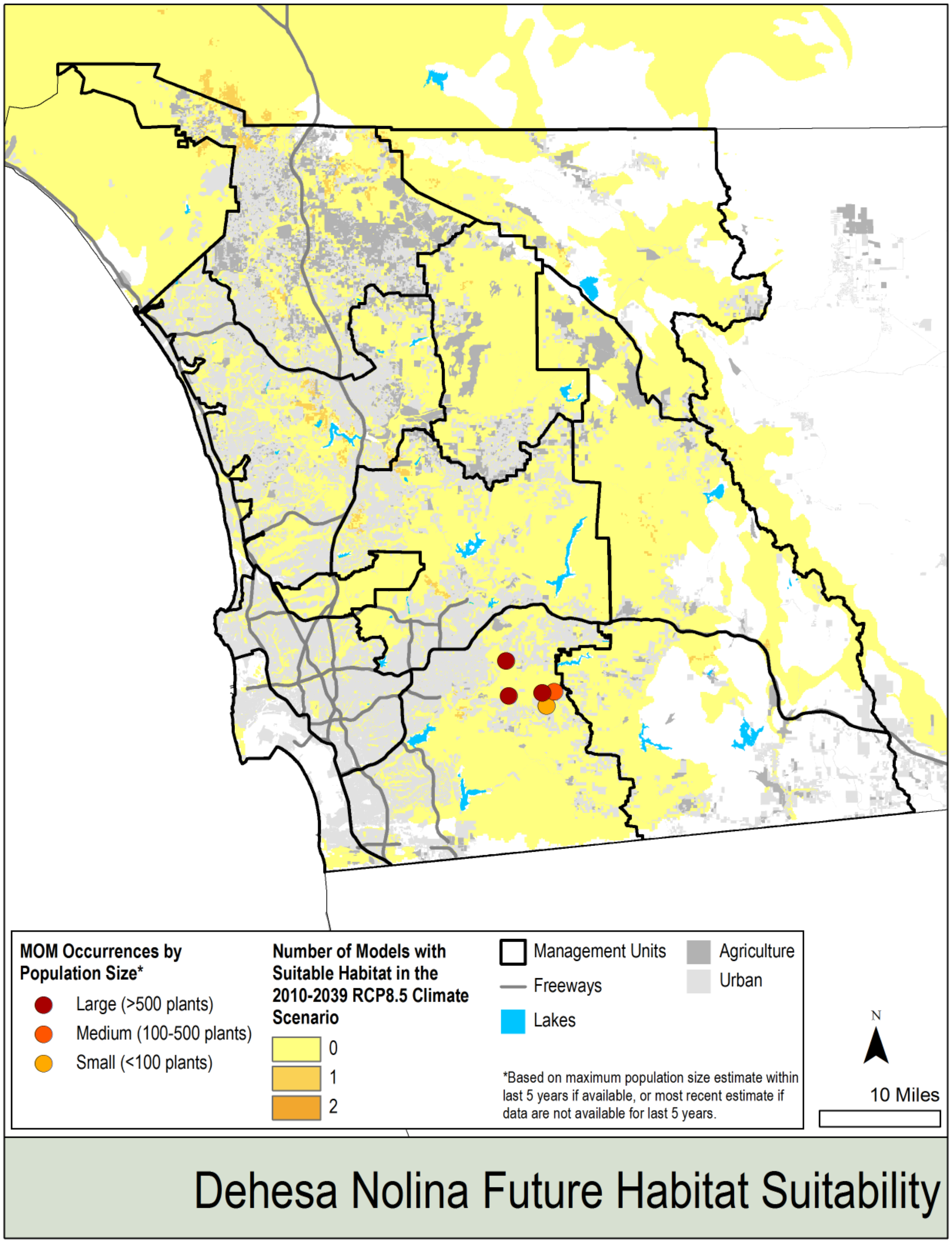


**Figure 4a**. Dehesa Nolina, Habitat Conditions under Future Climate Scenarios. Cumulative models maps, high emissions scenario (RCP 8.5), time period 2010-2039.

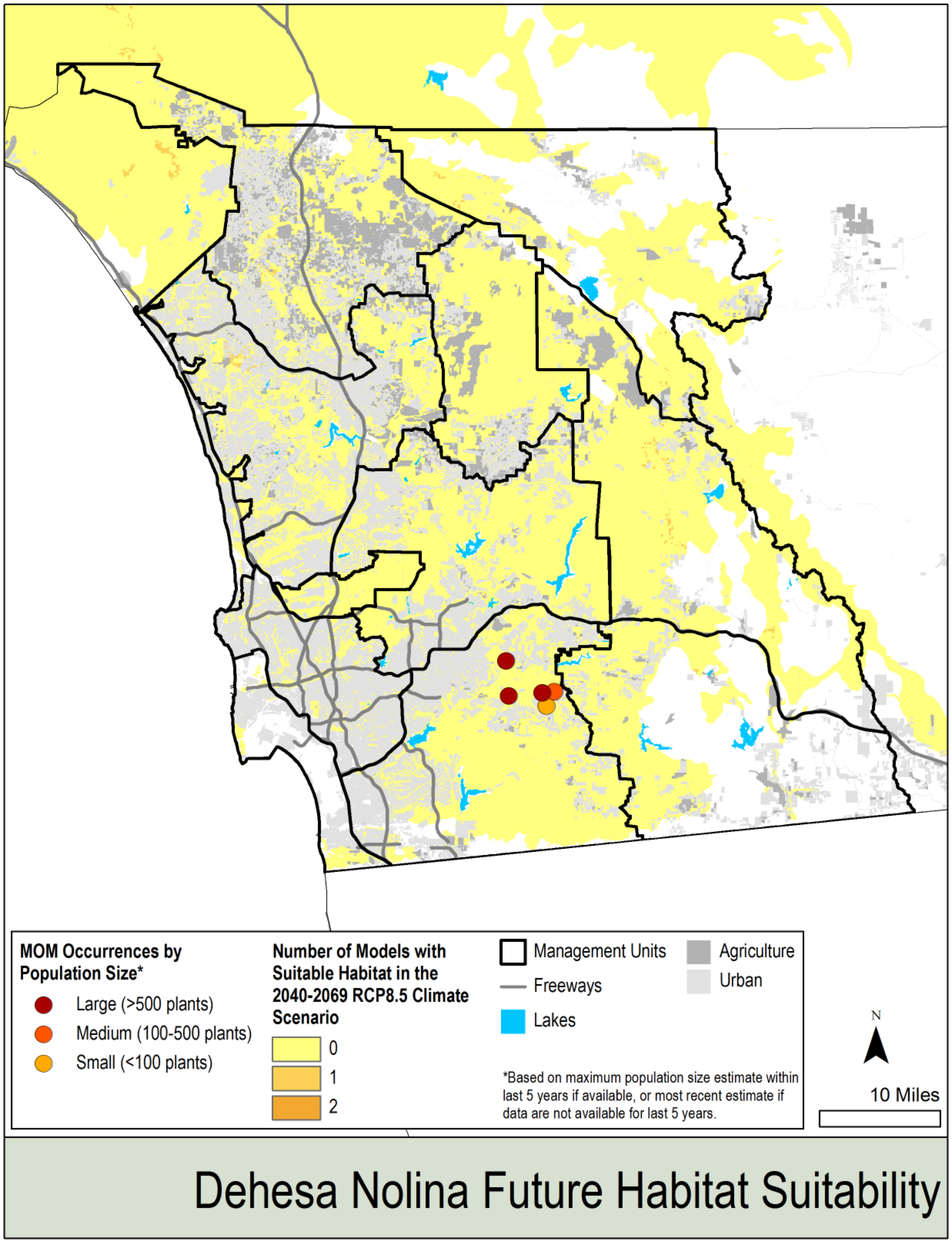


**Figure 4b**. Dehesa Nolina, Habitat Conditions under Future Climate Scenarios. Cumulative models maps, high emissions scenario (RCP 8.5), time period 2040-2069.

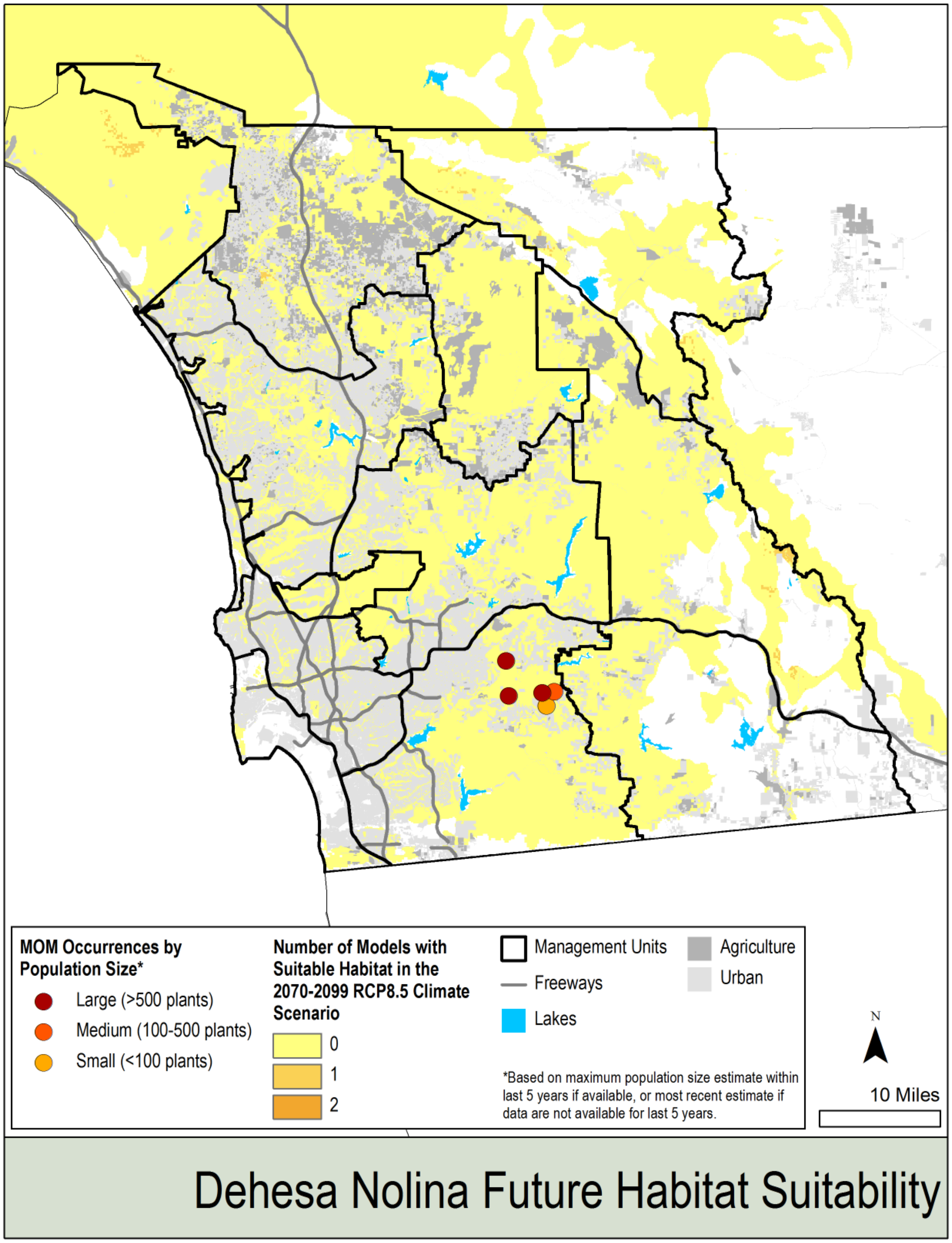


**Figure 4c**. Dehesa Nolina, Habitat Conditions under Future Climate Scenarios. Cumulative models maps, high emissions scenario (RCP 8.5), time period 2070-2099.

## Parry's Tetracoccus

For Parry's tetracoccus, all emission scenarios predict future suitable habitat in all time periods; however, the high emissions scenario (RCP 8.5) predicts more suitable habitat than the lower emission scenarios. Under the high emissions scenario, the first two time periods (2010-2039 and 2040-2069) provide similar estimates of predicted habitat, while the last time period (2070-2099) shows somewhat declining habitat. In general, suitable habitat persists in the coastal valleys and foothills and expands into the mountains of San Diego County during all three time periods, while contracting at existing occurrences (Figure 5). Outside San Diego County, suitable habitat persists in the Santa Ana Mountains and east of Ventura and Santa Clarita, and new areas of suitable habitat occur in the San Gabriel Mountains, along the Santa Barbara coastline, and in the mountains of Riverside County (see Preston and Perkins in review).

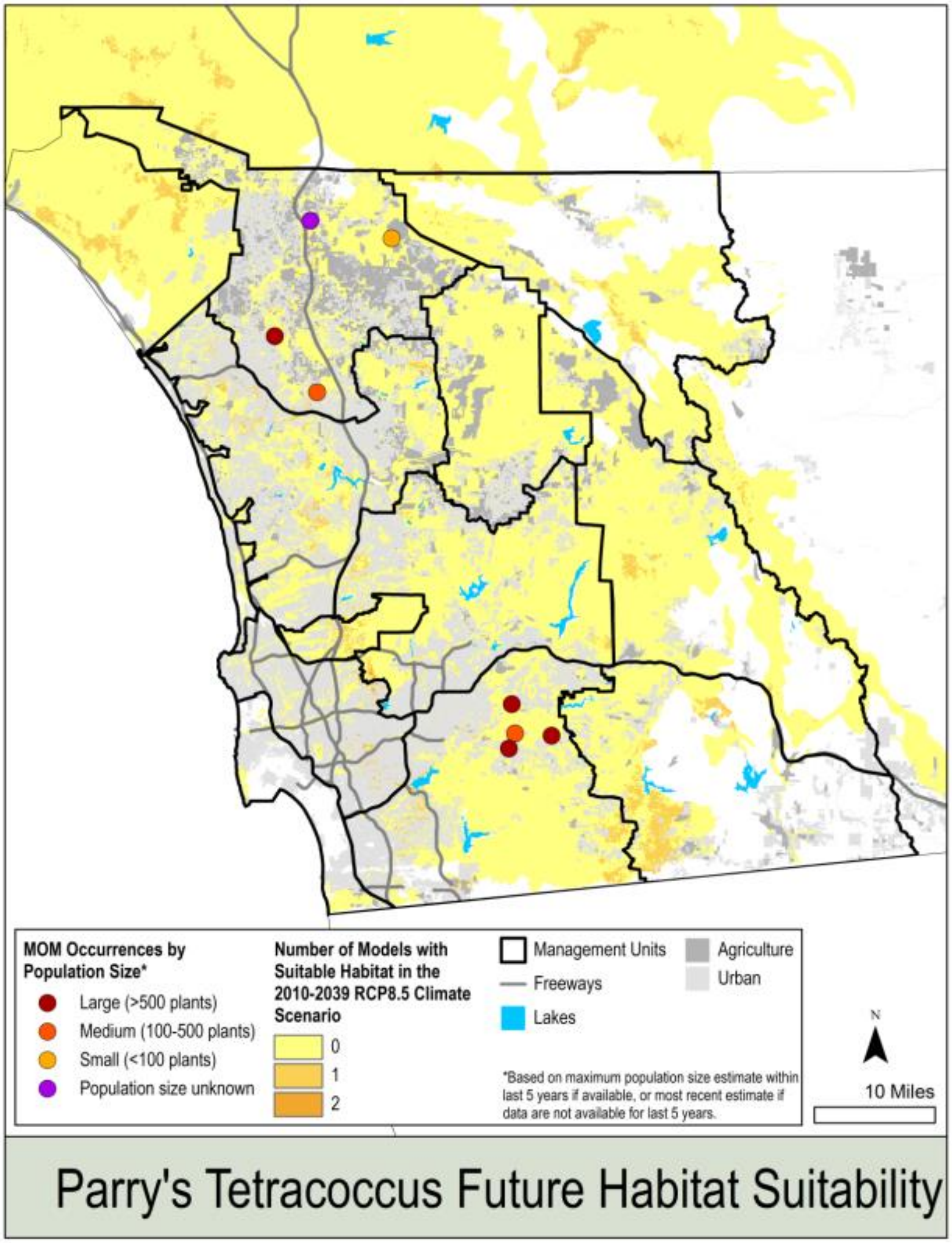


**Figure 5a**. Parry's Tetracoccus, Habitat Conditions under Future Climate Scenarios. Cumulative models maps, high emissions scenario (RCP 8.5), time period 2010-2039.

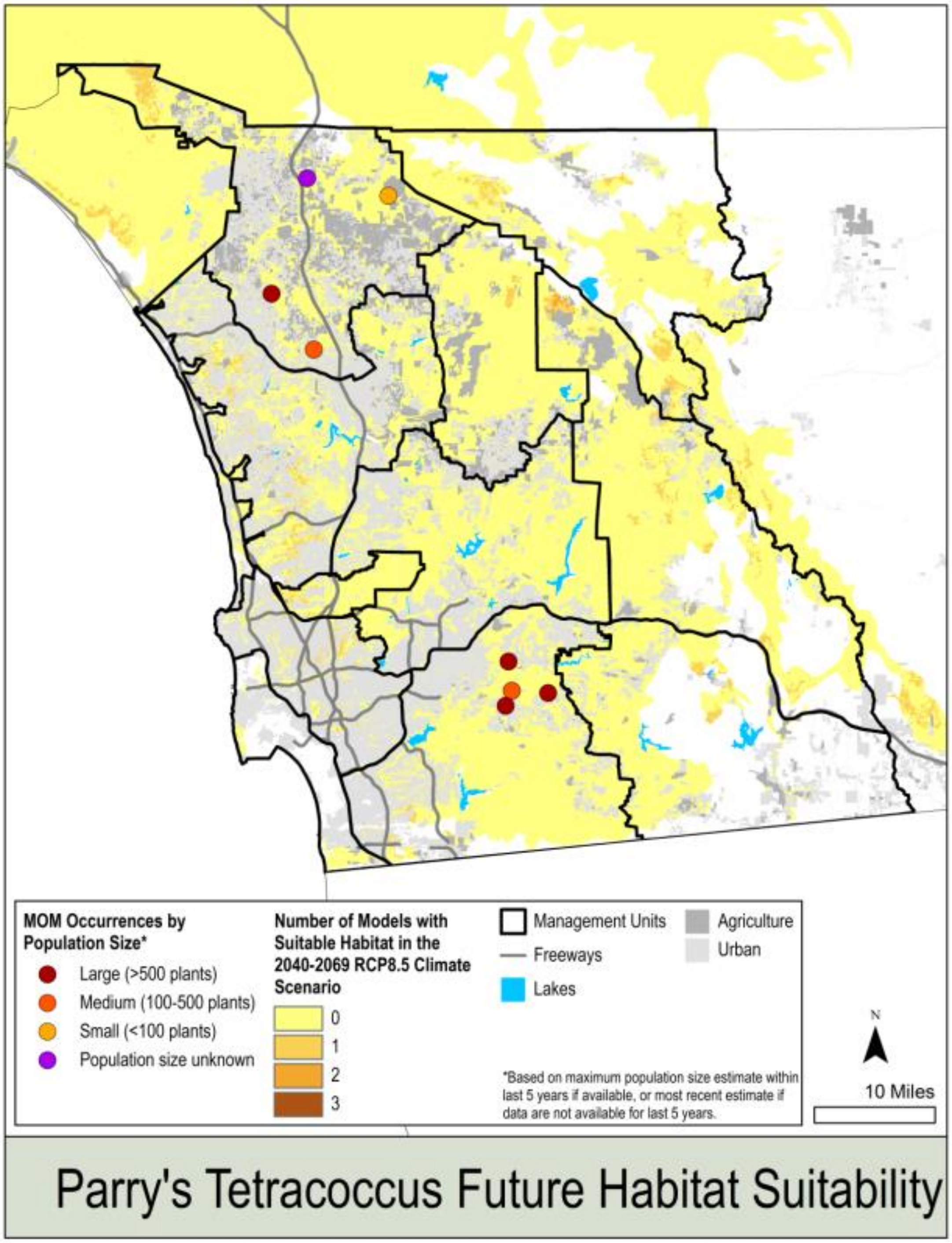


**Figure 5b**. Parry's Tetracoccus, Habitat Conditions under Future Climate Scenarios. Cumulative models maps, high emissions scenario (RCP 8.5), time period 2040-2069.

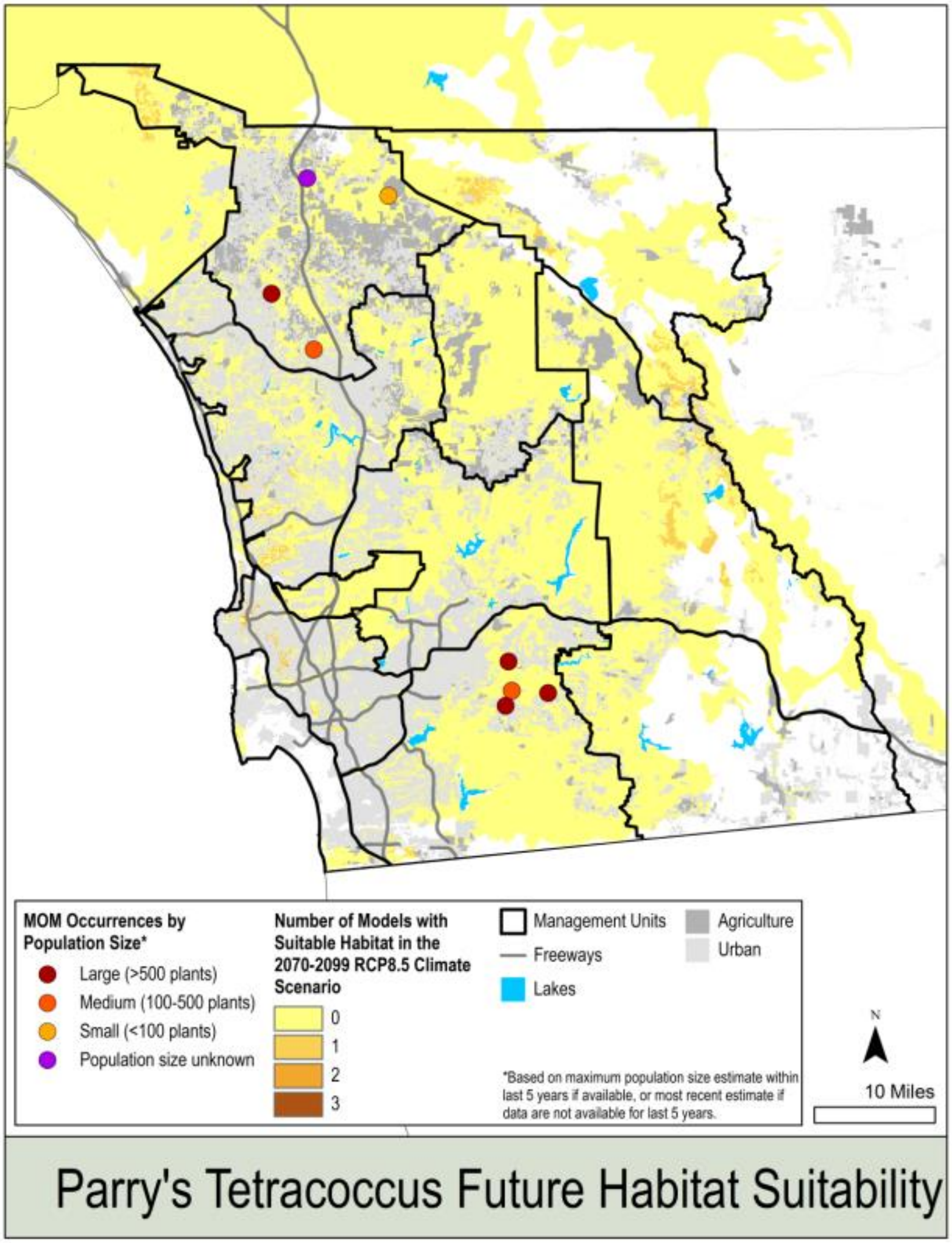


**Figure 5c**. Parry's Tetracoccus, Habitat Conditions under Future Climate Scenarios. Cumulative models maps, high emissions scenario (RCP 8.5), time period 2070-2099.

# Regional Population Structure

We refer to the distribution of a species across the landscape, the relationship between populations of that species, and the proximity of existing populations to suitable habitat for expansion or migration in the context of climate change as *regional population structure*. Within this structure, we can identify populations or population groups important to the long-term resilience of a species based on size, condition, location, or other factors.

We developed regional population structures for each target species using distribution data, habitat suitability models, genetic principles, and in some cases, genetic data. In the absence of genetic studies or historical data regarding past relationships, we base these structures on a number of assumptions (e.g., Menges 1991, Ellstrand and Elam 1993, Kolb 2008):

- Small populations are more susceptible to extirpation than large populations, especially those with recent reductions in population size.
- Small population size reduces reproductive success, particularly in fragmented landscapes.
- Relatively low levels of gene flow may be sufficient to offset effects of genetic drift in small populations.
- Small populations are more likely to receive gene flow from large populations than from other small ones, even if the latter are closer.

## Size Class Distribution

For annual plants, in particular, population size can provide an indication of a species' potential to persist under changing conditions. Large populations are generally more resilient to stochastic events and natural catastrophes, and less affected by demographic and genetic stochasticity than small populations (Menges 1991 and others). While there is debate in the literature regarding the use and validity of a set population size as a conservation target, there is consensus that larger populations are more resistant to extinction or extirpation than smaller populations (e.g., Flather et al.2007, Traill et al. 2010, Brook et al. 2011, Flather et al. 2011, Jamison and Allendorf 2012). Estimates of total population size necessary to buffer against environmental stochasticity range from $10^3$-$10^6$ plants (Shaffer 1987 and others), while estimates of *effective* population size range from 5-30% of the total population size (see Espeland and Rice 2010). The presence of a seed (or corm) bank further confounds assessments of population size (Nunney 2002).

Regardless of guidelines on total and effective population sizes, many rare plants persist in small populations, and it is important to consider both published guidelines and available census data in categorizing populations based on size. Some of our target species clearly have the potential to exist in large populations under certain conditions and form persistent seed banks, while others occur only in relatively small numbers, even in intact habitat.

With these factors in mind, we stratified occurrences of the target species into population size classes to assess their potential for long-term resilience (Table 2).

**Table 2**. Population Size Classes.

| Target Species | Life form | Population Size Class[1] | | |
|---|---|---|---|---|
| | | Large | Medium | Small |
| San Diego thornmint | Annual | >10,000 | 1,000-10,000 | <1,000 |
| Thread-leaved brodiaea | Perennial Herb[2] | >10,000 | 1,000-10,000 | <1,000 |
| Otay tarplant | Annual | >10,000 | 1,000-10,000 | <1,000 |
| Dehesa nolina | Perennial Herb[3] | >500 | 100-500 | <100 |
| Parry's tetracoccus | Shrub | >500 | 100-500 | <100 |

[1] Numbers represent estimated number of above-ground individuals or, for Dehesa nolina, number of clusters.
[2] Thread-leaved brodiaea is a geophyte.
[3] Some sources consider Dehesa nolina a subshrub.

For each occurrence, we based the size class on the maximum number of plants observed in the last 5-year monitoring period (2012-2017). Where no monitoring occurred within that timeframe, we used the most recent monitoring data available, which was often 10-15 years old. Refer to Appendix A for population size estimates for MOM occurrences in this study, based on monitoring data. For a species that experiences wide population fluctuations, maximum number may provide an indication of potential carrying capacity. We recognize that some occurrences may no longer have the ability to reach this potential, based on threats and site history. Nonetheless, population potential may be an important consideration in setting management priorities, particularly where threats are controlled.

We present hypothesized regional population structures for the five target species, based on underlying assumptions and available data. We recommend refining structures as data gaps are filled and genetic studies completed. To delineate population structures, we focused on occurrences in the MOM database, which are on conserved lands. Within population group boundaries, however, we included additional, unconserved areas where there are records for the target species and potential habitat still exists. We show regional population structures on maps with predicted suitable habitat under current conditions, as modeled by SDMMP (Preston and Perkins in review). We also consider population groups within Management Units (MUs), as descripted in the MSP Roadmap (SDMMP and TNC 2017).

## Habitat Connectivity

Connectivity is the degree to which the landscape facilitates or impedes movement among resource patches (Taylor et al. 2006). Connectivity of natural open space is widely regarded as essential to maintaining functional landscapes and evolutionary processes (e.g., Noss 1987, 1991, Saunders et al. 1991, Beier and Noss 1998). For plants, habitat connectivity allows for movement of pollinators and possibly, dispersal agents between populations; thus, facilitating gene flow. Habitat connectivity may also provide opportunities for species expansion or migration under existing conditions and in response to climate change (Primack 1996, Anacker et al. 2013).

Within the MSPA, gaps in connectivity are most apparent in urbanized areas as a result of habitat loss and fragmentation. In these areas, some populations that were connected historically are separated completely now or divided into subpopulations. Smaller population size and an increase in edge effects may affect population persistence over time. The challenge will be to enhance population resilience by increasing population size and/or creating or maintaining gene flow, possibly through steppingstones occurrences or pollinator habitat in gap areas.

Potential gaps in connectivity may also occur where there are large distances between populations. Where isolated populations appear stable with suitable intervening habitat, gaps may approximate historic conditions in terms of gene flow and may not require efforts to improve connectivity, although surveys of intervening habitat could inform future management. Isolated populations that are small or declining may benefit by establishing occurrences within gap areas. For endemic species, however, gap areas may not support suitable soils

We identified potential gaps within and between population groups that might be important to maintain or strengthen regional population structure. Additional surveys and genetic studies would determine whether these gaps pose a threat to population persistence. Gaps within population groups occur within population group boundaries, as designated on Figures 6-10, while gaps between groups occur on high suitability habitat between (not within) these groups. High suitability habitat corresponds to a habitat suitability index of 0.75-1 (Figures 6-10, Preston and Perkins in review).

# Target Species

## San Diego Thornmint

### Size Class Distribution

San Diego thornmint occurs in MUs 2, 3, 4, 5, and 6 of the MSPA, with 46 occurrences on conserved lands (Table 3). Only 3 of the 46 occurrences (7%) are large, while 7 are medium (15%) and 36 are small (78%; Table 3). Recent monitoring data were not available for 10 of 46 occurrences (22%), so we used data from the last known monitoring period to assign size class. Although this method is imprecise, it highlights the need for comprehensive monitoring data.

**Table 3**. San Diego Thornmint Size Class Distribution.

| Management Unit | Occurrence Size Class[1] | | | Total |
|---|---|---|---|---|
| | Large | Medium | Small | |
| 2 | 0 | 0 | 2 | 2 |
| 3 | 1 | 4 | 10 | 15 |
| 4 | 1 | 2 | 10 | 13 |
| 5 | 0 | 0 | 1 | 1 |
| 6 | 1 | 1 | 13 | 15 |
| Total | 3 | 7 | 36 | 46 |

[1] Refer to text for description of size classes. Size estimate is based on monitoring data within the last 5 year or, if not available, the last known size estimate data.

All populations with historic and current population size estimates had smaller population sizes in 2017 than their recorded maximum size, although we do not know if this is due to environmental variables or other factors. Of the small occurrences, 16 had no plants in their last monitoring period, and 9 had fewer than 25 plants. In other words, 25 occurrences (69% of all conserved thornmint occurrences) had fewer than 25 plants during their last monitoring period.

In delineating regional population structure, we identified 17 population groups that include 44 occurrences (Figure 6, Table 4). This refines an earlier regional population structure developed for San Diego thornmint (CBI 2014). We describe population groups in Appendix A.

### Habitat Connectivity

Habitat fragmentation and loss of connectivity is a particular concern for population groups in the north and west portions of the MSPA, where gaps occur within and between groups (Figure 6). While a network of conserved lands connects many population groups (at least tenuously), Population Groups 4, 6, and 10 are isolated and likely to remain so because there is little suitable

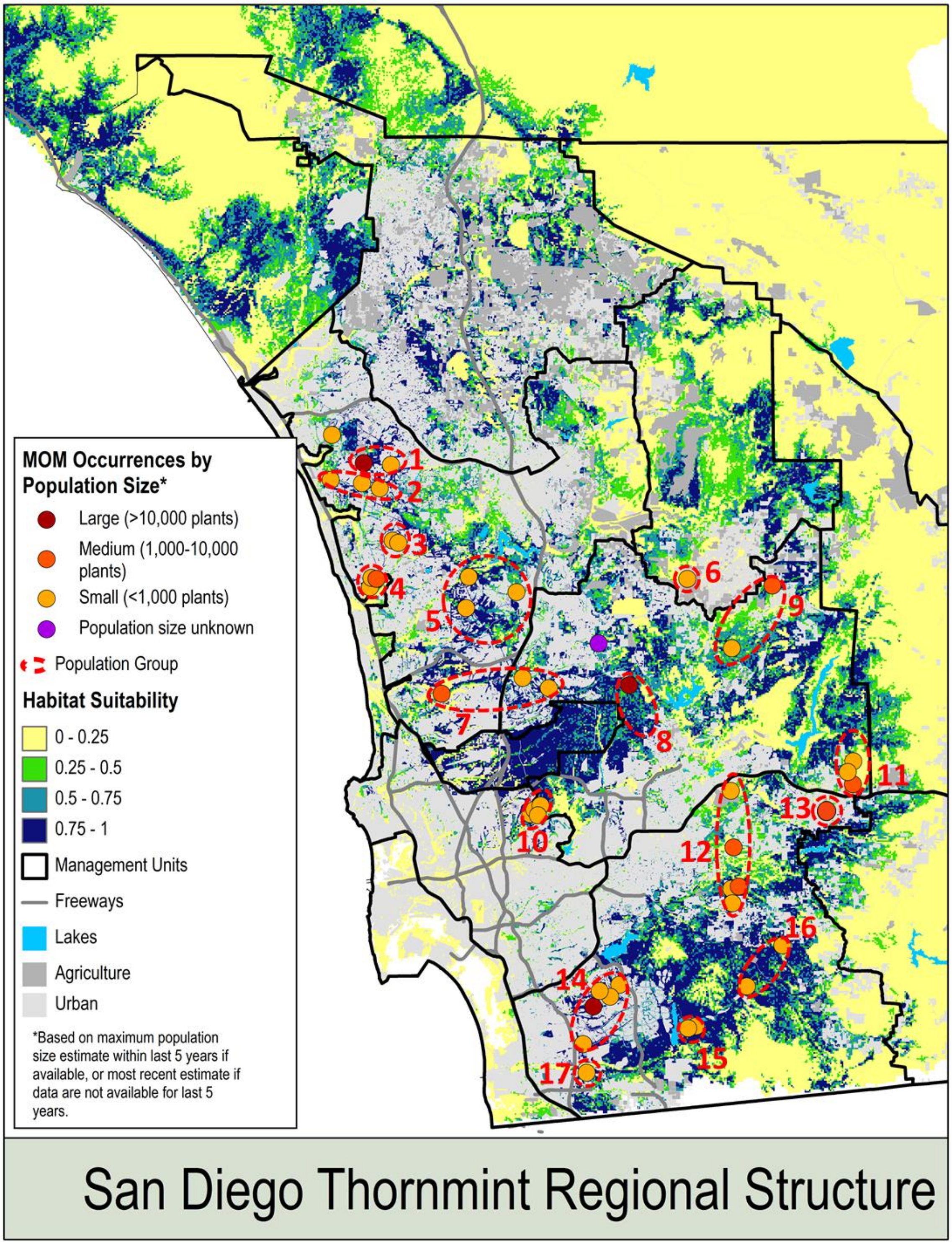


**Figure 6**. San Diego Thornmint Regional Population Structure.

**Table 4**. San Diego Thornmint Population Groups.

| Population Group[1] | Population Group Name | MOM Occurrence ID[2] | Population Size[3,4] | Population Group Characterization |
|---|---|---|---|---|
| 1 | Palomar Airport Road | ACIL_6PARO043<br>ACIL_6CARA034 | Large<br>Small | Mixed |
| 2 | North Carlsbad | ACIL_6EMPO037<br>ACIL_6LCGR038<br>ACIL_6RACA044 | Small<br>Small<br>Small | Small |
| 3 | South Carlsbad | ACIL_6CARL035<br>ACIL_6CARL036 | Small<br>Small | Small |
| 4 | Lux Canyon-Manchester Avenue Mitigation Bank | ACIL_6LUCA040<br>ACIL_6LUCA042<br>ACIL_6MAMI041 | _Small_*<br>_Small_*<br>Medium | Mixed |
| 5 | Black Mountain-Rancho Santa Fe-4-S Ranch | ACIL_6BLMO032<br>ACIL_6RSFE045<br>ACIL_6THCO046 | Small<br>_Small_*<br>_Small_* | Small |
| 6 | Ramona Grasslands | ACIL_5RAGR031 | Small | Small |
| 7 | Los Peñasquitos-Sabre Springs | ACIL_6LPCA039<br>ACIL_4SASP024<br>ACIL_4SASP025 | Small<br>_Small_<br>Small | Small |
| 8 | Sycamore Canyon | ACIL_4SYCA027 | Large | Large |
| 9 | Cañada San Vicente-Simon Preserve | ACIL_4CSVI019<br>ACIL_4CSVI020<br>ACIL_4SIPR026 | _Small_*<br>_Small_<br>Medium | Mixed |
| 10 | Mission Trails-Tierrasanta | ACIL_2EDHI001<br>ACIL_2EDHI002<br>ACIL_4MTRP021<br>ACIL_4MTRP022 | _Small_*<br>_Small_*<br>Small<br>_Small_* | Small |
| 11 | Viejas Mountain | ACIL_4VIMT028<br>ACIL_4VIMT029<br>ACIL_4VIMT030 | _Small_<br>Medium<br>Small | Mixed |
| 12 | Crestridge-South Crest-McGinty Mtn. | ACIL_3CERE004<br>ACIL_3SOCR016<br>ACIL_3MGMT008<br>ACIL_3MGMT009<br>ACIL_3MGMT010 | _Small_<br>Medium<br>Small<br>Small<br>Medium | Mixed |
| 13 | Wright's Field | ACIL_3WRFI018 | Medium | Medium |
| 14 | Central City Preserve-Bonita Meadows | ACIL_3BOME003<br>ACIL_3LONC007<br>ACIL_3PMA1013<br>ACIL_3WHRI017 | Medium<br>Small<br>Large<br>Small | Mixed |
| 15 | Otay Lakes | ACIL_3OTLA011<br>ACIL_3OTLA012 | _Small_<br>_Small_ | Small |
| 16 | Hollenbeck-Rancho Jamul | ACIL_3HCWA006<br>ACIL_3RJER015 | Small<br>_Small_ | Small |
| 17 | Dennery Ranch East | ACIL_3DREA005 | Small | Small |

[1] Population group = one or more Master Occurrence Matrix (MOM) occurrences and other mapped localities that are in proximity to one another and potentially interbreed.

[2] MOM = Master Occurrence Matrix.
[3] Population size categories: large = >10,000 plants; medium = 1,001-10,000 plants; small = <1,000 plants.
[4] Italics indicate population size was recorded as 0 during last monitoring event; * indicates >5 years since last monitoring event.

habitat in gap areas. Conversely, Population Groups 8, 9, and 11 contain high suitability habitat that may support additional occurrences.

## *Thread-leaved Brodiaea*

### Size Class Distribution

Thread-leaved brodiaea occurs only in MUs 6 and 8 in the MSPA. Within this area, there are 21 occurrences with population size data on conserved lands. Only 4 of the 21 occurrences (19%) are large, based on population size estimates within the last 5 years (2012-2017). Of the remaining occurrences, 4 are medium (19%) and 13 are small (62%; Table 5). Recent monitoring data were not available for 6 of 21 occurrences (29%), so we used data from the last known monitoring period to assign size class.

**Table 5**. Thread-leaved Brodiaea Size Class Distribution.

| Management Unit | Occurrence Size Class[1] | | | Total |
|---|---|---|---|---|
| | Large | Medium | Small | |
| 6 | 4 | 3 | 12 | 19 |
| 8 | 0 | 1 | 1 | 2 |
| Total | 4 | 4 | 13 | 21 |

[1] Refer to text for description of size classes. Size estimate is based on monitoring data within the last 5 year or, if not available, the last known size estimate data.

All occurrences for which we had historic and current population size estimates had smaller population sizes in 2017 compared to their recorded maximum population size, although we do not know if this was due to environmental variables versus competition from invasive species.

In delineating the regional population structure, we identified 6 population groups that include all 21 occurrences (Figure 7, Table 6). Refer to Appendix A for a description of population groups.

### Habitat Connectivity

Connectivity gaps occur within and between population groups (Figure 7). Habitat within Population Groups 1-3 and 5 is particularly fragmented. Within Groups 2 and 3, the presence of multiple conserved occurrences and a network of conserved lands that is largely connected may enhance long-term persistence, particularly if population size of small occurrences increases

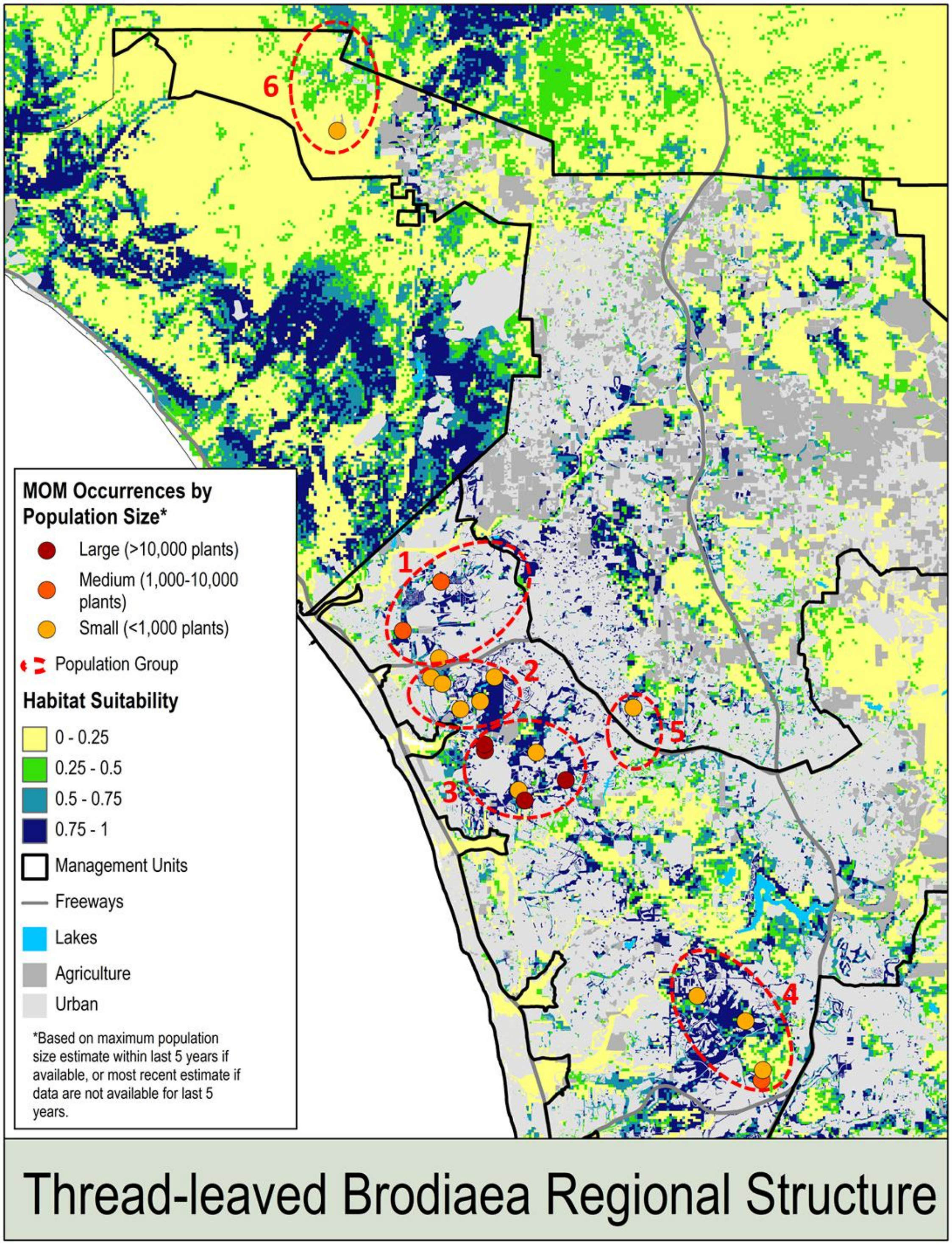


**Figure 7**. Thread-leaved Brodiaea Regional Population Structure.

**Table 6**. Thread-leaved Brodiaea Population Groups.

| Population Group[1] | Population Group Name | MOM Occurrence ID[2] | Population Size[3,4] | Population Group Characterization |
|---|---|---|---|---|
| 1 | Oceanside | BRFI_6MDOR013<br>BRFI_6MGDR014<br>BRFI_6MMOC022<br>BRFI_6MOCE015 | Small<br>Medium*<br>Small<br>Medium* | Mixed |
| 2 | Carlsbad North | BRFI_6BVCR004<br>BRFI_6CAHI005<br>BRFI_6CAHI006<br>BRFI_6LACA008<br>BRFI_6LACA021 | Small<br>Small*<br>Small<br>*Small*<br>Small | Small |
| 3 | Carlsbad South | BRFI_6CONO007<br>BRFI_6LECA010<br>BRFI_6LECA012<br>BRFI_6RACA017<br>BRFI_6RLCO018<br>BRFI_6RLCO019 | Small<br>Large<br>Large<br>Large<br>Medium<br>Large | Mixed |
| 4 | Black Mountain and Vicinity | BRFI_64SRA009<br>BRFI_6ARTR001<br>BRFI_6BMLO003<br>BRFI_6BMRA002 | Small*<br>Small*<br>Small*<br>Small | Small |
| 5 | San Marcos | BRFI_8NEMI016 | Medium | Medium |
| 6 | Devil Canyon | BRFI_8DECA020 | Small | Small |

1 Population group = one or more Master Occurrence Matrix (MOM) occurrences and other mapped localities that are in proximity to one another and potentially interbreed.

2 MOM = Master Occurrence Matrix.

3 Population size classes: large = >10,000 plants; medium = 1,001-10,000 plants; small = <1,000 plants.

4 Italics indicates population size was recorded as 0 during last monitoring event; * indicates >5 years since last monitoring event.

through management. Occurrences in Population Groups 1 and 5 are largely isolated with few opportunities to connect to other occurrences within or beyond the group.

Population Group 4 is isolated from other groups in the MSPA, but small areas of high suitability habitat occur in the gap between this group and Group 3, and could potentially support additional occurrences. Much of the habitat in this gap is currently unconserved. Population Group 6 also appears isolated, but we suspect is supports additional occurrences. In addition, it lies between thread-leaved brodiaea populations on Marine Corps Base Camp Pendleton and the Santa Rosa Plateau in Riverside County.

## *Otay Tarplant*

### Size Class Distribution

Otay tarplant is restricted primarily to MU 3 within the MSPA, with one occurrence is in MU 2. Within the MSPA, there are currently 28 occurrences on conserved lands. Of this total, 9 occurrences (32%) are large, based on population size estimates, 7 are medium (25%), and 12 are small (43%; Table 7). Recent monitoring data were not available for 5 occurrences, so we used data from the last known monitoring period to assign size class.

For Otay tarplant, we identified 13 population groups that include 25 occurrences (Figure 8, Table 8). Refer to Appendix A for a description of population groups.

### Habitat Connectivity

Fragmentation within the western portion of the species range is a relatively recent event (Population Groups 4-5, 7-11; Figure 8), with high density urban development occurring largely in the last several decades. In this area, there is little opportunity to connect groups directly; thus, it will be important to manage them so they persist.

Population groups in the eastern portion of the range (1-3, 6, 12-13) support several large and medium occurrences, but are at a distance from one another. In addition, they occur on low suitability habitat under current conditions (Figure 8). For these groups, management will also be important to ensure they persist. Conservation of tarplant outside these population groups (e.g., Otay River Valley) would improve connectivity between western and eastern population groups.

**Table 7**. Otay Tarplant Size Class Distribution.

| Management Unit | Occurrence Size Class[1] | | | Total |
|---|---|---|---|---|
| | Large | Medium | Small | |
| 2 | 0 | 0 | 1 | 1 |
| 3 | 9 | 7 | 11[2] | 27 |
| Total | 9 | 7 | 12 | 28 |

[1] Refer to text for description of size classes. Size estimate is based on monitoring data within the last 5 year or, if not available, the last known size estimate data.
[2] This MU includes one additional small occurrence on land that will be conserved in the future; however, the land owner requested that the data be kept confidential at this time, so details are not included in this report.

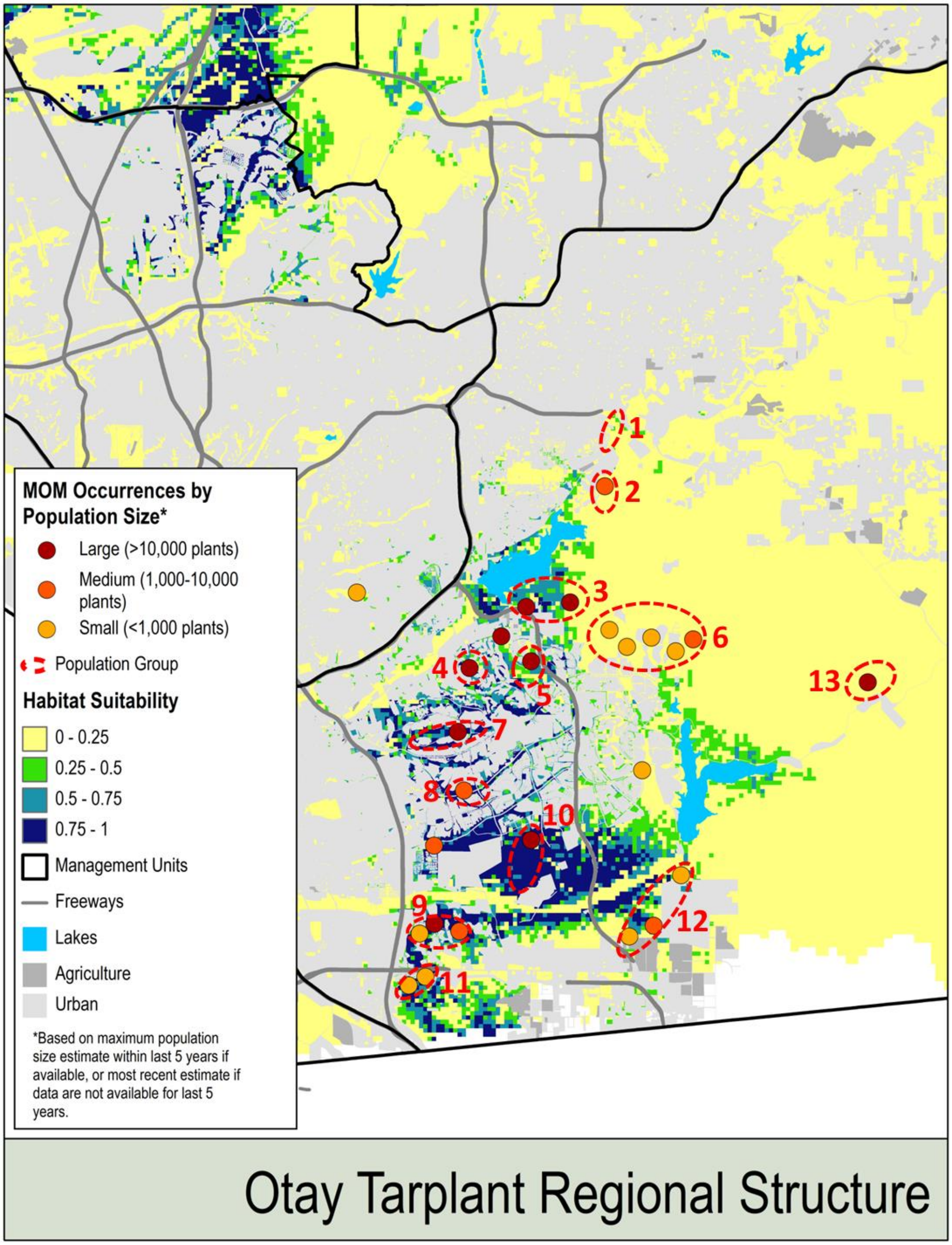


**Figure 8**. Otay Tarplant Regional Population Structure.

**Table 8**. Otay Tarplant Population Groups.

| Population Group[1] | Population Group Name | MOM Occurrence ID[2] | Population Size[3,4] | Population Size Characterization |
|---|---|---|---|---|
| 1 | Jamacha Boulevard | DECO13_3JABO028 | Large | Large |
| 2 | Jamacha Hills | DECO13_3JAHI006 | Medium | Medium |
| 3 | Sweetwater Reservoir | DECO13_3SVPC007<br>DECO13_3MMGR010 | Large<br>Large | Large |
| 4 | PMA 4 | DECO13_3PMA4005 | Large | Large |
| 5 | Trimark-Bonita Meadows | DECO13_3TRIM008<br>DECO13_3BOME008<br>DECO13_3BOME009 | Large<br>Medium<br>Small | Mixed |
| 6 | Proctor Valley | DECO13_3PRVA013<br>DECO13_3PRVA014<br>DECO13_3SMHA024<br>DECO13_3SMHA025<br>DECO13_3RHRA012 | Medium<br>*Small*<br>Small<br>Small<br>Small | Mixed |
| 7 | PMA1 (Rice Canyon & Other Canyons) | DECO13_3PMA1002 | Large | Large |
| 8 | PMA2 | DECO13_3PMA2003 | Medium | Medium |
| 9 | Dennery Ranch East | DECO13_3DREA021<br>DECO13_3DENC022<br>DECO13_3DERA020 | Large<br>Medium*<br>Small | Mixed |
| 10 | Otay River Valley | DECO13_ORVA018 | Large* | Large |
| 11 | Southwest Otay Mesa | DECO13_3OMEA026<br>DECO13_3WMCA023 | Small<br>Small | Small |
| 12 | Johnson Canyon-Lonestar | DECO13_3JOCA019<br>DECO13_3LOST027<br>DECO13_ORVA017 | Medium<br>Medium<br>Small* | Medium |
| 13 | Rancho Jamul | DECO13_3RJER015 | Large | Large |

[1] Population group = one or more Master Occurrence Matrix (MOM) occurrences and other mapped localities that are in proximity to one another and potentially interbreed.

[2] MOM = Master Occurrence Matrix.

[3] Population size categories: large = >10,000 plants; medium = 1,001-10,000 plants; small = <1,000 plants.

[4] Italics indicates population size was recorded as 0 during last monitoring event; * indicates >5 years since last monitoring event.

## *Dehesa Nolina*

### Size Class Distribution

Dehesa nolina occurs only in MU 3 in the U.S. Within this area, there are five occurrences on conserved lands. Four of these occurrences (80%) are large, based on population size estimates, and the other occurrence is small (Table 9). There are additional, unconserved stands of Dehesa nolina near the Dehesa Mountain, McGinty Mountain, and Skyline Truck Trail preserves. One occurrence previously reported from McGinty Mountain (NOIN_3MGMT001) was misidentified; no plants occur in this location.

**Table 9**. Dehesa Nolina Size Class Distribution.

| Management Unit | Occurrence Size Class[1] | | | Total |
|---|---|---|---|---|
| | Large | Medium | Small | |
| 3 | 4 | 0 | 1 | 5 |
| Total | 4 | 0 | 1 | 5 |

[1] Refer to text for description of size classes. Size estimate is based on monitoring data within the last 5 year or, if not available, the last known size estimate data.

Evidence suggests that there is no genetic divergence within the Dehesa nolina populations in the U.S. currently (Heaney pers. comm.). Nonetheless, we identified four population groups that include all five conserved occurrences because of the potential for loss of connectivity between these groups (Figure 9, Table 10). Refer to Appendix A for a description of population groups.

### Habitat Connectivity

The four population groups capture the majority of known occurrences of Dehesa nolina; unconserved plants occur within Population Groups 1, 2, and 4. Gaps occur between Population Groups 1 and 2 and 2 and 3 (Figure 9); conservation of habitat in these gap areas would encourage continued gene flow by supporting pollinators. Finally, potentially suitable habitat east of the current species' distribution may support additional occurrences (Figure 9).

## *Parry's Tetracoccus*

### Size Class Distribution

Parry's tetracoccus occurs on conserved lands in MUs 3, 4, 8, and 11 within the MSPA, with additional records from MU 6. Surveys and monitoring for this species have not been as comprehensive as for the other target species, and we have population size information for only 8 occurrences on conserved lands in MUs 3 and 8.

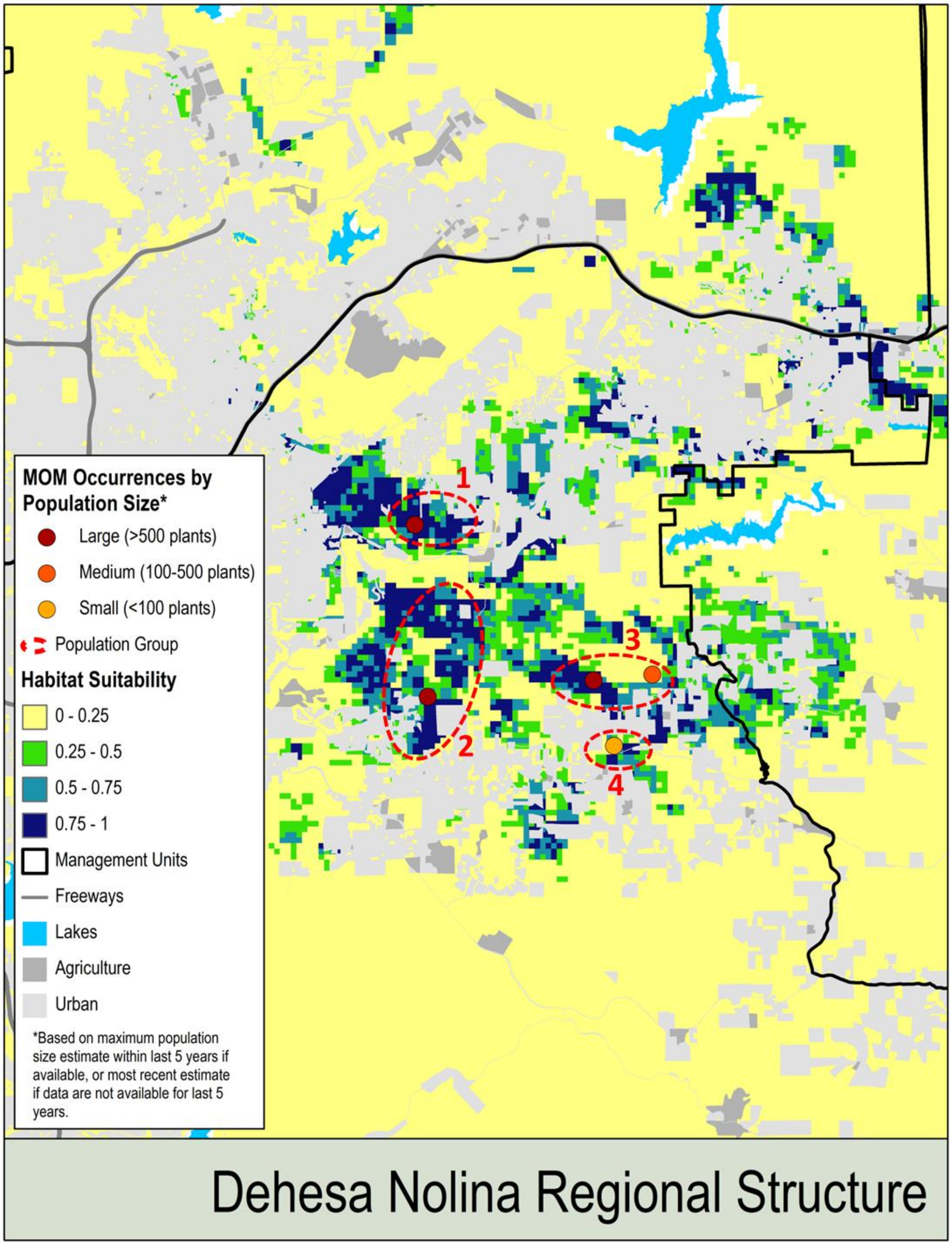


**Figure 9**. Dehesa Nolina Regional Population Structure.

**Table 10**. Dehesa Nolina Population Groups.

| Population Group[1] | Population Group Name | MOM Occurrence ID[2] | Population Size[3,4] | Population Group Characterization |
|---|---|---|---|---|
| 1 | Dehesa Mountain | NOIN_3SOCR003 | Large | Large |
| 2 | McGinty Mountain | NOIN_3MGMT002 | Large | Large |
| 3 | Sycuan Peak | NOIN_3SYPE004<br>NOIN_3SYPE005 | Large<br>Large | Large |
| 4 | Skyline Truck Trail East | NOIN_3STTR006 | Small | Small |

[1] Population group = one or more Master Occurrence Matrix (MOM) occurrences and other mapped localities that are in proximity to one another and potentially interbreed.

[2] MOM = Master Occurrence Matrix.

[3] Population size classes: large = >500 plants; medium = 101-500 plants; small = <100 plants.

[4]Unknown = occurrence not monitored, population size unknown.

Of the 8 Parry's tetracoccus occurrences on conserved lands for which we have size data, 3 are large (38%), 4 are medium (50%), and 1 is small (12%; Table 11). There is an additional occurrence on conserved lands in MU 8 for which we have no population size information.

**Table 11**. Parry's Tetracoccus Size Class Distribution.

| Management Unit | Occurrence Size Class[1] | | | Total |
|---|---|---|---|---|
| | Large | Medium | Small | |
| 3 | 2 | 3 | 0 | 5 |
| 8 | 1 | 1 | 1 | 3[2] |
| Total | 3 | 4 | 1 | 8[2] |

[1] Refer to text for description of size classes. Size estimate is based on monitoring data within the last 5 year or, if not available, the last known size estimate data.

[2] There is another occurrence of unknown size in MU 8; thus, the total number of conserved MOM occurrences in MU 8 is 4 and the total number of conserved MOM occurrences in the MSPA is 9.

In delineating the regional population structure for Parry's tetracoccus, we identified four population groups (Figure 10, Table 12). Of these, three groups include the eight occurrences and the fourth is a general boundary that includes plants on conserved lands that are not in the MOM database. Refer to Appendix A for a description of population groups.

## Habitat Connectivity

Parry's tetracoccus is restricted to gabbroic soils in four, discrete population groups that span the length of the county. Loss of connectivity within groups is not as severe as for the other target species and is largely due to rural development in Population Groups 1, 3, and 4, and urban development in Population Group 2. Nonetheless, conservation of additional habitat, particularly in Population Groups 1 and 2 would benefit this species. High suitability habitat currently

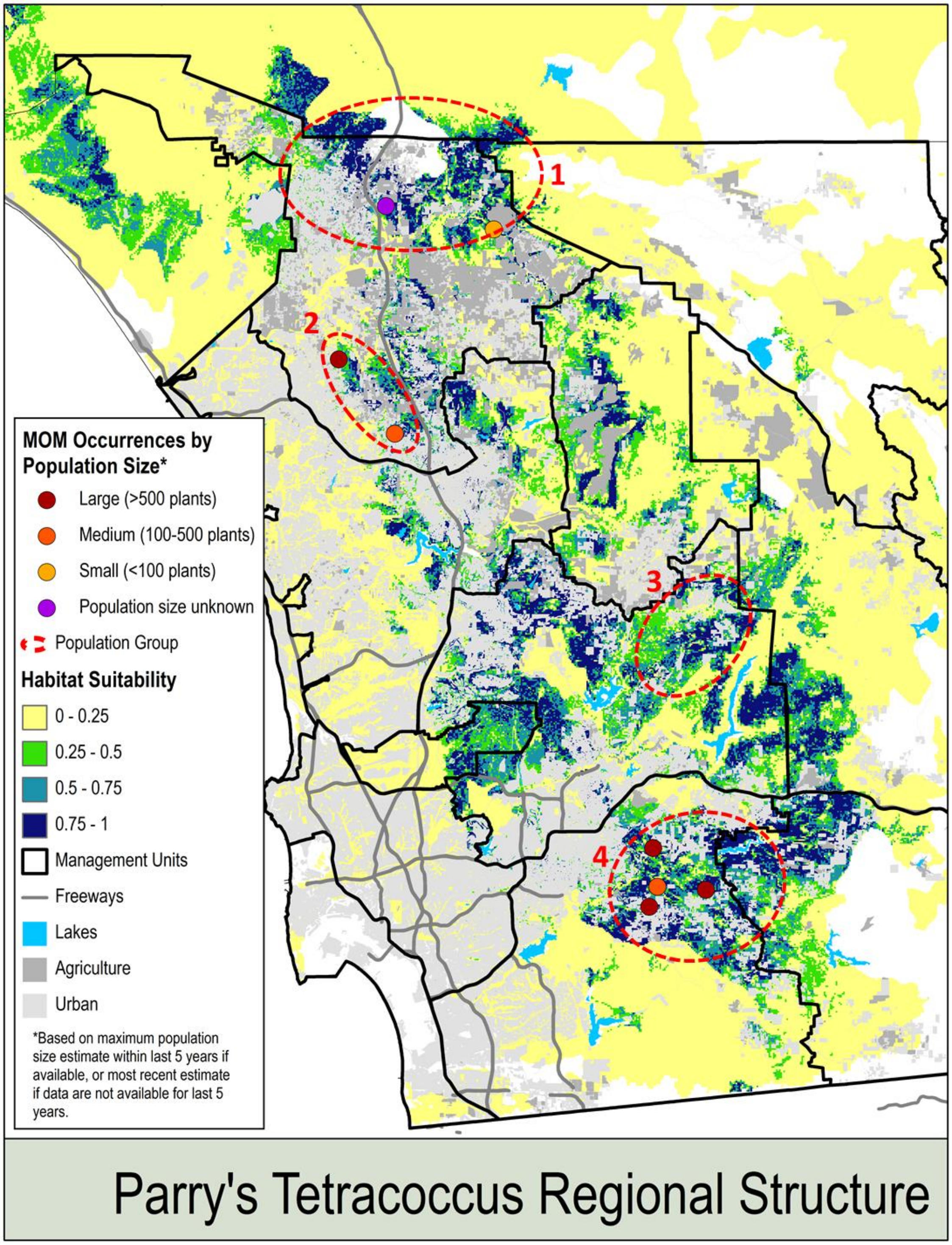


**Figure 10**. Parry's Tetracoccus Regional Population Structure.

**Table 12**. Parry's Tetracoccus Population Groups.

| Population Group[1] | Population Group Name | MOM Occurrence ID[2] | Population Size[3,4] | Population Group Characterization |
|---|---|---|---|---|
| 1 | Fallbrook-Pala | TEDI_8MMPR007<br>TEDI_8WIGA008 | Unknown<br>Small | Mixed? |
| 2 | Merriam-San Marcos Mountains | TEDI_6MEMT006<br>TEDI_8SMMO005 | Medium<br>Large* | Mixed |
| 3 | Mt. Gower-Barona | --- | Unknown[5] | Unknown |
| 4 | South County[6] | TEDI_3MGMT002<br>TEDI_3MGMT003<br>TEDI_3SOCR001<br>TEDI_3SYPE004 | Medium<br>Large<br>Medium<br>Large | Mixed |

[1] Population group = one or more Master Occurrence Matrix (MOM) occurrences and other mapped localities that are in proximity to one another and potentially interbreed.
[2] MOM = Master Occurrence Matrix.
[3] Population size classes: large = >500 plants; medium = 101-500 plants; small = <100 plants.
[4] * indicates >5 years since last monitoring event; unknown = occurrence not monitored, population size unknown.
[5] Visual observations of the Mt. Gower-Barona group in 2017 indicate that the population is likely medium or large.
[6] Parry's tetracoccus also occurs on the Skyline Truck Trail Preserve but is not in the MOM database yet.

occurs between all groups (Figure 10) but has not been well-surveyed or population information is lacking.

# 6 Regional Management Strategies for Opportunity Areas

Regional management is based on a 'top-down' or landscape-level approach that considers the entire distribution of a species in the MSPA, connectivity within and between populations[2] and MUs, and critical gaps in distribution or connectivity that threaten species persistence. A regional management approach allows us to identify and prioritize management actions in specific locations (opportunity areas) that would provide the greatest benefit to a species. Management then occurs at either regional or preserve-levels. In the following sections, we present management strategies and identify management opportunities for the five target species.

Opportunity Areas are conserved lands within the MSPA that have the potential to enhance regional population structure and long-term resilience of the target species through various conservation and management actions (Table 13). Opportunity areas occur within population groups, in gap areas between population groups, or beyond the current species distribution in response to a changing climate.

**Table 13**. Conservation and Management Actions.

| Action | Definition |
|---|---|
| Conserve | Conserve additional land within or between population groups that supports occurrences or provides habitat for pollinators. |
| Survey | Survey areas with limited survey efforts to date that support high suitability habitat, with a focus on connectivity gaps. |
| Establish | Establish new occurrences in gap areas to improve between-group connectivity. |
| Enhance | Enhance existing occurrences to reduce threats (e.g., invasive plants). |
| Expand | Expand small occurrences into adjacent, unoccupied habitat with appropriate soils (as determined through soil testing) and high habitat suitability. |
| Augment | Augment occurrences by introducing genetically appropriate plant propagules into (a) extirpated occurrences with suitable habitat or (b) small occurrences where population numbers have not increased in response to enhancement. Test for soil suitability and possibly, the presence of an extant seed or corm bank before augmenting |
| Translocate | Translocate (move) the target species into predicted high suitability habitat outside its current range in response to changing climatic conditions. |

[2] In general, we use the term 'population' when discussing regional population structure. We use the term 'occurrence' (as used in the MSP Roadmap [SDMMP and TNC 2017] and Master Occurrence Matrix [MOM]) when discussing specific locations of target species on conserved lands.

Identifying regional population structures, connectivity gaps, and opportunity areas and actions provides a framework for managing the target species across the region. For most of the target species, we have included the majority of conserved occurrences within population groups. However, not all groups – or all occurrences within a group – will be managed at the same level. We recommend the following strategies to help prioritize management.

1. **Conserve** additional occurrences within population groups. This applies most generally to population groups with few or small conserved occurrences in proximity to additional, occurrences exist. Conserve through acquisition or other conservation mechanisms.

2. **Survey** high suitability habitat within population groups or gap areas that has not been well-surveyed in the past. Although opportunities are limited, detecting additional occurrences would strengthen regional population structures.

3. **Establish** target species in suitable but unoccupied habitat within the current species' range to fill gaps in connectivity and promote genetic flow. This is most appropriate to connect population groups with suitable, intervening habitat after (1) surveys have determined no natural occurrences are present and (2) soil testing ensures site conditions are appropriate.

4. **Enhance** population groups as needed, based on monitoring results. In this context, enhancement refers to management actions to improve existing habitat (e.g., invasive species control, thatch removal, habitat restoration). Invasive plants are currently the primary threat to most occurrences.

    a. *Enhance* all large populations as needed. In general, large populations (a) are less susceptible to extirpation, (b) possess higher levels of genetic diversity, (c) have higher reproductive success than small populations, (d) function as a source of gene flow to smaller populations in proximity, and (e) function as a seed source for restoration/augmentation efforts. Large populations may occur alone and function independently or may occur as part of a population group (*metapopulation*) that consists of noncontiguous populations of various sizes that potentially interact through gene flow or dispersal.

    b. *Enhance* medium or 'mixed' (medium and small) population groups as needed. In the absence of a large population, a population group that consists of medium populations or a combination of medium and small populations in proximity may or may not retain adequate levels of genetic diversity for long-term persistence and adaptation. Based on an assessment of size, threats, and connectivity between these populations, one or more populations within medium or mixed population groups may require augmentation for long-term persistence.

c. *Enhance selected* small populations or population groups. Population groups that consist only of small populations are at increased risk of extirpation due to genetic degradation (e.g., inbreeding depression, lowered reproductive success). Based on an assessment of threats and connectivity, enhance one or more small occurrences within a small population group to improve long-term persistence. Small populations of particular importance act as steppingstones between other populations (within or beyond the population group), function as refugia from specific threats and stressors, or are a source of genetic diversity. Where we cannot reasonably control threats or improve connectivity, these occurrences are not likely to contribute significantly to regional population structure and would be a lower priority for regional management.

5. **Expand** *selected* small populations or population groups into adjacent, high suitability habitat (if available) by enhancing adjacent habitat (3c, above) and/or introducing genetically appropriate propagules into the habitat. Test soils first to determine if they are appropriate to support the target species.

6. **Augment** *selected* small populations or population groups by introducing genetically appropriate propagules into existing occurrences to increase population size and reduce the risk of extirpation.

7. **Translocate** a target species into suitable habitat beyond the current species' range to assist migration in response to climate change. When considering translocation to ensure species persistence, consider other factors. For example, the ability of a species to adapt to new conditions could offset the effects of climate change. It will be important to continue monitoring species status in relation to environmental factors to determine the need for translocation in the future (Preston and Perkins in review).

Future monitoring may show that some isolated populations are stable and there is suitable (unoccupied) habitat between them and other known populations. This situation may approximate historical conditions, i.e., either populations are stable despite their isolation, or gene flow exists between them, despite their distance. For these groups, we recommend managing the existing population to minimize threats (**enhance**), as needed, and surveying suitable intervening habitat (**survey**) for the presence of additional populations.

Finally, some extant populations may not be critical to maintaining a viable regional population structure. Continue managing these populations at a local (preserve) level. In some cases, effective management may elevate the status of a population in the future.

Refer to Appendix A-1 for a complete list of recommended conservation and management actions for each species population group. Actions may not necessarily apply to all occurrences within a group. In this section, we highlight key actions within and between population groups for each target species, first under current habitat suitability conditions and then under future predicted habitat suitability conditions (Preston and Perkins in review).

## *San Diego Thornmint*

### Current Conditions

- **Conserve** additional habitat that supports San Diego thornmint in Population Groups 1 (e.g., north of Palomar Airport Road), 8 (vicinity of Slaughterhouse Canyon), and 11 (vicinity of Viejas Mountain).
- **Survey** high suitability habitat within Population Groups 8, 9, and 11 to determine whether additional occurrences exist.
- **Survey** high suitability habitat in gap areas between Population Groups 8 and 9 (e.g., Boulder Oaks Preserve), 9 and 11 (e.g., slopes east and west of El Capitan Reservoir), and possibly 15 and 16 (e.g., Jamul Mountains) to determine if additional occurrences exist.
- **Establish** new occurrences in high suitability habitat between Population Groups 8 and 9, 9 and 11, and possibly 15 and 16 *if* survey results to locate new occurrences in these gap areas are negative.
- **Enhance** all occurrences through site-specific management actions, including invasive plant control and other measures recommended through IMG monitoring.
- **Augment** selected small occurrences that do not respond positively to enhancement by introducing seed from genetically appropriate source populations. A positive response to enhancement is an increase in population size under favorable climatic conditions. Small occurrences are present in all identified population groups. The USGS Western Ecological Research Center (WERC) is finalizing a genetic study that includes San Diego thornmint, and results will inform management of this species (e.g., identifying genetically appropriate seed sources for augmentation).

  For small occurrences that supported no plants in recent monitoring periods (Appendix A, Table A-1), test soil first to ensure it is still suitable to support the target species. Consider testing for an extant seed bank.

- **Expand** selected small occurrences by enhancing adjacent habitat and/or introducing propagules (typically, seeds) from genetically appropriate source populations. Test soil first to ensure it is suitable to support the species.

#### Future Conditions

- **Conserve** future predicted suitable habitat outside the current species' range, both in San Diego County and in counties to the north. In San Diego County, this includes habitat in coastal and inland valleys initially, and then at higher elevations in the mountains (see Preston and Perkins in review and Section 4.0)
- **Translocate** the species experimentally into future suitable habitat outside the current species' range as habitat/climatic conditions change *if* warranted by monitoring data (e.g., east and west of El Capitan Reservoir in San Diego County).

### *Thread-leaved Brodiaea*

#### Current Conditions

- **Conserve** additional habitat that supports thread-leaved brodiaea in Population Groups 1 (Oceanside) and 5 (San Marcos).
- **Survey** high suitability habitat on conserved lands in Population Group 6 to determine whether additional occurrences exist (e.g., Devil Canyon, Tenaja Canyon).
- **Survey** potentially suitable habitat in gap areas between Population Groups 3 and 4 for additional occurrences (e.g., vicinity of Lusardi Creek Open Space north to Encinitas Creek) if these areas have not been well-surveyed.
- **Establish** new occurrences in high suitability habitat between Population Groups 3 and 4 *if* survey results for new occurrences are negative. Test soils for suitability prior to establishing new occurrences.
- **Enhance** all occurrences in Population Groups 1-5 through site-specific management actions, including invasive plant control and other measures recommended through IMG monitoring.
- **Expand** selected small occurrences in Population Groups 1-5 by enhancing adjacent habitat and/or introducing propagules (typically, corms) from genetically appropriate source populations. Test soil first to ensure it is suitable to support the species.

- **Augment** small occurrences in Population Groups 2-4 that do not respond positively to enhancement by introducing propagules (typically, corms) from genetically appropriate source populations.

#### Future Conditions

- **Enhance** (or maintain) habitat on the Santa Rosa Plateau in Riverside County.
- **Conserve, enhance, expand**, and **augment** (as needed) habitat/occurrences near Diamond Valley Lake-Perris, and Lake Matthews in Riverside County. Test soils to determine if populations reported on "alkaline soils" are actually on smaller patches of unmapped clay which, while salty, are not alkaline.
- **Translocate** the species experimentally into future suitable habitat outside the current species' range as habitat/climatic conditions change *if* warranted by monitoring data (e.g., southeast of San Vicente Reservoir, southwest of Capitan Grande Reservoir, and east of Jamul in San Diego County).

### *Otay Tarplant*

#### Current Conditions

- **Conserve** additional habitat that supports Otay tarplant in Population Group 10 (e.g., in and near Wolf Canyon).
- **Enhance** all occurrences through site-specific management actions including invasive plant control and other measures recommended through IMG monitoring. The Otay tarplant project (CBI 2017) demonstrated that controlling invasive grasses can increase Otay tarplant population size if an extant seed bank is present. Otay tarplant occurrences that have declined significantly over the last 14-16 years may benefit from invasive plant control.
- **Augment** small occurrences in Population Groups 6 (e.g., Proctor Valley), 11 (Furby-North, West Moody Canyon), and 12 Otay River Valley) that do not respond positively to enhancement with seed from genetically appropriate source populations. The USGS WERC is finalizing a genetic study that includes Otay tarplant; results will inform management efforts (e.g., identifying genetically appropriate seed sources for augmentation).

### Future Conditions

There is no suitable habitat predicted for Otay tarplant under any of the global climate models, emission scenarios, or time periods (Preston and Perkins in review). This underscores the need to build resilience into the current regional population structure through enhancement, expansion, and possibly, augmentation of selected occurrences. In addition, this species might be tolerant to a wider range of soil conditions than reported here. If so, translocation outside the current range may be an option for this species in the future.

## *Dehesa Nolina*

### Current Conditions

- **Conserve** additional habitat that supports Dehesa nolina in or near Population Groups 1 (e.g., Sycuan Tribal lands) and 4 (e.g., Wood Valley).
- **Conserve** additional habitat that supports Dehesa nolina or pollinators between Population Groups 1 and 2 (vicinity of Sloane Canyon) and between Groups 2 and 3 (vicinity of Beaver Hollow).
- **Enhance** occurrences in Population Groups 1-3 by controlling invasive plants in Dehesa nolina habitat at South Crest (Population Group 1), in and adjacent to nolina habitat on McGinty Mountain (Population Group 2), and along trails adjacent to occupied habitat on Sycuan Peak (Population Group 3).

In addition, survey potentially suitable habitat east of the identified population groups (e.g., Wood Valley, Lawson Valley) to determine if additional occurrences are present in this area.

### Future Conditions

- **Conserve** future potentially suitable habitat in the mountains of San Diego County.
- **Translocate** the species experimentally into future high suitability habitat outside the current species' range as habitat conditions change *if* warranted by monitoring data (e.g., Laguna Mountains). Refer to CBI (2016) for guidelines on seed collection, nursery propagation, and outplanting for this species.

## *Parry's Tetracoccus*

### Current Conditions

- **Conserve** additional habitat that supports Parry's tetracoccus in Population Groups 1-4. This includes habitat in the vicinity of Fallbrook-Rainbow-Pala (Population Group 1), the Merriam and San Marcos Mountains (Population Group 2), near Barona (Population Group 3), and in Lyons Valley (Population Group 4).
- **Survey** high suitability habitat within all population groups to determine whether additional occurrences exist. Potential survey locations include (1) the vicinity of Fallbrook-Rainbow-Pala (Population Group 1), (2) Merriam and San Marcos Mountains (Population Group 2), (3) near Barona (Population Group 3), and (4) Lyons Valley (Population Group 4).
- **Survey** high suitability habitat in gap areas to detect additional occurrences. Potential survey locations are east of I-15, in the vicinity of Hidden Meadows-Moosa Canyon-Keys Creek (Population Groups 1 to 3); between Boulder Oaks Preserve and Escondido (Population Groups 2 to 3); and near Japatul Valley, Poser and Viejas mountains, and Capitan Grande Reservation.
- **Enhance** selected occurrences in Population Group 4 by controlling invasive plants on the South Crest Preserve, adjacent to occupied habitat in the McGinty Mountain Ecological Reserve, and along trails at Sycuan Peak Ecological Reserve. Controlling invasive species now would prevent their spread into Parry's tetracoccus habitat post-fire.

In addition, survey high suitability habitat for Parry's tetracoccus on conserved lands east of the population groups (e.g., U.S. Forest Service [USFS]) to determine whether additional occurrences exist.

### Future Conditions

- **Conserve** future suitable habitat (if not already conserved) to the east, west, and north of existing occurrences.
- **Translocate** the species experimentally into future suitable habitat outside the current species' range as habitat conditions change *if* warranted by monitoring data (e.g., vicinity of Corte Madera Mountain, southeast of Pine Valley in San Diego County)

# 7 Next Steps

## Applicability to Other Areas

Our approach to enhancing the resilience of edaphic endemic plants – refining our understanding of regional and site-specific factors that influence persistence and resilience – has widespread applicability to management of rare plant species in other regions of the state, particularly when combined with regional monitoring to address species status and threats. In addition, study results are directly applicable to a number of NCCP areas and subarea plan areas in southern California. For example, we can use soils and vegetation characterization results to identify suitable sites for surveys and refine site selection for species management. Opportunity areas will guide conservation or acquisition, types of management actions needed, and funding priorities for management.

Marine Corps Base Camp Pendleton is not included in the MSPA, but supports thread-leaved brodiaea. Results from this study could inform management of brodiaea on Camp Pendleton. A detailed soils study conducted on base for this species provided useful information in the design phase of the soils study for this project (AMEC 2009). Likewise, Marine Corps Air Station Miramar is not included in the MSPA. There is at least one historic record of San Diego thornmint from Miramar, although there have been no observations of this species in recent years. Both bases support a small amount of predicted future suitable habitat for San Diego thornmint and Parry's tetracoccus.

Thread-leaved brodiaea and Parry's tetracoccus occur in Riverside County, within the Western Riverside County Multiple Species Habitat Conservation Plan (MSHCP) area (e.g., Santa Rosa Plateau, San Jacinto Wildlife Area, San Mateo Canyon Wildlife Area, Santa Margarita Ecological Reserve). These species also occur in Orange County, within the Orange County Southern Subregion Habitat Conservation Plan (HCP). Results from the soils study could be useful for enhancing or expanding occurrences of thread-leaved brodiaea in these counties, while monitoring data from those counties would provide a more complete picture of the overall status of the target species, particularly if collected using the IMG (or similar) monitoring protocol.

Conserving and managing predicted future suitable habitat in Riverside and Orange counties, as well as counties to the north, may be important to survival of thread-leaved brodiaea, Dehesa nolina, and Parry's tetracoccus.

# Future Studies

San Diego thornmint is possibly the most threatened of the target species because of the small population size of nearly 70% of the conserved occurrences. Biologists and restoration practitioners have successfully enhanced habitat for San Diego thornmint at several locations, but (in general) population size has not rebounded in response. Although many factors may drive these results – including soils – we recommend testing a subset of these sites to determine if the species persists as an extant seed bank. Seeds germinate readily in a greenhouse setting with no pre-treatment, and seed bulking for outplanting has been successful. There appears to be little or no seed dormancy, at least in a controlled setting.

Appendix C lists a number of recommended studies and experiments to further refine our understanding of plant-soil relationships. Examples that would directly benefit management by further refining site selection parameters include:

- Examine the bulk physical properties (structure, density, friability) of soils in clay lenses for San Diego thornmint.
- Test the effects of Na on thread-leaved brodiaea establishment and growth.
- Test the tolerance of Otay tarplant to soils with chemical properties outside the ranges reported in this study.
- Test whether pH, Ca, or both are important for Dehesa nolina success.
- Test the ability of Parry's tetracoccus to thrive on non-gabbroic soils.

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# Appendices

A Target Species Biology, Distribution, and Status

B Conceptual Models

C Soil and Vegetation Characterization

# Appendix A

# Target Species Biology, Distribution, and Status

# Appendix A

# Target Species Biology, Distribution, and Status

In this section, we document biology, distribution, and status of the five target species: San Diego thornmint (*Acanthomintha ilicifolia*), thread-leaved brodiaea (*Brodiaea filifolia*), Otay tarplant (*Deinandra conjugens*), Dehesa nolina (*Nolina interrata*), and Parry's tetracoccus (*Tetracoccus dioicus*). We also describe population groups on conserved lands in western San Diego County. See Appendix A-1 for conservation and management actions for target species. Information on species status is from the San Diego Management and Monitoring Program's Master Occurrence Matrix (MOM) database; population size estimates are from the SDMMP Inspect and Manage (IMG) rare plant monitoring or other monitoring efforts. We report population groups by Management Units (MUs), as designated by SDMMP in the regional Management and Monitoring Strategic Plan (MSP) for conserved lands in San Diego County (MSP Roadmap; SDMMP and TNC 2017).

## San Diego Thornmint

San Diego thornmint is an annual species that is restricted to San Diego County and Baja California, Mexico (CNDDB 2013, Beauchamp 1986, SANDAG 2012). Within San Diego County, thornmint occurs primarily on clay soils or clay lenses in chaparral, scrub, and grassland habitats (Oberbauer and Vanderwier 1991, SANDAG 2012). At the regional-level, this species is threatened by invasive plants, small population size (and possible inbreeding depression), altered fire regimes, habitat fragmentation, nitrogen deposition, and climate change (Bauder and Sakrison 1997, 1999, Lawhead 2006, USFWS 2009a, Conlisk et al. 2013, and others). Preserve-level impacts include invasive plants, trampling, and competitive native plants, among others (Bauder and Sakrison 1997, 1999, Lawhead 2006, USFWS 2009a, CBI 2014a,b).

San Diego thornmint occurs in a relatively large number of populations for a rare species; however, many of these populations face multiple challenges that threaten population and, possibly, species' persistence across the region. Refer to Table A-1 for San Diego thornmint MOM occurrences on conserved lands in San Diego County, including estimated population sizes. Refer to Table A-2 for a list of San Diego thornmint population groups; we describe these groups by MU below.

### Management Unit 2

Historically, MU 2 likely played an important role in thornmint population dynamics. At this time, only remnants of suitable habitat remain. The two occurrences in this MU are possibly

**Table A-1**. San Diego Thornmint Occurrences on Conserved Lands in San Diego County.[1]

| Occurrence ID[2] | Occurrence Name | Preserve[3] | Land Owner[4] | Land Manager[4] | Max Pop Size[5] (year) | Recent Max Pop Size[6] (year) |
|---|---|---|---|---|---|---|
| **Management Unit 2** | | | | | | |
| *Small Populations* | | | | | | |
| ACIL_2EDHI001 | El Dorado Hills | El Dorado Hills | San Diego | San Diego PRD | 50 (2003) | 1 (2009) |
| ACIL_2EDHI002 | El Dorado Hills | El Dorado Hills | San Diego | San Diego PRD | 200 (1986) | 0 (2010) |
| **Management Unit 3** | | | | | | |
| *Large Populations* | | | | | | |
| ACIL_3PMA1013 | PMA1 (Rice Canyon) | Central City Preserve | Chula Vista | Chula Vista | 32,000 (2012) | 11,228 (2017) |
| *Medium Populations* | | | | | | |
| ACIL_3BOME003 | Bonita Meadows | Bonita Meadows | Caltrans | Caltrans | 1,200 (2017) | 1,200 (2017) |
| ACIL_3MGMT010 | McGinty Mountain (summit and ridgeline) | SDNWR | USFWS | USFWS | 2,559 (2010) | 168[7] (2017) |
| ACIL_3SOCR016 | South Crest (Suncrest) | South Coast Properties | EHC | EHC | 1,135 (2012) | 620[7] (2017) |
| ACIL_3WRFI018 | Wright's Field (north & south) | Wright's Field | BCLT | BCLT | 800 (1995) | 2,750 (2017) |
| *Small Populations* | | | | | | |
| ACIL_3CERE004 | Crestridge Ecological Reserve | Crestridge ER | CDFW | EHC | 505 (2000) | 0 (2017) |

**Table A-1**. San Diego Thornmint Occurrences on Conserved Lands in San Diego County.[1]

| Occurrence ID[2] | Occurrence Name | Preserve[3] | Land Owner[4] | Land Manager[4] | Max Pop Size[5] (year) | Recent Max Pop Size[6] (year) |
|---|---|---|---|---|---|---|
| ACIL_3DREA005 | Dennery Ranch East | Dennery Ranch | San Diego | San Diego PRD | 536 (2012) | 16 (2016) |
| ACIL_3HCWA006 | Hollenbeck Wildlife Area | Hollenbeck Canyon WA | CDFW | CDFW | 32,000 (2003) | 579 (2017) |
| ACIL_3LONC007 | Long Canyon (PMA 4-2b) | Central City Preserve | Chula Vista | Chula Vista | 92 (2017) | 92 (2017) |
| ACIL_3MGMT008 | McGinty Mountain | SDNWR | USFWS | USFWS | 6,500 (2011) | 10 (2017) |
| ACIL_3MGMT009 | McGinty Mountain (southwest slope) | Flying Dolphin Trust | TNC | TNC | 1,000 (2011) | 756 (2017) |
| ACIL_3OTLA011 | Lower Otay Reservoir | Otay Mountain ER | CDFW | CDFW | 0 (2016) | 0 (2016) |
| ACIL_3OTLA012 | Otay Lakes (south side) | Otay Lakes Cornerstone Lands | San Diego PUD | San Diego PRD | 61 (2003) | 0 (2016) |
| ACIL_3RJER015 | Rancho Jamul Ecological Reserve | Rancho Jamul ER | CDFW | CDFW | 125 (2010) | 0 (2017) |
| ACIL_3WHRI017 | Bonita, Wheeler Ridge (Long Canyon PMA 4-1cW) | Central City Preserve | Chula Vista | Chula Vista | 935 (2017) | 935 (2017) |
| **Management Unit 4** | | | | | | |
| *Large Populations* | | | | | | |
| ACIL_4SYCA027 | Sycamore Canyon | Sycamore Canyon and Goodan Ranch Preserves | County DPR | County DPR | 777,300 (2017) | 777,300 (2017) |

**Table A-1**. San Diego Thornmint Occurrences on Conserved Lands in San Diego County.[1]

| Occurrence ID[2] | Occurrence Name | Preserve[3] | Land Owner[4] | Land Manager[4] | Max Pop Size[5] (year) | Recent Max Pop Size[6] (year) |
|---|---|---|---|---|---|---|
| *Medium Populations* | | | | | | |
| ACIL_4SIPR026 | Simon Preserve | Simon Preserve | County DPR | County DPR | 7,500 (2009) | 6,000 (2017) |
| ACIL_4VIMT0029 | Viejas Mountain (southwest slope) | Viejas Hills Partners, LLC | Viejas Hills Partners, LLC | --- | 21,015 (2010) | 2,245 (2017) |
| *Small Populations* | | | | | | |
| ACIL_4CSVI019 | Canada San Vicente-Daney Canyon | Canada de San Vicente | CDFW | CDFW | 100 (1995) | 0 (2010) |
| ACIL_4CSVI020 | Canada San Vicente--Monte Vista (Long's Gulch) | Canada de San Vicente | CDFW | CDFW | 26 (2006) | 0 (2016) |
| ACIL_4MTRP021 | Mission Trails Regional Park | Mission Trails Regional Park | San Diego | San Diego PRD | 737 (2013) | 105 (2016) |
| ACIL_4MTRP022 | Mission Trails Regional Park (Southwest Tierra Santa parcel, NW of Mission Gorge) | Mission Trails Regional Park | San Diego | San Diego PRD | 250 (1994) | 0 (2016)[8] |
| ACIL_4POGR023 | Poway Grade | RAAN LLC | RAAN LLC | Unknown | Unknown (2001) | Unknown (2001)[9] |
| ACIL_4POMT035 | Poser Mountain | Cleveland National Forest | USFS | USFS | 7 (2017) | 7 (2017) |
| ACIL_4SASP024 | Saber Springs (east) | City of Poway Open Space | Poway | Poway | Unknown (2001) | 0 (2016) |
| ACIL_4SASP025 | Sabre Springs (east, subpopulation 1) | Sabre Springs | San Diego | San Diego PRD | 19,721 (2003) | 11 (2016) |
| ACIL_4VIMT0028 | Viejas Mountain | Cleveland National Forest | USFS | USFS | 44 | 0 |

**Table A-1**. San Diego Thornmint Occurrences on Conserved Lands in San Diego County.[1]

| Occurrence ID[2] | Occurrence Name | Preserve[3] | Land Owner[4] | Land Manager[4] | Max Pop Size[5] (year) | Recent Max Pop Size[6] (year) |
|---|---|---|---|---|---|---|
| | (northwest slope) | | | | (2010) | (2016) |
| ACIL_4VIMT0030 | Viejas Mountain (west-southwest flank) | Cleveland National Forest | USFS | USFS | 1,638 (2010) | 233 (2017) |
| **Management Unit 5** | | | | | | |
| *Small Populations* | | | | | | |
| ACIL_5RAGR031 | Ramona Grasslands/Hobbes Property | Ramona Grasslands Preserve | Ramona MWD | County DPR | 58 (2010) | 49 (2013) |
| **Management Unit 6** | | | | | | |
| *Large Populations* | | | | | | |
| ACIL_6PARO043 | Palomar Airport Road | Carlsbad Oaks North Habitat Conservation Area | County PWD | CNLM | 36,533 (2017) | 36,533 (2017) |
| *Medium Populations* | | | | | | |
| ACIL_6MAMI041 | Lux Canyon (east), Manchester Avenue Mitigation Bank | Manchester Mitigation Bank | CNLM | CNLM | 11,400 (1989) | 4,722 (2017) |
| *Small Populations* | | | | | | |
| ACIL_6BLMO032 | Black Mountain | Black Mountain Open Space Park | San Diego | San Diego PRD | 1,115 (2000) | 5 (2016) |
| ACIL_6CAHI033 | Calavera Hills | Calavera Hills Phase 2 & Robertson Ranch | Calavera Hills HOA | CNLM | 4 (2009) | 0 (2013) |
| ACIL_6CARA034 | Carlsbad Racetrack (south) | Carlsbad Raceway | Fenton Raceway LLC | Fenton Raceway LLC | 1,000 (1986) | 3 (2017) |
| ACIL_6CARL035 | Southeast Carlsbad (East) | Santa Fe Trails HOA | Santa Fe Trails HOA | Santa Fe Trails HOA | 2,000 (1994) | 200 (2010) |
| ACIL_6CARL036 | Southeast Carlsbad | Ranch Carlsbad HOA | Ranch Carlsbad | La Costa HOAs | 1,000 | 500 |

**Table A-1**. San Diego Thornmint Occurrences on Conserved Lands in San Diego County.[1]

| Occurrence ID[2] | Occurrence Name | Preserve[3] | Land Owner[4] | Land Manager[4] | Max Pop Size[5] (year) | Recent Max Pop Size[6] (year) |
|---|---|---|---|---|---|---|
| | (West) | | HOA | | (1994) | (2010) |
| ACIL_6EMPO037 | Emerald Pointe | Emerald Point Open Space | SDHC | SDHC | 110 (2009) | 17 (2017) |
| ACIL_6LCGR038 | La Costa Greens | Rancho La Costa Habitat Conservation Area | CNLM | CNLM | 1,000 (2003) | 996 (2017) |
| ACIL_6LPCA039 | Los Peñasquitos Canyon | Los Peñasquitos Canyon Preserve | San Diego | San Diego PRD | 2,091 (2005) | 38 (2016) |
| ACIL_6LUCA040 | Lux Canyon (west) | Pacific Pines Racquet Club HOA | Viejas Hills Partners, LLC | Pacific Pines Racquet Club HOA | 30 (1986) | 0 (2006) |
| ACIL_6LUCA042 | Lux Canyon (west of Manchester Avenue Mitigation Bank) | Calle Ryan Homeowner's Association | Calle Ryan Homeowner's Association | Calle Ryan Homeowner's Association | 500 (1994) | 0 (2006) |
| ACIL_6RACA044 | El Fuerte Street (Rancho Carrillo) | Rancho Carrillo HOA | Rancho Carrillo Master HOA | Rancho Carrillo Master HOA | 170 (1991) | 23 (2017) |
| ACIL_6RSFE045 | Rancho Santa Fe | MS Rialto to the Lakes CA LLC | MS Rialto to the Lakes CA LLC | MS Rialto to the Lakes CA LLC | 500 (1991) | 0 (2001) |
| ACIL_6THCO046 | Thornmint Court | 4-S Ranch | 4S Ranch HOA | 4S Ranch HOA | 1,000 (1983) | 0 (2011) |

[1] Table lists only occurrences in the San Diego Management and Monitoring Program's Master Occurrence Matrix (MOM) database. We do not show one occurrence because land owner did not want information released.

[2] Occurrence Identification (ID) per the San Diego Management and Monitoring Program (SDMMP) Master Occurrence Matrix (MOM) database.

[3] Preserve: Central City Preserve = City of Chula Vista Central City Preserve; Crestridge ER = Crestridge Ecological Reserve; HOA = Homeowner's Association; Hollenbeck WA = Hollenbeck Wildlife Area; Otay Mountain ER = Otay Mountain Ecological Reserve; Rancho Jamul ER = Rancho Jamul Ecological Reserve; SDNWR = San Diego National Wildlife Refuge.

[4] Land owner/land manager: BCLT = Back Country Land Trust; Caltrans = California Department of Transportation; CDFW = California Department of Fish and Wildlife; CNLM = Center for Natural Lands Management; Chula Vista = City of Chula Vista; County DPR = County of San Diego, Department of Parks and Recreation; County PWD = County of San Diego, Public Works Department; EHC = Endangered Habitats Conservancy; HOA = Homeowner's Association; Poway = City of Poway; Ramona MWD = Ramona Municipal Water District; San Diego = City of San Diego; San Diego PRD = City of San

Diego, Parks and Recreation Department; San Diego PUD = City of San Diego, Public Utilities Department; SDHC = San Diego Habitat Conservancy; TNC = The Nature Conservancy; USFS = U.S. Forest Service; USFWS = U.S. Fish and Wildlife Service.

[5] Indicates maximum recorded population size.

[6] Indicates maximum recorded population size in the last 5 years (2012-2017) if data are available, or most recent year overall if data are not available.

[7] Population categorized as medium because size estimates exceeded 1,000 individuals within the last 5 years (2012-2017).

[8] CBI surveyed this location in 2016 as part of the soils assessment for this project; we did not find any plants.

[9] Occurrence not depicted on Figure 1 of report; current status unknown.

**Table A-2**. San Diego Thornmint Population Groups.

| Population Group[1] | Population Group Name | MOM Occurrence ID[2] | Population Size[3,4] | Population Group Characterization |
|---|---|---|---|---|
| 1 | Palomar Airport Road | ACIL_6PARO043<br>ACIL_6CARA034 | Large<br>Small | Mixed |
| 2 | North Carlsbad | ACIL_6EMPO037<br>ACIL_6LCGR038<br>ACIL_6RACA044 | Small<br>Small<br>Small | Small |
| 3 | South Carlsbad | ACIL_6CARL035<br>ACIL_6CARL036 | Small<br>Small | Small |
| 4 | Lux Canyon-Manchester Avenue Mitigation Bank | ACIL_6LUCA040<br>ACIL_6LUCA042<br>ACIL_6MAMI041 | *Small**<br>*Small**<br>Medium | Mixed |
| 5 | Black Mountain-Rancho Santa Fe-4-S Ranch | ACIL_6BLMO032<br>ACIL_6RSFE045<br>ACIL_6THCO046 | Small<br>*Small**<br>*Small** | Small |
| 6 | Ramona Grasslands | ACIL_5RAGR031 | Small | Small |
| 7 | Los Peñasquitos-Sabre Springs | ACIL_6LPCA039<br>ACIL_4SASP024<br>ACIL_4SASP025 | Small<br>*Small*<br>Small | Small |
| 8 | Sycamore Canyon | ACIL_4SYCA027 | Large | Large |
| 9 | Canada San Vicente-Simon Preserve | ACIL_4CSVI019<br>ACIL_4CSVI020<br>ACIL_4SIPR026 | *Small**<br>*Small*<br>Medium | Mixed |
| 10 | Mission Trails-Tierrasanta | ACIL_2EDHI001<br>ACIL_2EDHI002<br>ACIL_4MTRP021<br>ACIL_4MTRP022 | *Small**<br>*Small**<br>Small<br>*Small** | Small |
| 11 | Viejas Mountain | ACIL_4VIMT028<br>ACIL_4VIMT029<br>ACIL_4VIMT030 | *Small*<br>Medium<br>Small | Mixed |
| 12 | Crestridge-South Crest-McGinty Mtn. | ACIL_3CERE004<br>ACIL_3SOCR016<br>ACIL_3MGMT008<br>ACIL_3MGMT009<br>ACIL_3MGMT010 | *Small*<br>Medium<br>Small<br>Small<br>Medium | Mixed |
| 13 | Wright's Field | ACIL_3WRFI018 | Medium | Medium |
| 14 | Central City Preserve-Bonita Meadows | ACIL_3BOME003<br>ACIL_3LONC007 | Medium<br>Small | Mixed |

**Table A-2**. San Diego Thornmint Population Groups.

| Population Group[1] | Population Group Name | MOM Occurrence ID[2] | Population Size[3,4] | Population Group Characterization |
|---|---|---|---|---|
| | | ACIL_3PMA1013<br>ACIL_3WHRI017 | Large<br>Small | |
| 15 | Otay Lakes | ACIL_3OTLA011<br>ACIL_3OTLA012 | *Small*<br>*Small* | Small |
| 16 | Hollenbeck-Rancho Jamul | ACIL_3HCWA006<br>ACIL_3RJER015 | Small<br>*Small* | Small |
| 17 | Dennery Ranch East | ACIL_3DREA005 | Small | Small |

[1] Population group = one or more Master Occurrence Matrix (MOM) occurrences and other mapped localities that are in proximity to one another and potentially interbreed.

[2] MOM = Master Occurrence Matrix.

[3] Population size categories: large = >10,000 plants; medium = 1,001-10,000 plants; small = <1,000 plants.

[4] Italics indicate population size was recorded as 0 during last monitoring event; * indicates >5 years since last monitoring event.

extirpated. Based on location, we include them in the Mission Trails-Tierrasanta population group; refer to the description of this group under MU 4.

## Management Unit 3

Management Unit 3 in south San Diego County supports fragmented habitat in the cities of Chula Vista and San Diego near the coast, and larger, intact habitat to the east. This MU supports 16 conserved occurrences, including 1 large and 4 medium occurrences. We designated 6 population groups that include all 16 occurrences. Five of the small occurrences supported no plants during the last monitoring period.

Population Group 12: Crestridge-South Crest-McGinty Mountain. This population group stretches from just south of I-8 near Crest southward to Jamul. We designated this large area as a population group because of both known occurrence and intermediary habitat on conserved lands that support potentially suitable habitat for additional occurrences and pollinators. Many of the thornmint populations in this group occur on clay soils in gabbroic outcrops. This group includes two medium (ACIL_3SOCR015, ACIL_3MGMT010) and two small extant occurrences (ACIL_3MGMT009 and -010), and one small questionably extant occurrence (ACIL_3CERE040).

Population Group 13: Wright's Field. This group includes of one medium occurrence (ACIL_3WRFI018) on conserved lands in Alpine. Habitat management and species augmentation have increased thornmint population size at this location in recent years.

Population Group 14: Central City Preserve-Bonita Meadows. Most occurrences in this group occur within the City of Chula Vista. Although fragmented, conserved lands within this group are relatively well-connected and managed. The group includes a mix of population sizes, with small occurrences (ACIL_3LONC007, ACIL_3WHRI017) in proximity to large (ACIL_3PMA1013) and medium (ACIL_3BOME003) occurrences.

Population Group 15: Otay Lakes. This population group occurs on conserved lands owned and managed by the City of San Diego at Otay Lakes, and includes two small, potentially extirpated occurrences (ACIL_3OTLA011 and -012). We include this area within the regional structure because of its location between two other population groups (14 and 16), and the potential for thornmint habitat restoration/enhancement and possible species augmentation.

Population Group 16: Hollenbeck-Rancho Jamul. This population group occurs on conserved lands owned and managed by CDFW on the Hollenbeck Wildlife Management Area and Rancho Jamul Ecological Reserve. The former occurrence (ACIL_3HCWA006) is managed and plants are present; nonnative grasses dominate the latter occurrence (ACIL_3RJER015) and no plants have been detected recently. There may be the potential for additional occurrences within this group.

Population Group 17: Dennery Ranch East. This population group is relatively isolated and currently supports a small occurrence (ACIL_3DREA005); however, we included it in the regional structure at this time because it is the southernmost thornmint occurrence and the City of San Diego manages and monitors this occurrence regularly.

### Management Unit 4

The western portion of MU 4 is fragmented, while the eastern portion includes large, intact conserved lands to the east. This MU supports the largest known thornmint occurrence and the easternmost occurrences. There are 13 occurrences on conserved lands in this MU. We identified 4 population groups that include 11 of these occurrences plus another 3 occurrences from adjacent MUs. Seven of the small occurrences supported no plants during the last monitoring period. We did not include the Poway Grade (ACIL_4POGR023) or Poser Mountain (ACIL_4POMT035) occurrences in groups at this time because of unknown status and/or small population size.

Population Group 7: Los Peñasquitos-Sabre Springs. This population group occurs on City of San Diego lands in MUs 6 and 4, west and east of I-15 and south of Hwy. 56 and Poway Road. The three small occurrences (ACIL_6LPCA039, ACIL_4SASP024 and -025) in this group connect potentially through a network of conserved lands along Los Peñasquitos Canyon.

Population Group 8: Sycamore Canyon. This group includes the Sycamore Canyon occurrence (ACIL_4SYCA027), which is currently the largest known San Diego thornmint population. This occurrence is in the Sycamore Canyon/Goodan Ranch Preserve, on lands owned and managed by the County of San Diego, Department of Parks and Recreation. There is at least one other large, unconserved occurrence in the vicinity of Sycamore Ranch.

Population Group 9: Canada San Vicente-Simon Preserve. This population group includes three occurrences, including one medium (ACIL_4SIPR026) and two small occurrences (ACIL_4CSVI019 and -020). Both of the small occurrences are questionably extant. We have designated this population group based on the presence of some potentially suitable habitat between the known occurrences, despite their distance.

Population Group 10: Mission Trails-Tierrasanta. This population group occurs on City of San Diego lands in MUs 2 and 4, west of Cowles Mountain. It includes one small occurrence at Mission Trail Regional Park (ACIL_4MTRP021), managed by the City of San Diego, and three additional small populations that are questionably extant (ACIL_2EDHI001 and -002, ACIL_4MTRP022). This group abuts development, and is in an area where conserved lands adjacent to occurrences support clay soils.

Population Group 11: Viejas Mountain. This population group occurs on U.S. Forest Service lands and private lands in the southeastern corner of MU 4, and supports the easternmost occurrences of San Diego thornmint throughout its range. It includes one medium occurrence (ACIL_4VIMT029) and two small occurrences (ACIL_4VIMT028 and -030). We detected no plants at one of the small occurrences during 2016 IMG monitoring. In general, these occurrences have fewer threats than occurrences in more urbanized areas, particularly with respect to invasive plants.

### Management Unit 5

There is one thornmint occurrence in this MU, in the Ramona grasslands. This is the north-easternmost occurrence of San Diego thornmint and the only known occurrence in MU 5.

Population Group 6: Ramona Grasslands. This population group consists of one small occurrence (ACIL_5RAGR031) on conserved lands in the Ramona grasslands.

## Management Unit 6

Management Unit 6 is highly fragmented due to urbanization, but has an important network of conserved lands that support San Diego thornmint in coastal locations of the county. There are 15 thornmint occurrences on conserved lands in this MU. We identified 5 population groups that include 13 of these occurrences. Another occurrence is adjacent to occurrences in MU 4 and is therefore included in a MU 4 population group (Mission Trails-Tierrasanta). The last occurrence is small and isolated. Recent survey information suggests there is only one large and one medium thornmint occurrence in this MU at the present time. All identified groups include more than one occurrence, although the status of some occurrences is questionable (i.e., extant versus extirpated).

Population Group 1: Palomar Airport Road. This population group occurs near Palomar Airport in the City of Carlsbad. It includes the largest known occurrence in this MU on conserved land at the airport (ACIL_PARO043) and a small occurrence to the east (ACIL_6CARA034).

Population Group 2: North Carlsbad. This population group occurs south of Palomar Airport Road and north of Alga Road in the City of Carlsbad, and includes three small occurrences distributed across a network of conserved lands (ACIL_6EMPO037, ACIL_6LCGR038, and ACIL_6RACA044). CNLM manages the La Costa Greens occurrence (ACIL_LCGR038), which appears to be stable with almost 1,000 plants in the last survey period, while the other 2 occurrences are very small.

Population Group 3: South Carlsbad. This population group occurs in the very southeastern corner of the City of Carlsbad, south and east of Rancho Santa Fe Road. The two small occurrences in this group (ACIL_6CARL035 and -036) are on conserved lands owned by HOAs and largely isolated from other conserved thornmint occurrences.

Population Group 4: Lux Canyon-Manchester Avenue Mitigation Bank. This population group occurs in the City of Encinitas, north of Manchester Avenue and west of Rancho Santa Fe Road on lands owned by CNLM or HOAs. The CNLM occurrence in the Manchester Avenue mitigation bank (ACIL_6MAMI041) is medium-sized; the other two at Lux Canyon (ACIL_6LUCA040 and -042) are questionably extant.

Population Group 5: Black Mountain-Rancho Santa Fe-4-S Ranch. This population group occurs on conserved lands west of I-15 and north of Hwy. 56 in the City and County of San Diego. We have designated a fairly large area that encompasses a network of conserved lands with clay soils that may support additional occurrences. At present, this group includes three small occurrences (ACIL_6BLMO032, ACIL_6RSFE045, and ACIL_6THCO046) and two are questionably extant. Detection of additional occurrences, or enhancement, augmentation, or translocation, would likely be required for this group to remain viable going forward.

### Thread-leaved Brodiaea

Thread-leaved brodiaea is a perennial herb (geophyte) endemic to southern California. It occurs in San Diego, Los Angeles, Orange, Riverside and San Bernardino counties. In addition to historic habitat loss from development, the primary threat to this species is invasive plants, particularly nonnative grasses such as *Brachypodium distachyon*.

Thread-leaved brodiaea reproduces both by seed and by clonal propagation of the underground corms (bulb-like storage organs), which produce above-ground leaves each winter (Niehouse 1971). Research on *Brodiaea* species in general indicates they are genetically self-incompatible and thus, require pollinators for gene flow, sexual reproduction, and seed production (Niehouse 1971). Observations of thread-leaved brodiaea populations suggest that clonal reproduction from corms is more common than recruitment from seed (USWS 1998, 2009b, 2011). Reports from restoration efforts suggest that herbivores such as rabbits and gophers may influence brodiaea population dynamics by consuming corms and reducing population size (USFWS 2009b, 2011). Thread-leaved brodiaea is strongly associated with clay soils (although it occasionally occurs on non-clay alkaline soils), which restrict its potential distribution and suitable areas for restoration or transplantation (USFWS 1998, 2009b, 2011). Targeted soil studies on Camp Pendleton (AMEC 2009) identified soil parameters that may drive the distribution of this species. Refer to Table A-3 for thread-leaved brodiaea MOM occurrences on conserved lands in San Diego County, including estimated population sizes. Refer to Table A-4 for a list of thread-leaved brodiaea population groups; we describe these groups by MU below.

### Management Unit 6

Nearly all of the thread-leaved brodiaea occurrences within the MSPA occur in MU 6. This MU is coastal, with smaller, urban preserves that are largely fragmented. This MU supports several large and medium occurrences, as well as many small occurrences. In total, this MU supports 19 occurrences on conserved lands. We identified 4 population groups that include all occurrences. Only one of the small occurrences supported no plants during the last monitoring period, although no monitoring has occurred at four other small occurrences in over 5 years.

<u>Population Group 1: Oceanside</u>. This population group occurs in MU 6 in the City of Oceanside, north of State Route (SR) 78. It includes both medium (BRFI_6MOCE015, BRFI_6MGOR014) and small occurrences (BRFI_6MDOR013, BRFI_6MMOC022) on

**Table A-3**. Thread-leaved Brodiaea Occurrences on Conserved Lands in San Diego County.[1]

| Occurrence ID[2] | Occurrence Name | Preserve[3] | Land Owner[3] | Land Manager[3] | Max Pop Size[4] (year) | Recent Max Pop Size[5] (year) |
|---|---|---|---|---|---|---|
| **Management Unit 6** | | | | | | |
| *Large Populations* | | | | | | |
| BRFI_6LECA010 | Letterbox Canyon- Taylor Made | Letterbox Canyon-Taylor Made | Taylor Made Golf | Helix Community Conservancy | 1,100,000 (2005) | 13,807 (2017) |
| BRFI_6LECA012 | Letterbox Canyon-Newton Business Center | Carlsbad Highlands Ecological Reserve | CDFW | CDFW | 39,522 (2005) | 18,230 (2017) |
| BRFI_6RACA017 | Rancho Carillo | Rancho Carrillo HOA | Rancho Carrillo Master HOA | Rancho Carrillo Master HOA | 797,000 (2005) | 56,222 (2017) |
| BRFI_6RLCO019 | Rancho La Costa North and South | Rancho La Costa Habitat Conservation Area | CNLM | CNLM | 50,000 (2012) | 1000s[6,7] (2017) |
| *Medium Populations* | | | | | | |
| BRFI_6MGDR014 | Mission Gate Drive | Mission Gate Drive | Standard Pacific Corp | Standard Pacific Corp | 1,310 (2004) | 1,310 (2004) |
| BRFI_6MOCE015 | Mount Olive Cemetery | Mount Olive Cemetery Association. | Mount Olive Cemetery Association. | Mount Olive Cemetery Association. | 2,000 (2003) | 2,000 (2003) |
| BRFI_6RLCO018 | Rancho La Costa North | Rancho La Costa Habitat Conservation Area | CNLM | CNLM | 1,531 (2009) | 1000s[8] (2017) |
| *Small Populations* | | | | | | |
| BRFI_64SRA009 | 4S Ranch Specific Plan Habitat Management Area | 4-S Ranch Specific Plan Habitat Management Area | 4-S Ranch Masters Assn | 4-S Ranch Masters Assn | 18 (2008) | 18 (2008) |
| BRFI_6ARTR001 | Artesian Trails | Artesian Trails | Centurion Artesian Trails Corporation | Centurion Artesian Trails Corporation | 688 (2003) | 688 (2003) |

**Table A-3**. Thread-leaved Brodiaea Occurrences on Conserved Lands in San Diego County.[1]

| Occurrence ID[2] | Occurrence Name | Preserve[3] | Land Owner[3] | Land Manager[3] | Max Pop Size[4] (year) | Recent Max Pop Size[5] (year) |
|---|---|---|---|---|---|---|
| BRFI_6BMLO003 | Black Mountain Open Space | Black Mountain Open Space | San Diego | San Diego PRD | 100 (2010) | 100 (2010) |
| BRFI_6BMRA002 | Black Mountain Ranch | Black Mountain Ranch | San Diego | San Diego PRD | 24 (2016) | 24 (2016) |
| BRFI_6BVCR004 | Buena Vista Creek Ecological Reserve | Buena Vista Creek Ecological Reserve | CDFW | CNLM | 1,300 (2011) | 108[9] (2017) |
| BRFI_6CAHI005 | Calavera Hills Village H | Calavera Hills and Robertson Ranch Habitat Conservation Area | Calavera Hills Masters Association | CNLM | 2,351 (2008) | 631 (2010) |
| BRFI_6CAHI006 | Calavera Hills Village X | Calavera Hills Phase 2 & Robertson Ranch | Calavera Hills HOA | CNLM | 767 (2010) | 100s[10] (2017) |
| BRFI_6CONO007 | Carlsbad Oaks North Habitat Conservation Area | Carlsbad Oaks North Habitat Conservation Area | CNLM | CNLM | 728 (2010) | 65 (2017) |
| BRFI_6LACA008 | Lake Calavera | Lake Calavera Municipal Mitigation Parcel | Carlsbad | CNLM | 412 (2012) | 0 (2016) |
| BRFI_6LACA021 | Carlsbad Highlands | Carlsbad Highlands Ecological Reserve | CDFW | CDFW | 216 (2017) | 216 (2017) |
| BRFI_6MDOR013 | Mission Del Oro | Mission Del Oro HOA | Mission Del Oro HOA | Mission Del Oro HOA | 20 (2006) | 20 (2006) |
| BRFI_6MMOC022 | --- | --- | City of Oceanside | Urban Corps | 46 (2017) | 46 (2017) |

**Table A-3**. Thread-leaved Brodiaea Occurrences on Conserved Lands in San Diego County.[1]

| Occurrence ID[2] | Occurrence Name | Preserve[3] | Land Owner[3] | Land Manager[3] | Max Pop Size[4] (year) | Recent Max Pop Size[5] (year) |
|---|---|---|---|---|---|---|
| **Management Unit 8** | | | | | | |
| *Medium Populations* | | | | | | |
| BRFI_8NEMI016 | New Millennium, Rancho Santalina, Loma Alta | Private | Private | Unknown | 12,000 (2004) | 6,001 (2017) |
| *Small Populations* | | | | | | |
| BRFI_8DECA020 | Devil Canyon | Cleveland National Forest | USFS | USFS | 2,000 (1992) | 284 (2017) |

1 Table lists only occurrences in the San Diego Management and Monitoring Program's Master Occurrence Matrix (MOM) database.

2 Occurrence Identification (ID) per the San Diego Management and Monitoring Program (SDMMP) Master Occurrence Matrix (MOM) database.

3 Preserve/land owner/land manager: CDFW = California Department of Fish and Wildlife; CNLM = Center for Natural Lands Management; Carlsbad = City of Carlsbad; HOA = Homeowner's Association; San Diego = City of San Diego; San Diego PRD = City of San Diego, Parks and Recreation Department; USFS = U.S. Forest Service.

4 Indicates maximum recorded population size.

5 Indicates maximum recorded population size in the last 5 years (2012-2017) if data are available, or most recent year overall if data are not available.

6 CNLM recorded 226 plants in the maximum population extent for 2017, but indicated there were thousands of plants in the area.

7 Population categorized as large because size estimates exceeded 1,000 individuals within the last 5 years (2012-2017).

8 CNLM recorded 540 plants in the maximum population extent for 2017, but indicated there were thousands of plants in the area.

9 Population estimate per CDFW monitoring data.

10 CNLM recorded 155 plants in the maximum population extent for 2017, but indicated there were hundreds of plants elsewhere onsite. CNLM uses a previously established monitoring method with different monitoring units and monitoring areas than the SDMMP IMG protocol. They count vegetative plants in quadrats and note that many more plants occur in the maximum extent.

**Table A-4**. Thread-leaved Brodiaea Population Groups.

| Population Group[1] | Population Group Name | MOM Occurrence ID[2] | Population Size[3,4] | Population Group Characterization |
|---|---|---|---|---|
| 1 | Oceanside | BRFI_6MDOR013<br>BRFI_6MGDR014<br>BRFI_6MMOC022<br>BRFI_6MOCE015 | Small<br>Medium*<br>Small<br>Medium* | Mixed |
| 2 | Carlsbad North | BRFI_6BVCR004<br>BRFI_6CAHI005<br>BRFI_6CAHI006<br>BRFI_6LACA008<br>BRFI_6LACA021 | Small<br>Small*<br>Small<br>*Small*<br>Small | Small |
| 3 | Carlsbad South | BRFI_6CONO007<br>BRFI_6LECA010<br>BRFI_6LECA012<br>BRFI_6RACA017<br>BRFI_6RLCO018<br>BRFI_6RLCO019 | Small<br>Large<br>Large<br>Large<br>Medium<br>Large | Mixed |
| 4 | Black Mountain and Vicinity | BRFI_64SRA009<br>BRFI_6ARTR001<br>BRFI_6BMLO003<br>BRFI_6BMRA002 | Small*<br>Small*<br>Small*<br>Small | Small |
| 5 | San Marcos | BRFI_8NEMI016 | Medium | Medium |
| 6 | Devil Canyon | BRFI_8DECA020 | Small | Small |

1 Population group = one or more Master Occurrence Matrix (MOM) occurrences and other mapped localities that are in proximity to one another and potentially interbreed.

2 MOM = Master Occurrence Matrix.

3 Population size classes: large = >10,000 plants; medium = 1,001-10,000 plants; small = <1,000 plants.

4 Italics indicates population size was recorded as 0 during last monitoring event; * indicates >5 years since last monitoring event.

conserved and unconserved land owned largely by private entities within a matrix of urban development. We have no recent population size data for three of the four MOM occurrences, and no size information or current status for mapped localities at the eastern end of this group, south of Guajome Regional Park.

Population Group 2: Carlsbad North. This group occurs in MU 6 in the City of Carlsbad, south of SR 78 and north of Cannon Road. It includes five small occurrences (BRFI_6BVCR004, BRFI_6CAHI005 and -006, BFFI_6LACA008 and -021) on conserved lands owned by CDFW, the City of Carlsbad, and Homeowner's Associations (HOAs).

There is a high level of connectivity between conserved lands that support thread-leaved brodiaea in this group.

Population Group 3: Carlsbad South. This group occurs in MU 6 in the City of Carlsbad, north and south of Palomar Airport Road. We combined occurrences on both sides of Palomar Airport Road into one group at this time because of the presence of potential (conserved and unconserved) habitat for thread-leaved brodiaea between these two areas. Development in this area would reduce connectivity between the two areas, in which case they be reevaluated as distinct groups for the purpose of management. This group is the most robust in terms of both population size and management. There are currently four large (BRFI_6LECA010 and -012, BRFI_6RLCO019, and BRFI_6RACA017) and two small occurrences (BRFI_6CONO007, BRFI_6RCLO018) in this group. All occurrences are on conserved lands owned by the County of San Diego Public Works Department, Center for Natural Lands Management (CNLM), HOAs, and private entities.

Population Group 4: Black Mountain and Vicinity. This group occurs near the southeastern portion of MU 6, west of Interstate (I)-15 and north of SR 56. It includes one medium (BRFI_6BMLO003) and three small occurrences (BRFI_64SRA009, BRFI_6BMRA002, BRFI_6ARTR001) on conserved lands owned by the City of San Diego and private entities. Although all occurrences are adjacent to or near development, they are also in proximity to other conserved lands.

## Management Unit 8

There are only two conserved occurrences of thread-leaved brodiaea in MU 8, although additional records for this species occur on conserved lands. We designated two population groups, and both have the potential to support additional occurrences (if conserved).

Population Group 5: San Marcos. This group occurs in MU 8 in the City of San Marcos, north and south of SR 78. This group supports one, medium-sized MOM occurrence (BRFI_8NEMI016) on conserved lands. This population was disked after the last monitoring period (Levy pers. comm.). Most of the mapped locations of thread-leaved brodiaea in this group are unconserved and we have no population size information or recent status information for them. Some may be extant based on the presence of suitable habitat, while development likely extirpated others. Residential or industrial development surrounds all locations.

Population Group 6: Devil Canyon. This population group occurs just south of the San Diego-Riverside County border and west of the Tenaja Truck Trail and DeLuz Road, in the northwestern portion of MU8. It includes one small MOM occurrence (BRFI_8DECA020) and several other mapped localities on USFS lands in or near Devil Canyon. Thread-leaved brodiaea occurs directly north and northeast of this population group in Riverside County.

## Otay Tarplant

Otay tarplant is a late-spring-blooming annual herb endemic to southern San Diego County, where it occurs on clay soils and sub-soils. The primary threat to Otay tarplant is invasive plants, especially annual grasses and forbs (USFWS 2009c, IEMM 2012). Other threats include off-highway vehicle activity, illegal trails, trampling, and maintenance of access roads, utility corridors, trails, and fuel modification zones. Urban development over the last several decades has fragmented Otay tarplant habitat, placing this species at risk from loss of genetic connectivity and pollinators (SDMMP 2013). Habitat fragmentation that leads to loss of genetic diversity in the future would be of concern because Otay tarplant cannot cross-breed with genetically similar individuals.

Refer to Table A-5 for Otay tarplant MOM occurrences on conserved lands in San Diego County, including estimated population sizes. Refer to Table A-6 for a list of Otay tarplant population groups; we describe these groups by MU below.

### Management Unit 2

There is one Otay tarplant occurrence in MU 2 (DECO13_3PAVA001), on City of San Diego lands in Paradise Valley. We have not included this occurrence as part of the regional structure at this time because of isolation, threats, and lack of status data.

### Management Unit 3

Management Unit 3 supports the remaining tarplant occurrences. Habitat in the western portion of this MU is fragmented and plants occur on small, urban preserves, while habitat further east is more intact and on larger blocks of conserved land. Most of the tarplant habitat is disturbed, and invaded by nonnative grasses and forbs. Although tarplant occurrences can experience large yearly population fluctuations, this species has more large and medium-sized occurrences than the other herbaceous species in this study. In addition, it appears to respond favorably to management.

Population Group 1: Jamacha Boulevard. This group consists of one large occurrence (DECO13_3JABO028) on the slopes northwest of Jamacha Boulevard and south of Jamacha Junction (not mapped). This occurrence supported the largest number of plants of all occurrences monitored in 2017 (>780,000 plants).

**Table A-5**. Otay Tarplant Occurrences on Conserved Lands in San Diego County.[1]

| Occurrence ID[2] | Occurrence Name | Preserve[3] | Land Owner[3] | Land Manager[3] | Max Pop Size[4] (year) | Recent Max Pop Size[5] (year) |
|---|---|---|---|---|---|---|
| **Management Unit 2** | | | | | | |
| *Small Populations* | | | | | | |
| DECO13_2PAVA001 | Paradise Valley | Paradise Hills Community Park | San Diego | San Diego PRD | 1,000 (2003) | 200 (2016)[6] |
| **Management Unit 3** | | | | | | |
| *Large Populations* | | | | | | |
| DECO13_3DREA021 | Dennery Ranch East | Dennery Ranch | San Diego | San Diego PRD | 151,000 (2016) | 151,002 (2016) |
| DECO13_3JABO028 | Jamacha Boulevard | SDNWR | USFWS | USFWS | 780,273 (2017) | 780,273 (2017) |
| DECO13_3MMGR010 | Mother Miguel Grassland | SDNWR | USFWS | USFWS | 50,000 (2003) | 12,500 (2017) |
| DECO13_3ORVA018 | North Side of Otay River Valley near Wolf Canyon | Future Chula Vista Central City Preserve | Chula Vista | Chula Vista | 50,000 (2003) | 50,000 (2003) |
| DECO13_3PMA1002 | PMA1 (Rice Canyon & Other Canyons) | Chula Vista Central City Preserve | Chula Vista | Chula Vista | 157,000 (2017) | 157,000 (2017) |
| DECO13_3PMA4005 | PMA4 | Chula Vista Central City Preserve | Chula Vista | Chula Vista | 60,750 (2017) | 60,750 (2017) |
| DECO13_3RJER015 | Rancho Jamul Ecological Reserve Subpopulation #1 | Rancho Jamul Ecological Reserve | CDFW | CDFW | 286,615 (2017) | 286,615 (2017) |
| DECO13_3SVPC007 | Shinohara Vernal Pool Complex - SE Sweetwater Reservoir | San Diego National Wildlife Refuge | USFWS | USFWS | 100,000 (2017) | 100,000 (2017) |

**Table A-5**. Otay Tarplant Occurrences on Conserved Lands in San Diego County.[1]

| Occurrence ID[2] | Occurrence Name | Preserve[3] | Land Owner[3] | Land Manager[3] | Max Pop Size[4] (year) | Recent Max Pop Size[5] (year) |
|---|---|---|---|---|---|---|
| DECO13_3TRIM008 | Trimark/Gobbler's Knob/Horseshoe Bend | SDNWR | USFWS | USFWS | 122,280 (2017) | 122,280 (2017) |
| *Medium Populations* | | | | | | |
| DECO13_3BOME008 | Bonita Meadows | Bonita Meadows | Caltrans | Caltrans | 3,750 (2017) | 3,750 (2017) |
| DECO13_3DENC022 | Dennery Canyon South | Hidden Trails | San Diego | San Diego PRD | 5,000 (2003) | 5,000 (2003) |
| DECO13_3JAHI006 | Jamacha Hills | SDNWR | USFWS | USFWS | 1,500 (2017) | 1,500 (2017) |
| DECO13_3JOCA019 | Johnson Canyon | Otay Valley Regional Park | County | Otay Valley Regional Park JEPA | 486,723 (2001) | 2,000 (2017) |
| DECO13_3LOST027 | Lonestar | Lonestar Preserve | Caltrans | Caltrans | 1,130 (2016) | 45[7] (2017) |
| DECO13_3PMA2003 | PMA2 | Chula Vista Central City Preserve | Chula Vista | Chula Vista | 4,920 (2017) | 4,920 (2017) |
| DECO13_3PRVA013 | Proctor Valley | Otay Lakes Cornerstone Lands | San Diego PUD | San Diego PUD | 45,737 (2003) | 1,238 (2016) |
| *Small Populations* | | | | | | |
| DECO13_3BOME009 | Bonita Meadows | Bonita Meadows | Caltrans | Caltrans | 18 (2017) | 18 (2017) |
| DECO13_3DERA020 | Dennery Ranch | Cal Terraces HOA | Cal Terraces HOA | San Diego PRD | 50 (2010) | 7 (2016) |
| DECO13_3OMEA026 | Furby North | Otay Mesa West (Furby North) | County DPR | County of San Diego DPR | 700 (2017) | 700 (2017) |
| DECO13_3ORVA017 | Otay Valley East End | Otay Ranch Preserve | Otay Ranch POM | POM (County & Chula Vista) | 10,020 (2003) | 3 (2010) |

**Table A-5**. Otay Tarplant Occurrences on Conserved Lands in San Diego County.[1]

| Occurrence ID[2] | Occurrence Name | Preserve[3] | Land Owner[3] | Land Manager[3] | Max Pop Size[4] (year) | Recent Max Pop Size[5] (year) |
|---|---|---|---|---|---|---|
| DECO13_3PRVA014 | Proctor Valley (Bella Lago) | SDNWR | USFWS | USFWS | 50,000 (2003) | 0 (2016) |
| DECO13_3RHRA012 | Rolling Hills Ranch | Rolling Hills Ranch | Private | Chula Vista | 50,000 (2003) | 104 (2016) |
| DECO13_3SCPA016 | Salt Creek Parcel | Future Chula Vista Central City Preserve | Chula Vista | Chula Vista | 1,000 (1992) | 0 (2009) |
| DECO13_3SMHA024 | San Miguel Habitat Management Area West - DECO13 | OMWD | OMWD | OMWD | 928 (2016) | 148 (2017) |
| DECO13_3SMHA025 | San Miguel Habitat Management Area West - DECO13 | OMWD | OMWD | OMWD | 308 (2016) | 186 (2017) |
| DECO13_3SVFB011 | Spring Valley Fuel Break | SDNWR | USFWS | USFWS | 300 (2010) | 300 (2010) |
| DECO13_3WMCA023 | West of Moody Canyon | Cal Terraces | San Diego | None | 1,348,000 (2003) | 200 (2015)[8] |

[1] Table lists only occurrences in the San Diego Management and Monitoring Program's Master Occurrence Matrix (MOM) database. We do not show one occurrence because land owner did not want information released.

[2] Occurrence Identification (ID) per the San Diego Management and Monitoring Program (SDMMP) Master Occurrence Matrix (MOM) database.

[3] Preserve/land owner/land manager: Caltrans = California Department of Transportation; CDFW = California Department of Fish and Wildlife; Chula Vista = City of Chula Vista; County = County of San Diego; County DPR = County of San Diego, Department of Parks and Recreation; HOA = Homeowner's Association; JEPA = Joint Exercise of Powers Agreement; OMWD = Otay Municipal Water District; Otay Ranch POM = Otay Ranch Preserve Owner Manager; San Diego = City of San Diego; San Diego PRD = City of San Diego, Parks and Recreation Department; San Diego PUD = City of San Diego, Public Utilities Department; SDNWR = San Diego National Wildlife Refuge; USFWS = U.S. Fish and Wildlife Service.

[4] Indicates maximum recorded population size.

[5] Indicates maximum recorded population size in the last 5 years (2012-2017) if data are available, or most recent year overall if data are not available.

[6] M. Mulligan provided the 2016 population size.

[7] Population categorized as medium because size estimates exceeded 1,000 individuals within the last 5 years (2012-2017).
[8] Mapped by CBI during rapid assessment surveys in 2015 for the Southwest Otay Mesa Framework Resource Management Plan.

**Table A-6**. Otay Tarplant Population Groups.

| Population Group[1] | Population Group Name | MOM Occurrence ID[2] | Population Size[3,4] | Population Size Characterization |
|---|---|---|---|---|
| 1 | Jamacha Boulevard | DECO13_3JABO028 | Large | Large |
| 2 | Jamacha Hills | DECO13_3JAHI006 | Medium | Medium |
| 3 | Sweetwater Reservoir | DECO13_3SVPC007<br>DECO13_3MMGR010 | Large<br>Large | Large |
| 4 | PMA 4 | DECO13_3PMA4005 | Large | Large |
| 5 | Trimark-Bonita Meadows | DECO13_3TRIM008<br>DECO13_3BOME008<br>DECO13_3BOME009 | Large<br>Medium<br>Small | Mixed |
| 6 | Proctor Valley | DECO13_3PRVA013<br>DECO13_3PRVA014<br>DECO13_3SMHA024<br>DECO13_3SMHA025<br>DECO13_3RHRA012 | Medium<br>*Small*<br>Small<br>Small<br>Small | Mixed |
| 7 | PMA1 (Rice Canyon & Other Canyons) | DECO13_3PMA1002 | Large | Large |
| 8 | PMA2 | DECO13_3PMA2003 | Medium | Medium |
| 9 | Dennery Ranch East | DECO13_3DREA021<br>DECO13_3DENC022<br>DECO13_3DERA020 | Large<br>Medium*<br>Small | Mixed |
| 10 | Otay River Valley | DECO13_ORVA018 | Large* | Large |
| 11 | Southwest Otay Mesa | DECO13_3OMEA026<br>DECO13_3WMCA023 | Small<br>Small | Small |
| 12 | Johnson Canyon-Lonestar | DECO13_3JOCA019<br>DECO13_3LOST027<br>DECO13_ORVA017 | Medium<br>Medium<br>Small* | Medium |
| 13 | Rancho Jamul | DECO13_3RJER015 | Large | Large |

1 Population group = one or more Master Occurrence Matrix (MOM) occurrences and other mapped localities that are in proximity to one another and potentially interbreed.

2 MOM = Master Occurrence Matrix.

3 Population size categories: large = >10,000 plants; medium = 1,001-10,000 plants; small = <1,000 plants.

4 Italics indicates population size was recorded as 0 during last monitoring event; * indicates >5 years since last monitoring event.

Population Group 2: Jamacha Hills. This population group consists of a single, medium-sized occurrence (DECO13_3JAHI006) on conserved land owned by the USFWS (SDNWR).

Population Group 3: Sweetwater Reservoir. This group occurs south of the Sweetwater Reservoir, primarily on conserved lands owned by the USFWS (San Diego National Wildlife Refuge) and Sweetwater Authority. The group includes the large Shinohara vernal pool complex (DECO13_3SVPC007) and Mother Miguel grassland (DECO13_3MMGR010) occurrences, as well as plants on surrounding lands. Restoration efforts have enhanced this population group.

Population Group 4: PMA 4. This group consists of one large, conserved occurrence (DECO13_3PMA4005) on City of Chula Vista land in the City's Central City preserve. This occurrence occurs at least partially on restored habitat, and appears to be thriving despite high invasive weed cover in some areas.

Population Group 5: Trimark-Bonita Meadows. This population group consists of one large, one medium, and one small occurrence on conserved lands, the Trimark/Gobbler's Knob/Horseshoe Bend occurrence (DECO13_3TRIM008) on USFWS (SDNWR) land and the Bonita Meadows occurrences (DECO13_3BOME008 and DECO13_3BOME009) on Caltrans land. While there are some invasive species within both occurrences, cumulative population size exceeded 150,000 plants in recent years.

Population Group 6: Proctor Valley. This group consists of one medium occurrence on conserved land owned by the City of San Diego, Public Utilities Department (DECO13_3PRVA013) and four small occurrences on conserved lands on conserved lands owned by the USFWS (DECO13_3PRVA014) and HOA's or development companies (DECO13_3SMHA024, 025, DECO13_3RHRA012). Nonnative grasses are a threat at all of these occurrences.

Population Group 7: PMA 1 (Rice Canyon & other canyons). This is another large, conserved occurrence (DECO13_3PMA1002) on City of Chula Vista land in the City's Central City preserve. Invasive species are present, but do not appear to be suppressing the Otay tarplant occurrence significantly at this time.

Population Group 8: PMA 2. This is a medium-sized occurrence (DECO13_3PMA2003) on City of Chula Vista land in the City's Central City preserve.

Population Group 9: Dennery Ranch East. This group consists of large (DECO13_3DREA021), medium (DECO13_3DENC022), and small (DECO13_3DERA020) occurrences on conserved lands managed by the City of San Diego, Parks and Recreation Department (PRD). Although invasive plants are present, they do not appear to be impacting the large occurrence significantly at this time. Monitoring of the medium occurrence last occurred in 2005, and current status is unknown. The small occurrence had very few plants present in 2017.

Population Group 10: Otay River Valley. For the most part, we do not have size information for this population group because the majority of land is in private ownership. The exception is the occurrence on the north side of the Otay River near Wolf Canyon (DECO13_ORVA018), estimated at 50,000 individuals in 2003. In addition to this occurrence, the group consists of many mapped locations in upland areas north and south of the Otay River. The USFWS, the City of Chula Vista (Central City Preserve), and the Flat Rock Land Company LLC own conserved lands within this group.

Population Group 11: Southwest Otay Mesa. This group includes small occurrences on Furby-North (DECO12_3OMEA026) and Cal Terraces (DECO13_3WMCA023). The latter occurrence supported over 1 million plants in 2003 but only about 200 plants in 2015. This group is isolated from other population groups.

Population Group 12: Johnson Canyon-Lonestar. This population group consists of two medium and one small occurrences on conserved lands, the Johnson Canyon occurrence within the Otay Valley Regional Park (DECO13_3JOCA019), the Lonestar occurrence within the Lonestar Preserve (DECO13_3LOST027), and the Otay Valley east end occurrence (DECO13_ORVA017). We do not know if the small occurrence is extant, but suitable habitat appears to be present. The Otay Valley Regional Park JEPA and the San Diego Habitat Conservancy owns the medium occurrences; the small occurrence is with the Otay Ranch POM (Preserve Owner Manger). The Johnson Canyon occurrence has declined from a large population in 2001 (almost 500,000 plants) to its current status in 2017, likely due to invasive plants.

Population Group 13: Rancho Jamul. The Rancho Jamul population group is a large occurrence (DECO13_3RJER015) that consists of several subpopulations on conserved land owned and managed by CDFW on the Rancho Jamul Ecological Reserve. Invasive species had suppressed much of this occurrence following fire; however, invasive species control as part of the South County Grasslands project (CBI 2017) restored Otay tarplant habitat and increased tarplant numbers dramatically.

## Dehesa Nolina

Dehesa nolina is a perennial herb that is endemic to San Diego County and Baja California, Mexico. This species is restricted to gabbroic or metavolcanic soils in chaparral or occasionally, coastal sage scrub or grassland habitats (Oberbauer 1979, Oberbauer and Vanderwier 1991, Beauchamp 1986, Rombouts 1996, CNPS 2012, CBI 2012, 2015, McNeal and Dice 2016).

Dehesa nolina is a fire-adapted, clonal species that re-sprouts from an underground stem, and also reproduces sexually through a dioecious breeding system (male and female flowers on separate plants) (Dice 1988, Rombouts 1996, CBI 2015).[1] Flowering generally occurs between June and July, and is sporadic unless stimulated by fire or other disturbance (Oberbauer 1979, Dice 1988, USFWS 1995, Rombouts 1996, and others). Flowers are presumably insect-pollinated (Rombouts, 1996), so plants of different sexes must occur within range of one another for successful pollination and viable seed production (Rombouts 1996, CBI 2015). Based on the breeding system, species distribution, and dependence on fire or other disturbance for flowering, recruitment from seed is rare (Oberbauer 1979, Dice 1988).

The genetic diversity of Dehesa nolina is extremely low; however, this may be normal for the species and genus. The dioecious mating system, which would typically maintain a high level of genetic diversity, possibly evolved after low levels of genetic diversity were already established (Rombouts 1996). There exists some genetic divergence between populations in the US and Mexico, but no divergence within these populations (Heaney pers. comm.).

Altered fire regimes and subsequent invasion of nonnative grasses potentially threaten all occurrences. To date, only the Dehesa Mountain (South Crest) and McGinty Mountain occurrences have significant invasive grass issues. Substantial plant losses occurred in invaded habitat on South Crest after the 2003 Cedar Fire. EHC is controlling invasive plants to reduce fine fuels and augmenting Dehesa nolina on South Crest to offset these losses and reduce future impacts. There are no significant declines in nolina population sizes at other occurrences.

Refer to Table A-7 for Dehesa nolina MOM occurrences on conserved lands in San Diego County, including estimated population sizes. Refer to Table A-8 for a list of Dehesa nolina population groups; we describe these groups by MU below.

### Management Unit 3

Dehesa nolina occurs in inland portions of MU 3, with the distribution centered on Dehesa Mountain, McGinty Mountain, and Sycuan Peak. While the majority of the species occurs on conserved lands, there are stands of unconserved plants on private lands.

Population Group 1: Dehesa Mountain. The Dehesa Mountain group includes one of the three largest occurrences (NOIN_3SOCR003) of this species throughout its range. The majority of plants in this group occur within the Greater Crestridge Ecological Reserve complex (South Crest, Odom, and Michelson preserves). Additional plants (unconserved)

[1] Although reportedly dioecious, CBI biologists have observed Dehesa nolina flowers with pistils and stamens and suggest it may be more accurate to describe these plants as functionally staminate or functionally pistillate.

**Table A-7**. Dehesa Nolina Occurrences on Conserved Lands in San Diego County.[1]

| Occurrence ID[2] | Occurrence Name | Preserve[3] | Land Owner[3] | Land Manager[3] | Max Pop Size[4] (year) | Recent Max Pop Size[5] (year) |
|---|---|---|---|---|---|---|
| **Management Unit 3** | | | | | | |
| *Large Populations* | | | | | | |
| NOIN_3MGMT002 | McGinty Mountain Summit & Ridges SW to Mexican Canyon. | McGinty Mountain Preserve/SDNWR | TNC/USFWS | TNC/USFWS | 4,500+ (2014) | 4,500+ (2014) |
| NOIN_3SOCR003 | South Crest Properties | South Crest Properties | EHC | EHC | 2,688 (2017) | 2,688 (2017) |
| NOIN_3SYPE004 | Sycuan Peak | Sycuan Peak ER | CDFW | CDFW | 50,000 (2017) | 50,000 (2017) |
| NOIN_3SYPE005 | Southeast of Sycuan Peak | Sycuan Peak ER | CDFW | CDFW | 5,000 (2017) | 5,000 (2017) |
| *Small Populations* | | | | | | |
| NOIN_3STTR006 | Skyline Truck Trail | Skyline Truck Trail | EHC | EHC | 52 (2014) | 9 (2017) |
| *Misidentified Population (Dehesa nolina does not occur at this location)* | | | | | | |
| NOIN_3MGMT001 | 1 Mile NW of McGinty Mountain | SDNWR | USFWS | USFWS | N/A | N/A |

[1] Table lists only occurrences in the San Diego Management and Monitoring Program's Master Occurrence Matrix (MOM) database..

[2] Occurrence Identification (ID) per the San Diego Management and Monitoring Program (SDMMP) Master Occurrence Matrix (MOM) database.

[3] Preserve/land owner/land manager: CDFW = California Department of Fish and Wildlife; EHC = Endangered Habitats Conservancy; SDNWR = San Diego National Wildlife Refuge; Sycuan Peak ER = Sycuan Peak Ecological Reserve; TNC = The Nature Conservancy; USFWS = U.S. Fish and Wildlife Service.

[4] Indicates maximum recorded population size.

[5] Indicates maximum recorded population size in the last 5 years (2012-2017).

**Table A-8**. Dehesa Nolina Population Groups.

| Population Group[1] | Population Group Name | MOM Occurrence ID[2] | Population Size[3,4] | Population Group Characterization |
|---|---|---|---|---|
| 1 | Dehesa Mountain | NOIN_3SOCR003 | Large | Large |
| 2 | McGinty Mountain | NOIN_3MGMT002 | Large | Large |
| 3 | Sycuan Peak | NOIN_3SYPE004<br>NOIN_3SYPE005 | Large<br>Large | Large |
| 4 | Skyline Truck Trail East | NOIN_3STTR006 | Small | Small |

[1] Population group = one or more Master Occurrence Matrix (MOM) occurrences and other mapped localities that are in proximity to one another and potentially interbreed.

[2] MOM = Master Occurrence Matrix.

[3] Population size classes: large = >500 plants; medium = 101-500 plants; small = <100 plants.

[4] Unknown = occurrence not monitored, population size unknown.

occur largely on Sycuan Tribal Development Corporation lands and other privately-owned parcels adjacent to Dehesa Road.

Population Group 2: McGinty Mountain. This is another of the three largest Dehesa nolina occurrences (NOIN_3MGMT002). The majority of this group occurs on conserved lands owned and managed by the USFWS (San Diego National Wildlife Refuge) and The Nature Conservancy. Additional plants occur within the boundary of this group on private lands, including lands owned by the Sycuan Tribal Development Corporation.

Population Group 3: Sycuan Peak. This population group contains two Dehesa nolina occurrences (NOIN_3SYPE004 and -005), and appears to be the largest known population of Dehesa nolina within the species' range. Both occurrences are on conserved lands owned and managed by CDFW (Sycuan Peak Ecological Reserve).

Population Group 4: Skyline Truck Trail East. This small population group is directly south of Group 3, and consists of scattered stands of plants on conserved and private lands (NOIN_3SKTT006). Conserved plants occur on the EHC-owned and managed Skyline Truck Trail Preserve.

### Parry's Tetracoccus

Parry's tetracoccus is a deciduous shrub that occurs between 165-1000 m elevation on gabbroic soils in chaparral and coastal sage scrub in Orange, Riverside, and San Diego counties, and Baja California, Mexico (CNPS 2012). In San Diego County, the species occurs sporadically in coastal foothills, but may be locally abundant (Dressler 1954).

Parry's tetracoccus is likely fire-adapted; however, the fire-response mechanism is not known. Altered fire regimes are a primary threat to this species, although plants on South Crest recovered well after the 2003 Cedar Fire. Development and habitat fragmentation also threaten this species.

The species is dioecious, bearing male and female flowers on different shrubs. Flowers are presumably insect-pollinated and governed by rainfall patterns; flowering typically occurs between April and May (CNPS 2012).

We know very little about the ecology of Parry's tetracoccus. We suspect that the species' affinity for gabbroic soils limit its distribution. Other factors that likely play a role in distribution include temperature and rainfall (Dressler 1954). Refer to Table A-9 for Parry's tetracoccus MOM occurrences on conserved lands in San Diego County, including estimated population sizes. Refer to Table A-10 for a list of Parry's tetracoccus population groups; we describe these groups by MU below.

### Management Units 3 and 11

Parry's tetracoccus occurs primarily in MU 3, although there are some mapped locations along the very western boundary of MU 11. In MU 3, large stands occur on the three major, gabbro peaks within this population group: Dehesa Mountain, McGinty Mountain, and Sycuan Peak. There are also mapped locations and suitable habitat for this species to the east, in Lawson and Lyons valleys. This species often occurs in proximity to Dehesa nolina.

> <u>Population Group 4: South County</u>. This group occurs primarily in MU 3, with a few plants to the east in MU 11. Many (but not all) of the populations within this group are on conserved lands owned by EHC (TEDI_3SOCR001, Skyline Truck Trail Preserve [no occurrence ID yet]), USFWS and TNC (TEDI_3MGMT002 and -003), and CDFW (TEDI_3SYPE004). Additional plants occur on private lands in the vicinity of these populations, and in Lyons Valley.

### Management Unit 4

There are no MOM occurrences in this population group; however, there are stands of Parry's tetracoccus within the County of San Diego-owned Mt. Gower Preserve and there are CNDDB records of this species scattered southward to Barona. This area could be important for Parry's tetracoccus because of the relatively undisturbed terrain, particularly in the north.

> <u>Population Group 3: Mt. Gower-Barona</u>. This group occurs in MU 4, where Parry's tetracoccus occurs locally on gabbroic soils between Mt. Gower and the Barona Indian

**Table A-9**. Parry's Tetracoccus Occurrences on Conserved Lands in San Diego County.[1]

| Occurrence ID[2] | Occurrence Name | Preserve[3] | Land Owner[3] | Land Manager[3] | Max Pop Size[4] (year) | Recent Max Pop Size[5] (year) |
|---|---|---|---|---|---|---|
| **Management Unit 3** | | | | | | |
| *Large Populations* | | | | | | |
| TEDI_3MGMT003 | McGinty Mountain South | McGinty Mountain Preserve/SDNWR | TNC/USFWS | TNC/USFWS | 1000+ (2017)[6] | 1000+ (2017)[6] |
| TEDI_3SYPE004 | Sycuan Peak | Sycuan Peak Ecological Reserve | CDFW | CDFW | 1000+ (2017)[6] | 1000+ (2017)[6] |
| *Medium Populations* | | | | | | |
| TEDI_3MGMT002 | McGinty Mountain North | SDNWR | USFWS | USFWS | 200 (2015) | 200 (2015) |
| TEDI_3SOCR001 | South Crest Properties | South Crest Properties | EHC | EHC | 388 (2015) | 388 (2015) |
| ---[7] | Skyline Truck Trail | Skyline Truck Trail Preserve | EHC | EHC | >100 (2016) | >100 (2016) |
| **Management Unit 8** | | | | | | |
| *Large Populations* | | | | | | |
| TEDI_8SMMO005 | San Marcos Mountains-North | Palisades Estate | CPH Vista Palisades LLC | CPH Vista Palisades LLC | 6,800 (2001)[8] | 6,800 (2001)[8] |
| *Medium Populations* | | | | | | |
| TEDI_8MEMT006 | South Merriam Mountains | City of Escondido Open Space | Escondido | Escondido | 1000+ (2017)[6] | 1000+ (2017)[6] |

**Table A-9**. Parry's Tetracoccus Occurrences on Conserved Lands in San Diego County.[1]

| Occurrence ID[2] | Occurrence Name | Preserve[3] | Land Owner[3] | Land Manager[3] | Max Pop Size[4] (year) | Recent Max Pop Size[5] (year) |
|---|---|---|---|---|---|---|
| *Small Populations* | | | | | | |
| TEDI_8WIGA008 | Wilderness Gardens | Wilderness Gardens Preserve | County | County | 2-20 (2015) | 2-20 (2015) |
| *Unknown Population Size* | | | | | | |
| TEDI_8MMPR007 | Monserate Mountain Preserve | Monserate Mountain Preserve | Fallbrook Land Conservancy | Fallbrook Land Conservancy | Unknown | Unknown |

[1] Table lists only occurrences in the San Diego Management and Monitoring Program's Master Occurrence Matrix (MOM) database.

[2] Occurrence Identification (ID) per the San Diego Management and Monitoring Program (SDMMP) Master Occurrence Matrix (MOM) database.

[3] Preserve/land owner/land manager: CDFW = California Department of Fish and Wildlife; County = County of San Diego; EHC = Endangered Habitats Conservancy; Escondido = City of Escondido; SDNWR = San Diego National Wildlife Refuge; TNC = The Nature Conservancy; USFWS = U.S. Fish and Wildlife Service.

[4] Indicates maximum recorded population size.

[5] Indicates maximum recorded population size in the last 5 years (2012-2017) if data are available, or most recent year overall if data are not available.

[6] Population size estimate based on visual observations during rare plant monitoring and/or soil sampling.

[7] Occurrence conserved and IMG monitoring conducted; does not yet have an Occurrence ID.

[8] Occurrence partially conserved.

**Table X**. Parry's Tetracoccus Population Groups.

| Population Group[1] | Population Group Name | MOM Occurrence ID[2] | Population Size[3,4] | Population Group Characterization |
|---|---|---|---|---|
| 1 | Fallbrook-Pala | TEDI_8MMPR007<br>TEDI_8WIGA008 | Unknown<br>Small | Mixed? |
| 2 | Merriam-San Marcos Mountains | TEDI_6MEMT006<br>TEDI_8SMMO005 | Medium<br>Large* | Mixed |
| 3 | Mt. Gower-Barona | --- | Unknown[5] | Unknown |
| 4 | South County[6] | TEDI_3MGMT002<br>TEDI_3MGMT003<br>TEDI_3SOCR001<br>TEDI_3SYPE004 | Medium<br>Large<br>Medium<br>Large | Mixed |

1 Population group = one or more Master Occurrence Matrix (MOM) occurrences and other mapped localities that are in proximity to one another and potentially interbreed.

2 MOM = Master Occurrence Matrix.

3 Population size classes: large = >500 plants; medium = 101-500 plants; small = <100 plants.

4 * indicates >5 years since last monitoring event; unknown = occurrence not monitored, population size unknown.

5 Visual observations of the Mt. Gower-Barona group in 2017 indicate that the population is likely medium or large.

6 Parry's tetracoccus also occurs on the Skyline Truck Trail Preserve, but is not in the MOM database yet.

Reservation. Although we have no population size information, and there are no established MOM occurrences, mapping exists within the County of San Diego's Mt. Gower Preserve, the Ramona Country Estates, and on the Barona Indian Reservation. Conserved plants occur only in the Mt. Gower Preserve.

### Management Unit 8

Management Unit 8 has a relatively low proportion of conserved to unconserved lands, particularly for lands that support Parry's tetracoccus. In addition, we do not have good population data for this species in this MU, but suspect that population numbers may be high in some areas of intact habitat.

Population Group 1: Fallbrook-Pala. This group occurs in MUs 8 and 9, and encompasses the northernmost occurrences of Parry's tetracoccus in San Diego County and those immediately north in Riverside County. We identified at least 6 discrete clusters of plants on conserved and unconserved lands. This includes one small MOM occurrence (TEDI_8WIGA008) and one MOM occurrence of unknown size (TEDI_8MMPR007). MOM occurrences and other mapped localities occur on conserved lands owned by the Bureau of Land Management (BLM), U.S. Forest Service (USFS), County of San Diego, Department of Parks and Recreation, Fallbrook Public Utility Department, and Fallbrook Land Conservancy (Monserate Mountain Preserve).

Population Group 2: Merriam-San Marcos Mountains. This group includes one large MOM occurrence (TEDI_6SMMO005) and one medium MOM occurrence (TEDI_8MEMT006). Additional mapped but unconserved plants occur throughout this area. Plants appear confined largely to slopes and ridgelines of the San Marcos and Merriam Mountains, surrounded by or in proximity to urban development. Conserved land that supports plants in the Merriam Mountains is owned by the City of Escondido, while part of the San Marcos Mountains population is partially conserved on private lands.

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# Appendix A

# Supplemental Information

## Appendix A-1

# Appendix A-1

# Potential Conservation and Management Actions

We discuss key conservation and management actions for target species in Section 6 of the report. In this appendix, we provide a complete list of potential conservation and management actions for each target species. Note that actions listed may not necessarily apply to all occurrences within a group. Refer to Section 6 of the report for locations of population groups (Figures 6-10) and definitions of management actions (Table 13).

**Table A-1**. Potential Conservation and Management Actions for San Diego Thornmint.

| Management Unit | Population Group | Conservation or Management Action | | | | | |
|---|---|---|---|---|---|---|---|
| | | Conserve | Survey | Establish | Enhance | Expand | Augment[1] |
| 6 | 1 | X | | | X | X | X |
| 6 | 2 | | | | X | X | X |
| 6 | 3 | | | | X | X | X |
| 6 | 4 | | | | X | X | X |
| 6 | 5 | | | | X | X | X |
| 5 | 6 | | | | X | X | X |
| 4 | 7 | | | | X | X | X |
| 4 | 8 | X | X | | X | | |
| 4 | 9 | | X | | X | | X |
| 4 | 10 | | | | X | X | X |
| 4 | 11 | X | X | | X | | |
| 3 | 12 | | | | X | X | X |
| 3 | 13 | | | | X | X | |
| 3 | 14 | | | | X | X | X |
| 3 | 15 | | | | X | X | X |
| 3 | 16 | | | | X | X | X |
| 3 | 17 | | | | X | X | X |

[1] Augmentation recommended only if enhancement measures do not recover species.

**Table A-2**. Potential Conservation and Management Actions for Thread-leaved Brodiaea.

| Management Unit | Population Group | Conservation or Management Action | | | | | |
|---|---|---|---|---|---|---|---|
| | | Conserve | Survey | Establish | Enhance | Expand | Augment[1] |
| 6 | 1 | X | | | X | X | |
| 6 | 2 | | | | X | X | X |
| 6 | 3 | | | | X | X | X |
| 6 | 4 | | | X | X | X | X |
| 8 | 5 | X | | | X | X | |
| 8 | 6 | | X | | | | |

[1] Augmentation recommended only if enhancement measures do not recover species.

**Table A-3**. Potential Conservation and Management Actions for Otay Tarplant.

| Management Unit | Population Group | Conservation or Management Action | | | | | |
|---|---|---|---|---|---|---|---|
| | | Conserve | Survey | Establish | Enhance | Expand | Augment[1] |
| 3 | 1 | | | | X | | |
| 3 | 2 | | | | X | | |
| 3 | 3 | | | | X | | |
| 3 | 4 | | | | X | | |
| 3 | 5 | | | | X | | |
| 3 | 6 | | | | X | | X |
| 3 | 7 | | | | X | | |
| 3 | 8 | | | | X | | |
| 3 | 9 | X | | | X | | |
| 3 | 10 | | | | X | | X |
| 3 | 11 | X | | | X | | |
| 3 | 12 | | | | X | | X[1] |
| 3 | 13 | | | | X | | |
| 3 | 14 | | | | X | | |

[1]Augmentation recommended only if enhancement measures do not recover species.

**Table A-4**. Potential Conservation and Management Actions for Dehesa Nolina.

| Management Unit | Population Group | Conservation or Management Action | | | | | |
|---|---|---|---|---|---|---|---|
| | | Conserve | Survey | Establish | Enhance | Expand | Augment[1] |
| 3 | 1 | X | | | X | | |
| 3 | 2 | | | | X | | |
| 3 | 3 | | | | X | | |
| 3 | 4 | X | | | | | |

[1] Augmentation recommended only if enhancement measures do not recover species.

**Table A-5**. Potential Conservation and Management Actions for Parry's Tetracoccus.

| Management Unit | Population Group | Conservation or Management Action | | | | | |
|---|---|---|---|---|---|---|---|
| | | Conserve | Survey | Establish | Enhance | Expand | Augment[1] |
| 8 | 1 | X | X | | | | |
| 6, 8 | 2 | X | X | | | | |
| 4 | 3 | X | X | | | | |
| 3 | 4 | X | X | | X | | |

[1] Augmentation recommended only if enhancement measures do not recover species.

# Appendix B

# Conceptual Models

# Appendix B
# Conceptual Models

We developed or refined conceptual models for the five target species to identify environmental covariates, focus field assessments, highlight management needs, and inform spatially explicit habitat suitability models under current and future climatic conditions.

Conceptual models align management actions with science and plan goals and objectives (Gross 2003). They make implicit ideas explicit and identify areas of critical uncertainty. Model structure can vary from a simple written statement to a complex diagram showing numerous interconnected elements. Regardless of structure, conceptual models formalize our understanding of system dynamics and identify relationships between different aspects of the system. Conceptual models must be concise and constrained by management goals and scientific consensus. They should include enough complexity to select achievable management actions, but not show all possible relationships, especially those not associated with management goals.

We adopted the format proposed by Hierl et al. (2007) and refined by the Institute for Ecological Monitoring and Management (IEMM) in a conceptual model workshop (Lewison et al. 2012). Hierl et al. (2007) described six steps for creating a conceptual model for adaptive management:

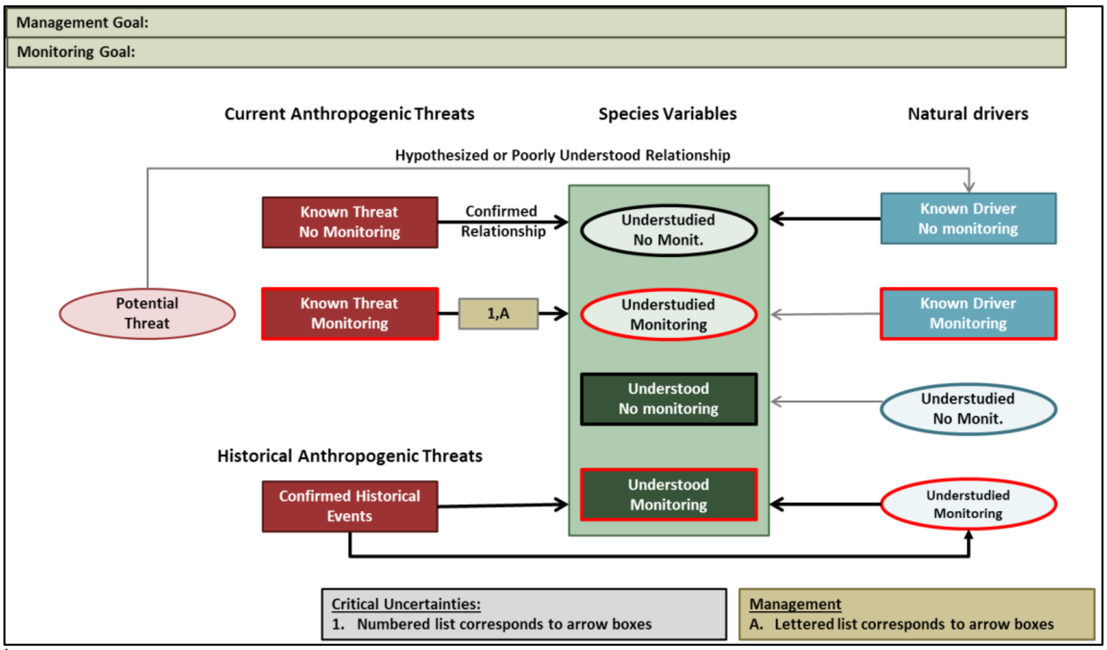
1. Identify the conservation management and monitoring goal.
2. Identify anthropogenic threats to the species.
3. Identify natural drivers of the species.
4. Identify variables within the species biology/ecology that evaluate (a) if goals are met and (b) response to management.
5. Describe potential management activities and what processes they will affect (as part of an iterative process).
6. Identify critical uncertainties (as part as an iterative process).

Conceptual models included in this document follow the same general structure, as outlined below and depicted in Figure B-1:

- We list management and monitoring goals at the top of the model.
- We separate model elements into three broad categories: anthropogenic threats (red), species variables (green), and natural drivers (blue).

- We use arrows to indicate the direction of relationships between model elements, with black lines depicting known relationships and grey lines depicting putative or unconfirmed, hypothetical relationships.

**Figure B-1**. Diagram of General Model Structure.[1]




[1] Anthropogenic threats in pink, species variables in light green and natural species drivers in light blue are critical uncertainties. Boxes indicate elements for which we have scientific information, and ovals represent understudied or poorly understood elements. Arrows point at species box and not necessarily specific variables. Elements outlined in red are monitoring targets.

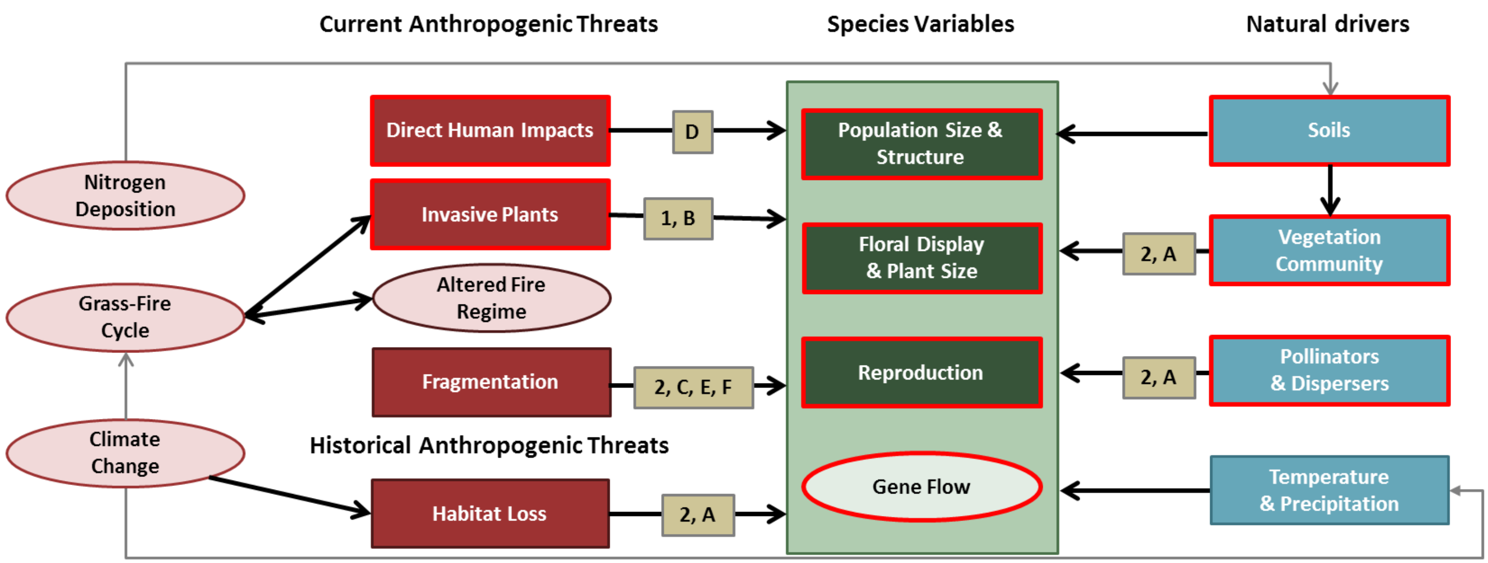
Although conceptual models should avoid critical uncertainties or hypothetical statements about process, we have included some important questions in light-colored circles where very little is known about a species, and at the bottom of the model along with potential management actions. We also include these in the model with a corresponding number or letter in a box next to the model element or relationship they influence. Critical uncertainties and management whose potential actions are unknown are included only at the bottom of the diagram. For these models, arrows for anthropogenic and natural drivers point to the species, but not to specific variables.

We present conceptual model diagrams in Figures B-2 to B-6 and supporting narratives in Tables B-1 to B-5 for the five target species. We based models and narratives on background information on species biology, threats, and distribution plus additional sources, as cited in the narratives. Identified natural drivers informed selection of habitat suitability modeling components; we used other model elements (e.g., threats, population size/structure, and natural drivers) to develop regional population structures.

**Figure. B-2**. San Diego Thornmint Conceptual Model Diagram.

**Management Goal:** Maintain large populations, enhance small populations, and establish new populations or pollinator habitat to buffer against environmental stochasticity, maintain genetic diversity, and promote connectivity, thereby enhancing resilience within and among MUs over the long-term (>100 years) in native habitats.

**Monitoring Goal:** Monitor extant, conserved populations annually to assess population status , identify threats, and determine management needs.




<u>Critical Uncertainties:</u>

1. Best management practices (BMPs) for habitat restoration/enhancement.
2. BMPs for controlling invasive plants.
3. Pollinator attractants.
4. Seed storage, germination rates, and propagation methods.

Others: Visualized Processes

<u>Management</u>

A. Restore/enhance habitat, including pollinator habitat.
B. Control weeds.
C. Enhance connectivity via 'steppingstone' populations.
D. Control access.
E. Collect and bank seeds.
F. Move seeds to facilitate gene flow.

**Table B-1. San Diego Thornmint Conceptual Model Narrative.**

| | | |
|---|---|---|
| **Goals** | | |
| Management | Maintain large populations, enhance small populations, and establish new populations or pollinator habitat to buffer against environmental stochasticity, maintain genetic diversity, and promote connectivity, thereby enhancing resilience within and among MUs over the long-term (>100 years) in native habitats. | |
| Monitoring | Monitor extant, conserved populations annually using a regional monitoring protocol to assess population status (abundance, spatial extent), identify threats, and determine management needs. | |
| **Anthropogenic Threats** | | |
| Direct Human Impacts | Human-related activities can result in plant mortality, reduced reproduction, and limited seed bank inputs through trampling, soil surface disturbance, erosion, and/or dispersal of nonnative propagules. Potential sources of disturbance include recreational activities (motorized ORVs, hiking, biking), irrigation runoff from adjacent development, and grazing (not currently an issue in San Diego County). | USFWS 2009a |
| Invasive Plants | Invasive species (primarily grasses and forbs) are the primary threat to San Diego thornmint persistence. Invasive plants out-compete thornmint for resources (nutrients, light, water, space), thus affecting thornmint size and reproductive output; suppress germination (thatch); potentially alter soil chemistry; and potentially contribute to a grass-fire cycle which may result in habitat alteration. Invasive species that produce dense thatch may impact potential pollinators (e.g., ground-dwelling bees). | Bauder and Sakrison 1997, 1999, Lawhead 2006, USFWS 2009a, Klein 2009 |
| Fragmentation | Fragmentation due to development or other disturbance may result in population isolation and reduced gene flow. Conserved populations in proximity to development are subject to increased invasive species, herbivory, erosion, trampling. If San Diego thornmint is self-incompatible, fragmentation could represent a severe threat to the species. | USFWS 2009a |
| Habitat Loss | With listing, habitat loss is no longer a primary to this species. | USFWS 2009a |
| **Natural Drivers** | | |
| Soils | Small clay lenses within a larger matrix of non-clay soil; the species appears restricted to clay soils, including clays derived from gabbro rock. The presence of appropriate soil determines the | Oberbauer and Vanderwier 1991, USFWS 2008 |

**Table B-1. San Diego Thornmint Conceptual Model Narrative.**

| | | |
|---|---|---|
| | distribution of potential habitat. The narrow extent of suitable soils exacerbates the role of habitat loss and fragmentation as a threat.<br>Our soils study showed that thornmint is restricted to clay soils with a particularly low sand content, and has a low tolerance for metals. | |
| Vegetation Community | Grasslands, coastal sage scrub, and chaparral; suitable associations must support thornmint pollinators. | USFWS 2008, SANDAG 2012 |
| Temperature & Precipitation | Rainfall and temperature both affect germination rate and successful reproduction. | Bauder and Sakrison 1997, USFWS 2009a |
| Pollinators & Dispersers | Dominant visitors/effective pollinators appear to be bees in the Apidae and Halictidae families. Seeds appear to be primarily gravity-dispersed locally. | Bauder and Sakrison 1997, Klein 2009 |
| Herbivory | Herbivory has been reported (e.g., rabbits, possibly snails), but is not considered a widespread threat or primary driver at this time, so is not included in the conceptual model. | City of San Diego 2005, USFWS 2009a |
| **Species Variables (Measurable Aspects of Species Response)** | | |
| Population Size & Structure | Includes population size, shape, geographic distribution, and fluctuations associated with environmental and demographic stochasticity. | Bauder and Sakrison 1999, USFWS 2009a |
| Floral Display & Plant Size | Includes plant biomass and flower visibility, plant height, branching, and flower production. Seed production increases with biomass; floral visibility is important for attracting pollinators. | Bauder et al. 1994, Bauder and Sakrison 1997, 1999, Klein 2009 |
| Reproduction | Includes plant fecundity (seed production), seed viability and germination rates, and inputs to seed bank. | Bauder and Sakrison 1997, Bauder and Sakrison 1999 |
| **Critical Species Variables Uncertainties** | | |
| Gene Flow | The breeding system is unknown. Insects visit flowers, so outcrossing may be the primary breeding mechanism. Other species of *Acanthomintha* exhibit some level of self-compatibility; however, the presence of sterile upper stamens suggests that self-pollination may be limited in San Diego thornmint. Small populations may be susceptible to inbreeding and genetic drift. The USGS Western Ecological Research Center is finalizing genetic studies for this species. | Steek 1995, Bauder and Sakrison 1997, Scalfani 2005, USFWS 2009a, Klein 2009 |
| **Critical Process Uncertainties** | | |
| Climate Change | Predicted warming temperatures may result in drier and hotter conditions in southern California in the | Bergengren et al. 2001, Araujo and New |

**Table B-1. San Diego Thornmint Conceptual Model Narrative.**

| | | |
|---|---|---|
| | future. Habitat suitability modeling for this project showed that thornmint habitat declined, but still persisted under future climate scenarios. Potential impacts to thornmint include (1) reduced germination and smaller population sizes; (2) inhibited germination; (3) increase in nonnative species due to a shift in timing of annual rainfall; (4) reduced pollinator effectiveness if timing of pollinator life-cycles and thornmint flowering become offset; and (5) increased fire frequency and subsequent erosion and nonnative/native plant invasion. | 2007, Westerling and Bryant 2008, Conlisk et al. 2013 |
| Altered Fire Regime | Altered fire regimes may affect population abundance by increasing seed mortality or promoting invasive species. | Bauder and Sakrison 1999, USFWS 2009a, Conlisk et al. 2013 |
| Grass-Fire Cycle | Nonnative grasses increase the fine fuel load and fire risk, and the reduced fire return interval then promotes nonnative grasses, leading to habitat type conversion. This cycle may affect soil and water budgets, increase erosion, promote invasive plant species, and impact pollinators. Habitat components that may be affected include bare ground and openings in shrub habitat, species composition, and cryptogamic crusts. | D'Antonio and Vitousek 1992, Brooks et al. 2004, Reiner 2007, and others |
| Nitrogen Deposition | Excess nitrogen may alter soil properties (including soil microbial community) and, subsequently, plant species composition and structure. Fire may alter/reduce effects of nitrogen deposition on productivity in the short-term. Nitrogen deposition likely affects most areas within the range of this species. | Allen et al. 1998, Zavaleta et al. 2003, Henry et al. 2006, Tonnesen et al. 2007, Talluto and Suding 2008, Vourlitis and Pasquini 2009, Bobbink et al. 2010, Fenn et al. 2010, Ochoa-Hueso and Manrique 2010, Ochoa-Hueso et al. 2011 |
| **Potential Management Actions** | | |
| A | Restore or enhance suitable habitat, including habitat for pollinators. | |
| B | Control weeds to reduce competition and fire risk. | |
| C | Enhance connectivity by establishing "steppingstone" populations at sites with appropriate soils using a suite of techniques (e.g., seeding, pollinator release); test soils prior to establishing or translocating populations. | |
| D | Control access by closing and/or rerouting trails and roads inside populations | |

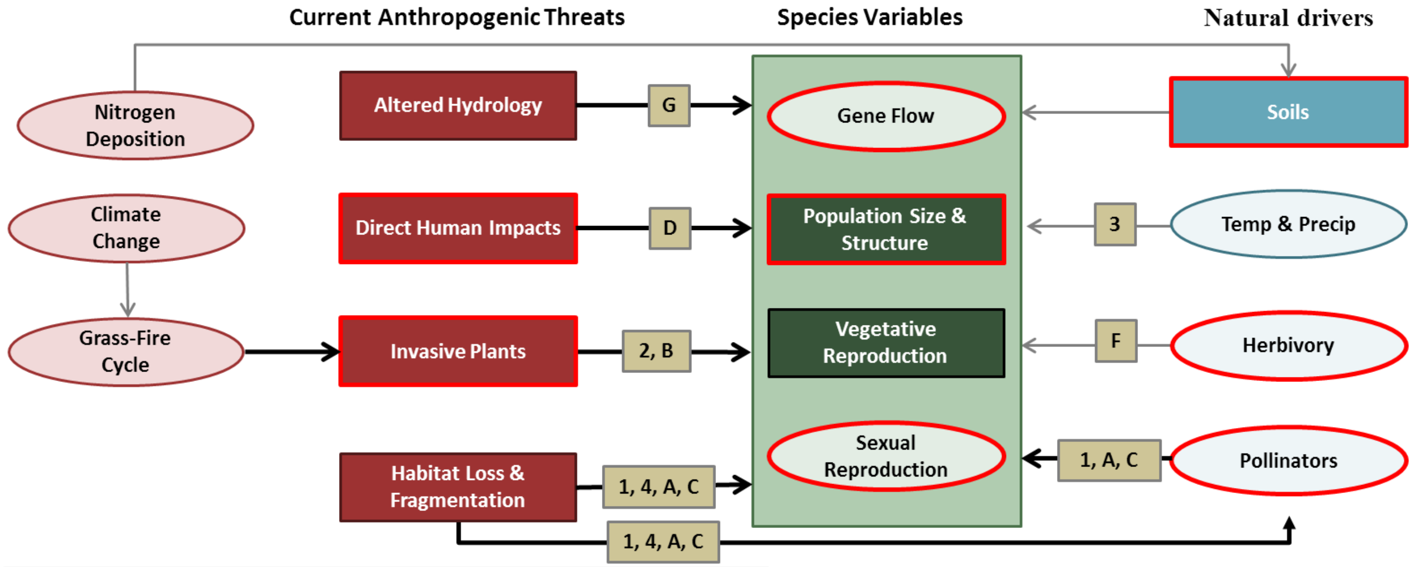
**Table B-1. San Diego Thornmint Conceptual Model Narrative.**

| | |
|---|---|
| | where possible. |
| E | Collect and bank seeds for propagation and conservation collections following guidelines from genetic studies. |
| F | Propagate, out-plant, and/or translocate seeds (of known genotypes) to improve connectivity and gene flow. |
| **Critical Management Uncertainties** | |
| 1 | Continue refining Best Management Practices (BMPs) for habitat restoration/enhancement. |
| 2 | Refine BMPs for invasive plant control, including possible impacts of herbicide on pollinators. |
| 3 | Investigate the effects of species abundance and plant size on floral display and pollinator attraction. |
| 4 | Develop BMPs for seed storage, germination, and propagation (note: refer to SDMMP 2013 and San Diego thornmint Adaptive Management Framework for seed collection and storage BMPs; San Diego thornmint has been successfully propagated and out-planted by AECOM). |

**Figure B-3.** Thread-leaved Brodiaea Conceptual Model Diagram.

**Management Goal:** Maintain very large and large populations and enhance and expand small populations to increase resilience to environmental stochasticity, maintain genetic diversity and ensure persistence over the long term (>100 years) in native plant communities.

**Monitoring Goal:** Monitor extant, conserved populations annually to assess population status , identify threats, and determine management needs.




**Critical Uncertainties:**

1. Best Management Practices (BMPs) for habitat restoration/enhancement.
2. BMPs for controlling invasive plants.
3. Apparent vs. actual population size
4. Propagation and transplantation methods.
5. Effective pollinators.
6. Hybridization with other species.
7. Influence of localized seed dispersal.

Others: Visualized Processes

**Management**

A. Restore/enhance habitat while promoting pollinators.
B. Control weeds.
C. Enhance connectivity by creating 'steppingstone' populations.
D. Control access.
E. Propagate, transplant, or translocate corms to restore populations, improve connectivity and gene flow.
F. Protect populations from herbivores.
G. Install erosion control devices.

**Table B-2. Thread-leaved Brodiaea Conceptual Model Narrative.**

| | | |
|---|---|---|
| **Goals** | | |
| Management | Maintain very large and large populations and enhance and expand small populations to increase resilience to environmental stochasticity, maintain genetic diversity and ensure persistence over the long term (>100 years) in native plant communities. | |
| Monitoring | Monitor extant, conserved populations using a regional monitoring protocol to assess population status (abundance, spatial extent), identify threats, and determine management needs. | |
| **Anthropogenic Threats** | | |
| Altered Hydrology | Increased urban run-off and diversion of natural water flow modifies habitat suitability and causes corm mortality. | USFWS 1998, 2009b, 2011, Vinje pers. obs. |
| Direct Human Impacts | Authorized and unauthorized activities (e.g., fuel modification, biological monitoring, trespass) impact plants through trampling, habitat degradation, and invasive plant introductions. | USFWS 1998, 2009b, 2011, CNDDB 2012 |
| Invasive Plant Species | Invasive plant species compete directly with thread-leaved brodiaea and alter habitat in ways that result in the loss of suitable habitat. | USFWS 1998, 2009b, 2011, CNDDB 2012 |
| Habitat Loss/Fragmentation | Current and historic habitat loss and fragmentation may reduce genetic diversity and long-term resilience by impeding gene flow within and between populations. | USFWS 1998, 2009b, 2011 |
| **Natural Drivers** | | |
| Soils | Occurs primarily on soils with high clay content and occasionally on non-clay alkaline soils. The narrow extent of suitable soils exacerbates the role of habitat loss and fragmentation as a threat. Additional uncharacterized soil factors may also contribute to habitat suitability.<br>Our study showed that brodiaea is tolerant to relatively high Na content in clays, yet avoids alkaline soils, staying within a relatively narrow pH range more typical of non-clay soils. | USFWS 1998, 2009b, 2011, AMEC 2009 |
| **Critical Natural Driver Uncertainties** | | |
| Temperature & Precipitation | Annual climatic conditions influence vegetative growth and flowering, although temperature and rainfall parameters (e.g., amount and timing of rainfall) that affect species response are uncertain. | USFWS 1998, 2009b, 2011, CNLM unpublished data |
| Herbivory | Corm damage/destruction (often by pocket gophers) reduces population density in some *Brodiaea* species; | Hobbs and Mooney 1995, Fiedler and |

**Table B-2. Thread-leaved Brodiaea Conceptual Model Narrative.**

| | | |
|---|---|---|
| | herbivory occurs but the level of damage is uncertain. | Lavin 1996 |
| Pollinators | Pollinators are required for sexual reproduction due to partial or complete self-incompatibility in this species. However, the importance of pollinators remains uncertain because the extent of self-incompatibility is unknown. | Keator 1968, Niehouse 1971, Doalson 1999 |
| **Species Variables (Measurable Aspects of Species Response)** | | |
| Population Size & Structure | Population size and structure reflect the abundance of corms in an occupied patch, and the proportion of vegetative versus flowering individuals in a given year. | USFWS 1998, 2009b, 2011, CNLM 2010 |
| Vegetative Reproduction | Vegetative reproduction occurs through production of cormlets from underground corms, and appears to be more common than recruitment from seed. The resultant spatial clustering of genetically identical individuals may influence the frequency of sexual reproduction, which can probably only occur between distinct genotypes. | Taylor 1991, USFWS 1998, 2009b, 2011 |
| **Critical Species Variables Uncertainties** | | |
| Sexual Reproduction | The species is largely self-incompatible and thus, requires outcrossing to produce seed. While partial self-compatibility and modest seed set/viability may be possible via pollination of closely related individuals, the extent to which this occurs is unknown. The importance of sexual versus vegetative reproduction in terms of population size is also uncertain. | Niehouse 1971, Taylor 1991, USFWS 1998, 2009b, 2011 |
| Gene Flow | *Brodiaea* species are generally self-incompatible and require pollinators to transfer pollen from unrelated individuals in order to produce viable seed. As a result, gene flow via pollinators is necessary for sexual reproduction. Some genetic systems may allow for partial self-compatibility whereby self-pollination produces a limited number of viable seeds, but it is uncertain whether thread-leaved brodiaea has this capacity. | Niehouse 1971, Taylor 1991, USFWS 1998, 2009b, 2011 |
| **Critical Process Uncertainties** | | |
| Climate Change | Predicted warming temperatures may result in drier and hotter conditions in southern California in the future. Habitat suitability modeling for this project showed that predicted suitable habitat for brodiaea declined under future climate scenarios. Potential | Bergengren et al. 2001, Araujo and New 2007, Westerling and Bryant 2008 |

**Table B-2. Thread-leaved Brodiaea Conceptual Model Narrative.**

| | | |
|---|---|---|
| | impacts from climate change include (1) reduced germination and smaller population sizes, (2) reduced vegetative growth or flowering, (3) increase in nonnative species due to a shift in timing of annual rainfall, (4) shifts in flowering times that may result in lowered pollination success and/or loss of compatible pollinators, (5) altered photosynthetic rates and nutrient uptake that may result in increased growth and competition of nonnative species or an increase in herbivores, and (6) increased fire frequency and subsequent loss of habitat and invasion by nonnative plants. | |
| Grass-Fire Cycle | Nonnative grasses increase the fine fuel load and fire risk, and the reduced fire return interval then promotes nonnative grasses, leading to habitat type conversion. This cycle may affect soil and water budgets, increase erosion, promote invasive plant species, and impact pollinators (e.g., ground-nesting bees). Vegetative and flowering production may increase temporarily following fire due to removal of thatch. | Stone 1951, Keator 1968, D'Antonio and Vitousek. 1992, Conlisk et al. 2013 |
| Nitrogen Deposition | Excess nitrogen may alter soil properties (including soil microbial community) and subsequently, plant species composition and structure. Invasive plant species may benefit from increased nitrogen. Fire may alter/reduce effects of nitrogen deposition on productivity in the short-term. Nitrogen deposition likely affects most areas within the species range. | Bobbink et al. 2010, Fenn et al., 2010 |
| **Potential Management Actions** | | |
| A | Restore or enhance suitable habitat, including habitat for pollinators. | |
| B | Control weeds. | |
| C | Enhance connectivity by establishing "steppingstone" populations at sites with appropriate soils using a suite of techniques (seeding, corm transplantation/out-plantings, pollinator release); test soils prior to establishing or translocating populations. | |
| D | Control access by closing and/or rerouting trails and roads inside populations where possible. | |
| E | Propagate, transplant, or translocate corms to restore populations and improve connectivity and gene flow. | |
| F | Protect populations from above-ground herbivores (note: there may be the potential to protect populations from below-ground herbivores during transplantation/out-planting of corms). | |

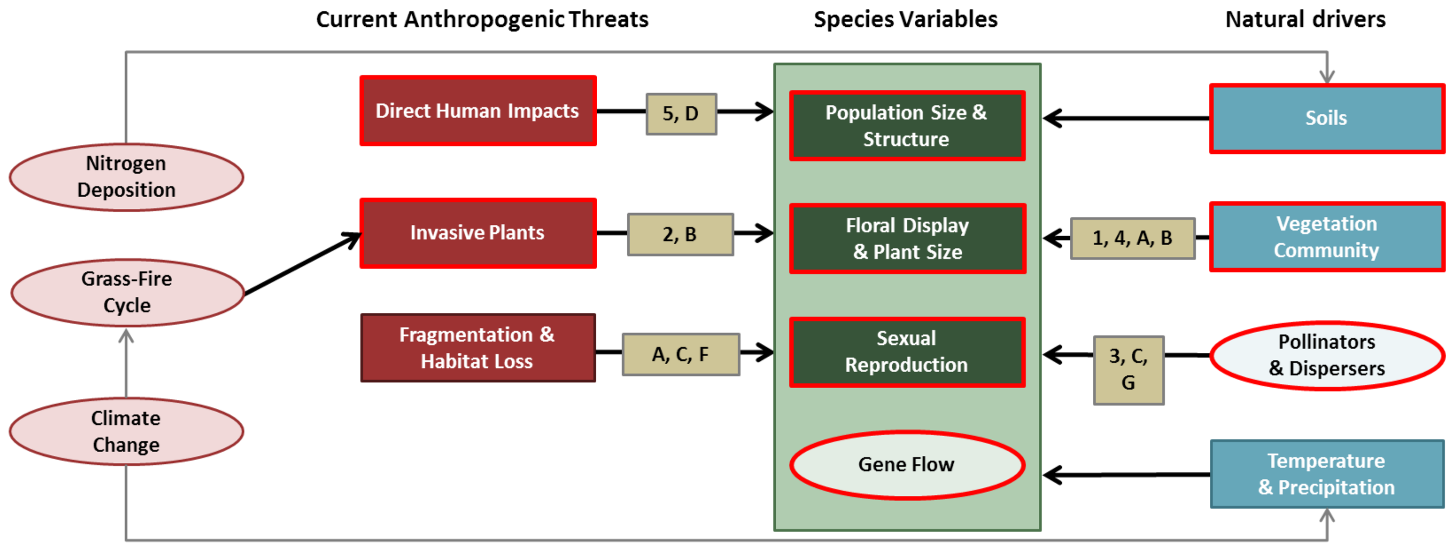
**Table B-2. Thread-leaved Brodiaea Conceptual Model Narrative.**

| **Critical Management Uncertainties** | |
|---|---|
| 1 | Develop/refine Best Management Practices (BMPs) for habitat restoration/enhancement. |
| 2 | Develop/refine BMPs for invasive plant control, including possible impacts of herbicide on pollinators. |
| 3 | Determine detected versus actual population size. The number of corms in a population may be 1,000 to 10,000 times greater than number of flowering individuals which are the typical monitoring unit of measurement. Flowers are far easier to detect, which streamlines and standardizes counts, but these data provide a population size that is orders of magnitude smaller than the actual population size. |
| 4 | Develop/refine effective propagation and transplantation methods to offset local extirpations, supplement gene flow, and bolster dwindling populations. Assisted migration as a response to fragmentation and/or climate change will require corm propagation. |
| 5 | Identify effective pollinators to guide management actions (e.g., expand bare ground for ground-nesting bees, control invasive plants, augment native plants) and locate potential connectivity areas based on pollinator dispersal capabilities. |
| 6 | Identify hybrids that may pose a threat to species persistence. Thread-leaved brodiaea may hybridize with congeners (*B. orcuttii*), although hybridization has not been confirmed with genetic testing and could represent undescribed species (Niehaus 1971, Chester et. al 2007, USFWS 1998, 2009, 2011). |
| 7 | Verify seed dispersal mechanisms. Seed dispersal is thought to be highly localized (e.g., gravity-dispersed), which would influence the distribution of self-incompatible alleles. |

**Figure B-4**. Otay Tarplant Conceptual Model Diagram.

**Management Goal:** Maintain large occurrences, expand small occurrences, and establish new occurrences to enhance connectivity , increase resilience to environmental stochasticity, maintain genetic diversity, and ensure persistence over the long-term (>100 years) in native plant communities.

**Monitoring Goal:** Monitor populations annually to assess population, identify threats, and determine management needs.




**Critical Uncertainties:**

1. Best Management Practices (BMPs) for habitat restoration/enhancement.
2. BMPs for controlling invasive plants, herbicide effects on pollinators.
3. Pollinators attractants.
4. Competition with other native species.
5. Disturbance experiments.
6. Spatial distribution of genetic variation and the rate of outcrossing.
7. Minimum patch size or s-allele diversity for adequate genetic mixing.
8. Seed storage, germination rates, and propagation methods.
9. Extent, viability, and longevity of soil seedbank.

Others: Visualized Processes

**Management**

A. Restore/enhance habitat.
B. Control weeds.
C. Enhance connectivity.
D. Control access.
E. Collect and bank seeds.
F. Move seeds to facilitate gene flow.
G. Promote pollinators.

**Table B-3. Otay Tarplant Conceptual Model Narrative.**

| | | |
|---|---|---|
| **Goals** | | |
| Management | Maintain large occurrences, expand small occurrences, and establish new occurrences to enhance connectivity between occurrences and to increase resilience to environmental stochasticity, maintain genetic diversity, and ensure persistence over the long-term (>100 years) in native plant communities. | |
| Monitoring | Monitor extant, conserved populations annually using a regional monitoring protocol to assess population status (abundance, spatial extent), identify threats, and determine management needs. | |
| **Anthropogenic Threats** | | |
| Direct Human Impacts | Authorized and unauthorized activities (e.g., utility maintenance, access roads, trails, fire breaks, off-highway vehicles, mountain bikes, equestrian use, grazing) resulting in above- or below-ground plant mortality. | USFWS 2004 |
| Invasive Plant Species | Nonnative forbs and grasses that compete directly with Otay tarplant or suppress germination through thatch/litter accumulation. | USFWS 2004 |
| Habitat Loss/Fragmentation | Current and historic habitat loss and fragmentation may reduce genetic diversity and long-term resilience by impeding gene flow within and between populations. | USFWS 2004 |
| **Natural Drivers** | | |
| Soils | Occurs primarily on clay soils, subsoils, or clay lenses. The narrow extent of suitable soils exacerbates the role of habitat loss and fragmentation as a threat.<br>Our study showed Otay tarplant correlates positively with clay, sodium, and magnesium, and occurs on soils with relatively low fertility. | USFWS 2004 |
| Vegetation Community | Grassland, open coastal sage scrub, or maritime succulent scrub with appropriate soils. In addition, the vegetation community must support Otay tarplant pollinators year-round. | USFWS 2004 |
| Temperature & Precipitation | Annual climatic conditions influence vegetative growth and flowering. Environmental stochasticity interacts with demographic stochasticity to create large fluctuations in population size each year. | USFWS 2004 |
| **Critical Natural Driver Uncertainties** | | |
| Pollinators & Dispersers | Insect-pollinated. The role of native versus nonnative pollinators, pollinator effectiveness, and pollinator foraging ranges are unknown. Seeds are animal- and | USFWS 2004 |

**Table B-3. Otay Tarplant Conceptual Model Narrative.**

| | | |
|---|---|---|
| | possibly, wind-dispersed. | |
| **Species Variables (Measurable Aspects of Species Response)** | | |
| Population Size & Structure | The number of populations, their size, shape, and geographic distribution. Includes population density and cover, seedbank spatial characteristics and viability, population size fluctuations associated with environmental stochasticity, and genetic diversity within patches. | USFWS 2004 |
| Sexual Reproduction | Includes seed production, adult fecundity, inputs to seedbank, and germination and viability rates. | USFWS 2004 |
| Floral Display & Plant Size | Cover and visibility of plants and flowers, flower production, plant height, plant branching. Visibility is important for attracting pollinators. | USFWS 2004 |
| **Critical Species Variables Uncertainties** | | |
| Gene Flow | In general, genetic mixing and the prevention of inbreeding and genetic drift are the primary goals. Otay tarplant is self-incompatible, and cannot cross with itself or another individual that shares the same allele at the 's' locus.' The USGS Western Ecological Research Center is finalizing genetic studies for this species. | USFWS 2004 |
| **Critical Process Uncertainties** | | |
| Climate Change | Climate change may result in species range shifts, fire regime alterations, habitat suitability changes, and invasive species increases, and compound the effects of demographic stochasticity. Some studies suggest that the most vulnerable species are in small populations, limited in distribution, and associated with certain habitats or edaphic conditions. A climate change vulnerability assessment suggested that other factors may mitigate the effects of climate change for some rare plants, including Otay tarplant, but it did not explicitly factor in the impact from invasive species. Habitat suitability modeling for this project showed that Otay tarplant has no predicted suitable habitat under any future climate scenarios. | Zavaleta et al. 2003, Henry et al. 2006, Bergengren et al. 2001, Araujo and New 2007, Westerling and Bryant 2008, Anacker et al. 2013, Conlisk et al 2013 |
| Grass-Fire Cycle | Nonnative grasses increase the fine fuel load and fire risk, and the reduced fire return interval then promotes nonnative grasses, leading to habitat type conversion. This cycle may affect soil and water budgets, increase erosion, promote invasive plant species, and impact pollinators. | D'Antonio and Vitousek 1992, Henry et al. 2006, Syphard et al. 2006 |

**Table B-3. Otay Tarplant Conceptual Model Narrative.**

| | | |
|---|---|---|
| Nitrogen Deposition | Excess nitrogen may alter soil properties (including soil microbial community) and subsequently, plant species composition and structure. Invasive plant species may benefit from increased nitrogen. Fire may alter/reduce effects of nitrogen deposition on productivity in the short-term. Nitrogen deposition likely affects most areas within the species range. | Talluto and Suding 2008, Vourlitis and Pasquini 2009, Bobbink et al. 2010, Fenn et al. 2010 |
| **Potential Management Actions** | | |
| A | Control weeds at extant and newly restored populations. | |
| B | Restore or enhance suitable habitat, including habitat for pollinators. | |
| C | Enhance connectivity by establishing “steppingstone” populations at sites with appropriate soils using a suite of techniques (e.g., seeding, pollinator release); test soils prior to establishing or translocating populations. | |
| D | Control access by closing and/or rerouting trails and roads inside populations where possible. | |
| E | Collect and bank seeds for propagation and conservation collections and genetic studies. | |
| F | Propagate, out-plant, and/or translocate seeds (of known genotypes) to improve connectivity and gene flow. | |
| G | Promote pollinators and dispersers via research, habitat enhancement, and reintroduction. | |
| **Critical Management Uncertainties** | | |
| 1 | Develop/refine Best Management Practices (BMPs) for habitat restoration/enhancement (note: BMP development is in-progress as part of the South County grasslands project). | |
| 2 | Develop/refine BMPs for invasive plant control, including possible impacts of herbicide on pollinators (note: BMP development for invasive plants is in-progress as part of the South County grasslands project). | |
| 3 | Investigate the effects of species abundance and plant size on floral display and pollinator attraction. | |
| 4 | Investigate the potential negative impacts of Otay tarplant on other native species. | |
| 5 | Identify small-scale disturbances that negatively affect Otay tarplant or its habitat or pollinators. | |
| 6 | Quantify the extent and temporal and spatial distributions of genetic variation, and determine the rate of outcrossing needed to create a robust breeding population (note: genetic studies are in-progress [USGS]). | |
| 7 | Determine patch size needed to maintain adequate genetic diversity within a population. | |
| 8 | Develop BMPs for seed storage, germination, and propagation (note: we successfully propagated Otay tarplant as part of the South County grasslands | |

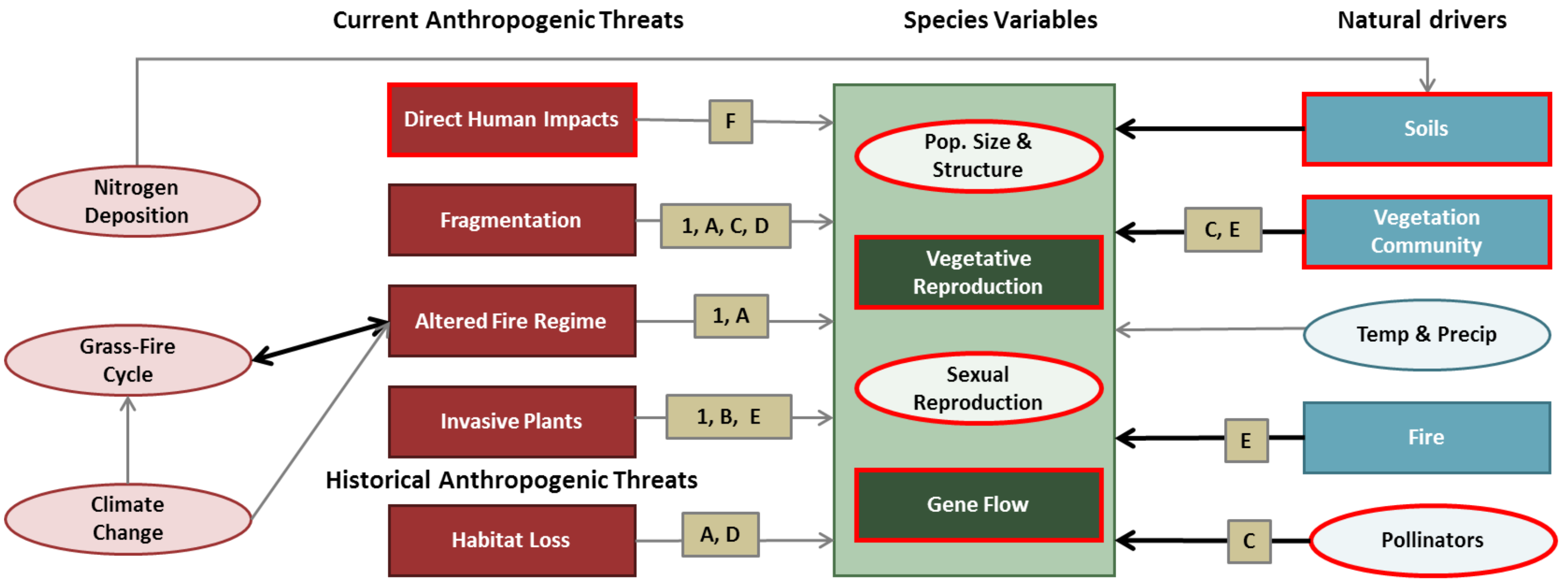
**Table B-3. Otay Tarplant Conceptual Model Narrative.**

| | |
|---|---|
| | project). |
| 9 | Measure the extent, viability, and longevity of the natural soil seedbank. |

**Figure B-5**. Dehesa Nolina Conceptual Model Diagram.

**Management Goal:** Maintain populations to increase resilience to environmental stochasticity, maintain genetic diversity and ensure persistence over the long term (>100 years) in native plant communities.

**Monitoring Goal:** Monitor conserved populations every 3-5 years or at a frequency determined by SDMMP to assess population status, identify threats, and determine management needs. See narrative for additional goals.




<u>Critical Uncertainties:</u>

1. Best Management Practices (BMPs) for habitat restoration/enhancement.
2. BMPs for controlling invasive plants.
3. Determine sex ratios, spatial distribution of alleles, and population structure.
4. Refine monitoring methods and counting unit.
5. Identify effective pollinators and mating system details.

Others: Visualized Processes

<u>Management:</u>

A. Restore/enhance suitable habitat.
B. Control weeds.
C. Enhance populations through out-planting and translocation.
D. Control access.
E. Collect and bank seeds.
F. Conserve unprotected populations.

**Table B-4. Dehesa Nolina Conceptual Model Narrative.**

| **Goals** | | |
|---|---|---|
| Management | Maintain populations to increase resilience to environmental stochasticity, maintain genetic diversity, and ensure persistence over the long term (>100 years) in native plant communities. | |
| Monitoring | Monitor extant, conserved populations every 3-5 years or at a frequency determined by SDMMP using a regional monitoring protocol to assess population status (abundance, spatial extent), identify threats, and determine management needs. Monitor burned populations for 3 consecutive years following the fire, regardless of other monitoring intervals or schedules, to assess recovery and threats (particularly, invasive species). | |
| **Anthropogenic Threats** | | |
| Direct Human Impacts | Authorized and unauthorized activities (e.g., road maintenance, off-highway vehicles) impact plants directly or degrade habitat. Unauthorized take or removal by humans including collecting for nursery trade is a low risk at this time. | Regan et al. 2006, CBI 2012, 2014, 2015 |
| Fragmentation | Ongoing activities that eliminate habitat within or between populations, such as development and roads. In a dioecious species like Dehesa nolina, effective pollination occurs when male and female flowers are in proximity to one another. | USFWS 1995, 1998, Gordon-Reedy and Vinje pers. obs. |
| Invasive Plant Species | Plant invasion, particularly nonnative grasses, may increase fire frequency and/or intensity, alter nutrient cycling, and eliminate suitable germination sites. The nonnative grass *Brachypodium distachyon* is of particular concern as it colonizes clay and gabbroic soils readily. | D'Antonio and Vitousek 1992, USFWS 1995, Keeley et al. 1999, Regan et al. 2006, CBI 2012, 2014, 2015 |
| Habitat Loss | Currently, five of seven extant populations occur on conserved lands within the San Diego Multiple Species Conservation Plan (MSCP) area, including the three largest populations: Sycuan Peak Ecological Reserve, McGinty Mountain Ecological Reserve, and South Crest-Dehesa Mountain. | CBI 2015 |
| Altered Fire Regime | Fire suppression may result in increased fuel loads and fire intensity, while increased fire frequency may prevent plants from reaching maturity and contributing to the soil seedbank. Results may include direct mortality, population declines or extirpation, and/or loss of genetic diversity. | Zedler et al. 1983, D'Antonio and Vitousek 1992, USFWS 1995, 1998, Keeley et al. 1999, Regan et al. 2006, CBI 2012, 2014, 2015 |

**Table B-4. Dehesa Nolina Conceptual Model Narrative.**

| | | |
|---|---|---|
| **Natural Drivers** | | |
| Soils | Occurs most commonly on clay soils derived from gabbroic (Las Posas series) or metavolcanic bedrock, but also found on soil with gabbro inclusions (Cieneba, Cieneba-Fallbrook, and Fallbrook series) and on clay soils (e.g., Auld series). The presence of appropriate soil determines the distribution of potential habitat. The narrow extent of suitable soils exacerbates the role of habitat loss and fragmentation as a threat.<br>Our study indicated that pH and calcium were the two most significant soil factors associated with nolina, with nolina occurring on soils with a higher calcium concentration than surrounding soils. In addition, the species is negatively associated with copper. | Oberbauer 1979, Oberbauer and Vanderwier 1991, Beauchamp 1986, USFWS 1998, CNPS 2012, CBI 2015 |
| Vegetation Community | Occurs primarily in chaparral, but also in coastal sage scrub and grasslands. Over half of the conserved populations are associated with *Adenostoma*-dominated alliances and associations. | USFWS 1995, USFWS 1998, CBI 2015 |
| Fire | Fire stimulates mass flowering necessary for sexual reproduction. Altered fire regimes threaten long-term species persistence through direct mortality, habitat type conversion, increase in invasive plants, and loss of genetic diversity. Conversely, fire suppression may result in increased fuel loads and fire intensity, senescent populations, and reduced flowering. | Rombouts 1996, Keeley et al. 1999, USFWS 1995 |
| **Critical Natural Driver Uncertainties** | | |
| Temperature & Precipitation | Climate and disturbance may stimulate sporadic flowering in the absence of fire. | USFWS 2004, Gordon-Reedy and Vinje pers. obs. |
| Pollinators & Dispersers | Potential pollinators include bees and possibly, bee flies and beetles. | Rombouts 1996, Gordon-Reedy and Vinje pers. obs. |
| **Species Variables (Measurable Aspects of Species Response)** | | |
| Vegetative Reproduction | Reproduces asexually by cloning a new plant from the underground caudex to create clusters of genetically identical ramets. | Dice 1988 |
| Gene Flow | The genetic diversity of Dehesa nolina is extremely low; however, this may be normal for the species and genus. The dioecious mating system, which would typically maintain a high level of genetic diversity, possibly evolved after low levels of genetic diversity | Rombouts 1996, Heaney pers. comm. |

**Table B-4. Dehesa Nolina Conceptual Model Narrative.**

| | | |
|---|---|---|
| | were already established. There exists some genetic divergence between populations in the US and Mexico, but no divergence within these populations. In general, populations with greater genetic diversity tend to be more resilient to stochastic events, environmental changes, and direct disturbance. Clonal growth may buffer populations from environmental stochasticity that might otherwise cause local extinction. | |
| **Critical Species Variables Uncertainties** | | |
| Population Size & Structure | The population size and demographic structure is difficult to determine visually due to the clonal nature of the plant. Genetic study has revealed that some populations may be entirely composed of the same genet and/or a single sex. Other studies have found that clusters (separated by no less than 2 m and no more than 20 m) often represented different genets. | Dice 1988, Rombouts 1996, CBI 2015 |
| Sexual Reproduction | Reproduces sexually through a dioecious breeding system which may help maintain genetic diversity within or between populations; however, Dehesa nolina appears to have little genetic diversity as a species overall. Fire stimulates mass flowering. Although plants bloom sporadically in the absence of fire, the proximity of male and female flowers dictates successful sexual reproduction. | Dice 1988, Rombouts 1996, CBI 2012, Gordon-Reedy and Vinje pers. obs. |
| **Critical Process Uncertainties** | | |
| Climate Change | Predicted warming temperatures may result in drier and hotter conditions in southern California in the future. Habitat suitability modeling for this project predicted small amounts of suitable habitat for Dehesa nolina for low and moderate emission scenarios. Climate change poses a particular threat to plants due to their relative lack of mobility. While plant species' ranges shift naturally, climate change may outpace the rate of shift, thus affecting the ability of some species to persist. The most vulnerable species to climate change occur in small populations, are limited in distribution, or are closely associated with certain habitats or edaphic conditions. Modeling for other rare and invasive species that occur in similar habitat and often with Dehesa nolina indicates that both invasive plants and fire frequency might pose threats under changing climatic conditions. | Bergengren et al. 2001, Walther et al. 2002, Parmesan and Yohe 2003, Araujo and New 2007, Westerling and Bryant 2008, Loarie et al. 2008, Cal-IPC 2012, Conlisk et al. 2013, Anacker et al. 2013 |

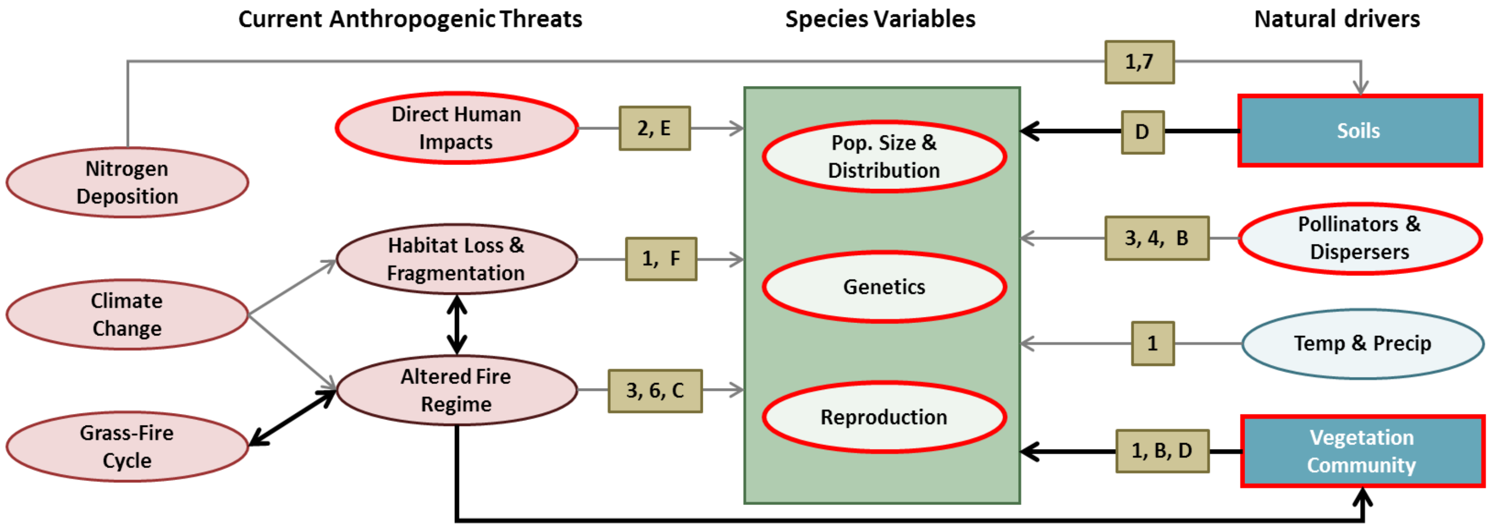
**Table B-4. Dehesa Nolina Conceptual Model Narrative.**

| | | |
|---|---|---|
| Grass-Fire Cycle | Nonnative grasses increase the fine fuel load and fire risk, and the reduced fire return interval then promotes nonnative grasses, leading to habitat type conversion. This cycle may affect soil and water budgets, increase erosion, promote invasive plant species, and impact pollinators. Fire regime alterations could have further implications for nolina, since fire stimulates mass flowering. | D'Antonio and Vitousek 1992, Conlisk et al. 2013 |
| Nitrogen Deposition | Primary threats from nitrogen deposition may be via nonnative grass invasion and alteration of the natural fire regime. The extent to which nitrogen deposition may directly affect Dehesa nolina is unknown; however, it's restriction to nutrient poor soil suggests there may be direct impacts. Nitrogen deposition likely affects most areas within the range of this species. | Bobbink et al. 2010, Fenn et al. 2010, CBI 2015 |
| **Potential Management Actions** | | |
| A | Restore or enhance suitable habitat, including habitat for pollinators. | |
| B | Control weeds. | |
| C | Out-plant and/or translocate propagated stock; test soils prior to moving plants into new locations to ensure that soils are suitable. | |
| D | Control access by closing and/or rerouting trails and roads inside populations where possible. | |
| E | Collect and bank seeds for propagation and conservation collections and genetic studies. | |
| F | Conserve unprotected populations, especially “steppingstone” populations which provide connectivity between large, conserved populations. | |
| **Critical Management Uncertainties** | | |
| 1 | Develop/refine Best Management Practices (BMPs) for habitat restoration/enhancement (note: BMP development is in-progress as part of the *Dudleya-Nolina* and *Brachypodium* Phase II projects). | |
| 2 | Develop/refine BMPs for invasive plant control, including possible impacts of herbicide on pollinators (note: BMP development for invasive plant control is in-progress as part of the *Brachypodium* Phase II project). | |
| 3 | Determine sex ratios, spatial distribution of alleles, and structure of populations. | |
| 4 | Refine monitoring methods and counting unit. | |
| 5 | Identify effective pollinators and floral morphology that produce viable seed. | |

**Table B-6**. Parry's Tetracoccus Conceptual Model Diagram.

**Management Goal:** Maintain conserved occurrences to increase resilience to environmental and demographic stochasticity, maintain genetic diversity, and improve chances of persistence over the long-term (>100 years) on Las Posas soils in chaparral vegetation communities.

**Monitoring Goal:** Monitor extant, conserved populations every 3-5 years or at a frequency determined by SDMMP to assess critical uncertainties, including population status, threats, and management needs.




**Critical Uncertainties:**

1. Species extent, distribution, suitable habitat.
2. Threats to species/population persistence.
3. Effective pollinators.
4. Genetic diversity within and among populations.
5. Reproductive capacity and breeding system.
6. Impacts of climate change on species/populations.
7. Impacts of nitrogen deposition on suitable habitat.

**Management**

A. Address critical uncertainties.
B. Restore/enhance suitable habitat.
C. Control weeds.
D. Propagate, transplant, or translocate plants to restore populations, improve connectivity and gene flow (if determined necessary).
E. Control access.
F. Conserve unprotected populations/habitat.

**Table B-5. Parry's Tetracoccus Conceptual Model Narrative.**

| | | |
|---|---|---|
| **Goals** | | |
| Management | Maintain conserved occurrences to increase resilience to environmental and demographic stochasticity, maintain genetic diversity, and improve chances of persistence over the long-term (>100 years) on Las Posas soils in chaparral vegetation communities. | |
| Monitoring | Monitor extant, conserved populations every 3-5 years or at a frequency determined by SDMMP using a regional monitoring protocol to assess critical uncertainties, including population status (abundance, spatial extent), threats, and determine management needs. | |
| **Anthropogenic Threats** | | |
| **Critical Anthropogenic Threats Uncertainties** | | |
| Direct Human Impacts | Authorized and unauthorized activities (e.g., fuel modification, illegal brush clearing, off-road vehicle activity) may potentially reduce populations through mortality and habitat degradation. | CBI 2012 |
| Habitat Loss & Fragmentation | Current and historic habitat loss and fragmentation may reduce genetic diversity and long-term resilience by impeding gene flow within and between populations. In addition, populations in proximity to development are subject to edge effects (e.g., invasive species, illegal clearing, altered fire regimes). | Regan et al. 2006, CBI 2012, CNDDB 2016, NatureServe 2016 |
| Altered Fire Regime | Altered fire regimes may affect populations by increasing plant mortality, depleting the soil seedbank, or promoting invasive species. | Regan et al. 2006, Conlisk et al. 2013 |
| **Natural Drivers** | | |
| Soils | Occurs on soils derived from gabbro parent material. The affinity for gabbroic soils may be one factor limiting the species distribution. The narrow extent of suitable soils exacerbates the role of habitat loss and fragmentation as a threat.<br>Our study indicated that this species is tolerant of a wide range of metals (e.g., copper, iron, zinc) in a metal-rich environment. | Dressler 1954, Oberbauer and Vanderwier 1991 |
| Vegetation Community | Chaparral and occasionally coastal sage scrub on gabbro-derived soils | CNDDB 2016, NatureServe 2016 |
| **Critical Natural Drivers Uncertainties** | | |
| Temperature & Precipitation | Climatic factors likely play a role in the distribution of this species on the landscape; however, specific climatic parameters governing this species' distribution are unknown. Flowering may also be dependent on rainfall patterns. | Dressler 1954 |

**Table B-5. Parry's Tetracoccus Conceptual Model Narrative.**

| | | |
|---|---|---|
| Pollinators & Dispersers | Most dioecious species are insect-pollinated and have unspecialized pollinators. Dispersal agents are unknown but seeds are presumed to be gravity- and/or animal-dispersed. | Dressler,1954, Proctor et al. 1996 |
| **Species Variables (Measurable Aspects of Species Response)** | | |
| **Critical Species Variables Uncertainties** | | |
| Population Size & Distribution | Total population size and distribution of Parry's tetracoccus is unknown at the landscape level. Individuals tend to occur across the landscape in a discontinuous fashion, but may be locally abundant. | Dressler 1954, CBI 2012, SDMMP 2013 |
| Genetics | There is little information on the genetics of Parry's tetracoccus. | --- |
| Reproduction | Parry's tetracoccus is dioecious (male and female flowers on separate plants). As a dioecious species, the ratio and distribution of male and female plants relative to one another may be important. However, we have observed high fruit production in many populations over several years and under varying climatic conditions. | Dressler 1954, Proctor et al. 1996, Gordon-Reedy and Vinje pers. obs. |
| **Critical Process Uncertainties** | | |
| Climate Change | Predicted warming temperatures may result in drier and hotter conditions in southern California in the future. Habitat suitability modeling for this project showed that predicted suitable habitat for Parry's tetracoccus declined, but still persisted under future climate scenarios. Climate change may threaten Parry's tetracoccus if areas of appropriate climatic conditions do not support appropriate soils. The magnitude of this potential threat is unknown because specific information on the species' climatological requirements is not yet available. Refer to Table 2 for additional, potential impacts from climate change. | Bergengren et al. 2001, Araujo and New, 2007, Westerling and Bryant 2008 |
| Grass-Fire Cycle | Nonnative grasses increase the fine fuel load and fire risk, and the reduced fire return interval then promotes nonnative grasses, leading to habitat type conversion. This cycle may affect soil and water budgets, increase erosion, promote invasive plant species, and impact pollinators. An altered fire regime could further threaten this species through increased plant mortality and soil seedbank depletion. | D'Antonio and Vitousek 1992, CBI 2012, Conlisk et al. 2013 |
| Nitrogen Deposition | Excess nitrogen may alter soil properties (including soil microbial community) and, subsequently, plant | Bobbink et al., 2010, Fenn et al. 2010 |

**Table B-5. Parry's Tetracoccus Conceptual Model Narrative.**

| | | |
|---|---|---|
| | species composition and structure. Fire may alter/reduce effects of nitrogen deposition on productivity in the short-term. Nitrogen deposition most likely affects most areas within the range of this species. | |
| **Potential Management Actions** | | |
| A | Address critical uncertainties through monitoring or research. | |
| B | Restore or enhance suitable habitat, including habitat for pollinators. | |
| C | Control weeds to reduce competition and fire risk. | |
| D | Out-plant or translocate seeds or propagated stock to restore populations and enhance connectivity and gene flow (if determined necessary); test soils prior to moving plants into new locations. | |
| E | Control access and reduce direct and indirect impacts by closing and/or rerouting trails and roads within populations, where possible. | |
| F | Conserve additional populations and habitat to bolster species resilience and accommodate range shifts due to climate change. | |
| **Critical Management Uncertainties** | | |
| 1 | Determine or refine species extent, distribution, and habitat parameters to guide management and conservation efforts. | |
| 2 | Identify threats to guide management actions. | |
| 3 | Identify effective pollinators to guide management actions and restoration efforts. | |
| 4 | Assess genetic diversity at the species and population-levels to guide out-planting and translocation efforts, if determined to be important for this species. | |
| 5 | Identify breeding system and reproductive capacity (e.g., seed production) to determine if either poses a threat to species persistence. | |

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# Appendix C

# Soil and Vegetation Characterization

# Appendix C
# Soil and Vegetation Characterization

The California floristic province is one of the most biodiverse regions in the world, and home to a large number of endemic plant species. The high degree of endemism is attributable to a diversity of climatic, topographic, and edaphic conditions creating unique microcosms for species specialization. Unfortunately, many of these microcosms have been lost to urbanization, leaving populations of edaphic endemic plants isolated by habitat fragmentation and loss of pollinators. In addition, specialists are extinction-prone and vulnerable to climate change. Land managers need more specific information about habitat requirements to successfully conserve these species.

The soils and vegetation characterization focused on soil chemistry and physical properties of the five target species. In this appendix, we will refer to these species by their 4-letter codes in text and tables: San Diego thornmint (ACIL), thread-leaved brodiaea (BRFI), Otay tarplant (DECO), Dehesa nolina (NOIN), and Parry’s tetracoccus (TEDI). As we improve our understanding of factors that contribute to species presence or absence, we can make better choices for managing the species, such as prioritizing suitable but unoccupied sites for enhancement, establishment, augmentation, or translocation. Further, we can use this information to explain species extirpation from a site and determine whether or not that site is salvageable. Finally, we expect this study to lead to additional experimentation that will refine management measures or provide additional management options. For example, a plant may occur on soils rich in iron as a means of avoiding competition without requiring high iron to survive. This information would change our understanding of the species’ fundamental ecological niche, and potentially allow us to expand the population beyond its current, realized niche.

## Methods

### Sampling Design

A number of studies have characterized soils that support rare plants. Our study goes a step further by comparing characteristics of soils that support rare plants (occupied soils) to adjacent or nearby soils that do not support those rare plants (unoccupied soils). This lets us identify specific factors that differ from the rest of the landscape statistically, rather than simply providing a range of conditions that support a species. For instance, a species might occur on soils with 1000-2000 parts per million (ppm) of magnesium (Mg), but without understanding if that concentration differs in occupied versus unoccupied habitat, it is impossible to determine if it is an interesting or relevant observation. Drawing direct comparisons to unoccupied soils allows us to distinguish factors or combinations of factors associated with occupancy.

At each species occurrence, we spatially matched three sampling locations (*in*, *near*, *far*) to compare soils within plant populations to soils nearby and far away without the target species (Figure C-1). Comparing occupied soils (*in*) to adjacent, unoccupied soils (*near*) might identify small-scale soil differences influencing species distribution. Comparing occupied soils (*in*) with far away soils (*far*) provides insight on a larger spatial scale, and a safety-net comparison group if nearby habitat is determined to be suitable but unoccupied.

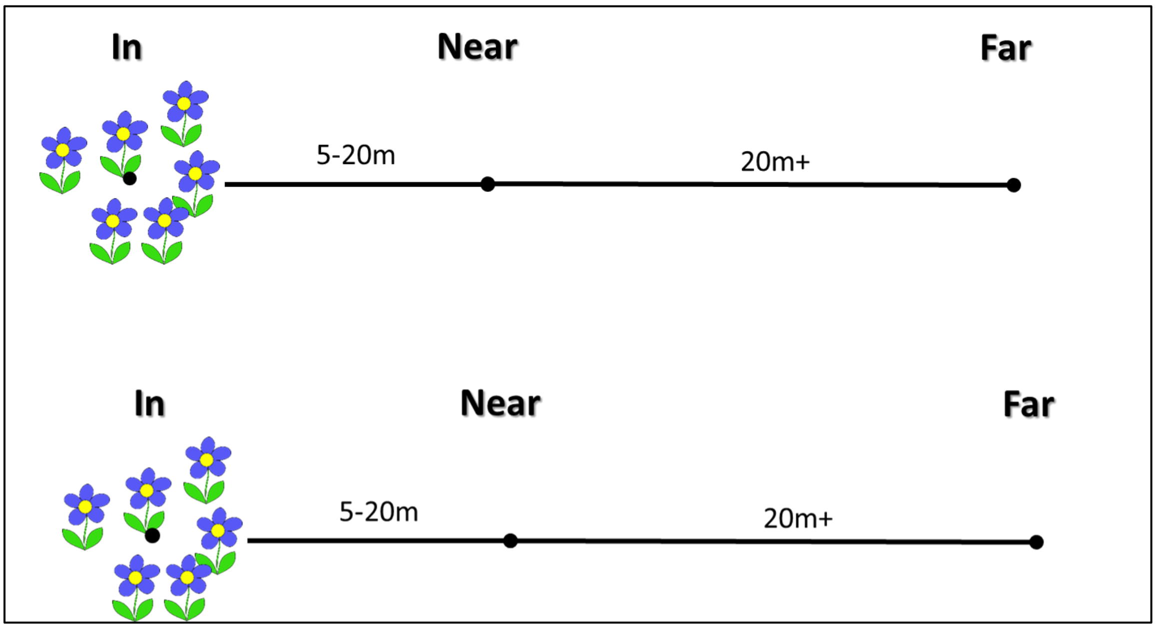


**Figure C-1**. Soil Sampling Design.

The sets of three samples (triads) are independent because we collected them at spatially disjunct sites within the range of the target species. However, the three samples within triads (*in*, *near*, *far*) are not independent because they are close together in the same general area.

## Advantages

Spatial matching of samples is statistically powerful because it reduces intra-subject variability by making comparisons between the same experimental unit (e.g., person, plot, or subject) before and after a treatment. In this study, the site is the subject and the samples (*in*, *near*, *far*) are the treatments. It is important to reduce when working with soils because they are notoriously patchy. This is particularly true of gabbroic soils because each out cropping of the parent material (gabbro) is chemically unique. Patchiness in soils also arises from site history, disturbances, pollution, and other factors.

### Disadvantages

One disadvantage of spatially matched sampling is the expense. For each plant occurrence in this study, we generated three samples and three sets of field data.

### Challenges

The chicken or egg problem is implicit in plant-soil interaction studies. Even when we detect differences between occupied and unoccupied soils, it remains unclear if the environment is driving occupancy or occupancy is driving the environment. For example, legumes form associations with *Rhizobium* bacteria which fix nitrogen (N). Finding a legume on soils with high N is a result of the plant's presence rather than the plant selecting for high N soils. We can make educated guesses about which factor (soil or plant) is the driver, but when little is known about a species, follow-up studies are often needed.

Our interest in these species stems from their rarity, which limits our sample size. Furthermore, this study is restricted to occurrences on conserved lands in San Diego County, further reducing the number of available sampling sites. Nevertheless, our samples represent a large proportion of extant populations of our target species. In other words, our sample is small yet representative for San Diego County. Three of the target species are found only or primarily in the county.

We include *near* sampling to identify suitable from unsuitable sites at a small spatial scale. However, some *near* sites may be suitable but unoccupied due to site history (e.g., invasive species, disturbance), natural randomness, or an unknown variable. In some cases, *near* samples collected on suitable but unoccupied habitat could muddy the interpretation of near data. For example, Figure C-2 depicts DECO present on one half of a field and absent on the other half. In this case, the difference is due to disturbance history rather than soil differences. Where DECO is present in the photo, the land manager removed nonnative grasses and thatch. Where DECO is absent, invasive grasses suppress DECO germination from a soil seedbank. To account for site history as a possible driving factor for species presence, we collected a *far* sample in habitat clearly different from the occupied site.

Similarly, it's possible that some currently occupied sites may be unsuitable for recruitment of new individuals. This is particularly true for long-lived perennials that have the ability to tolerate stress as adults. Because of changing conditions over time, the site may not support seedlings or young plants that are more susceptible to stress.

**Figure C-2**. Site History and Rare Plant Distribution. Left side of photo: nonnative grasses present and DECO absent. Right side of photo: nonnative grasses controlled and DECO cover high.

We addressed the possibility of unsuitable occupied sites by screening the data for extreme outliers. Outliers are not necessarily due to unsuitable conditions. They can result from laboratory error, natural variability, or even coincidence. However, they do deserve careful consideration and can indicate a problem. For example, during the course of this study we encountered a BRFI site with sodium (Na) levels more than double that of other BRFI sites. It is associated with a salty water source that led to extirpation of BRFI on another site.

## Response Design (Field Methods)

We collected *in* samples as close to the center of an occurrence as feasible (Figure C-1). We sampled next to ACIL, BRFI, and DECO and under the canopies of NOIN and TEDI. We collected *near* samples between 5 and 20 meters (m) from the edge of occupied habitat (Figure A). We specifically chose unoccupied areas with vegetation and soils similar to those inside the occurrence. ACIL occurs on discrete patches of clay, so we collected *near* samples just outside the clay lens and *far* samples at least 20 m away from *near* samples and at least 25 m from the edge of occupied habitat. For *far* samples, we targeted areas with visually different soils and vegetation than *in* and *near* samples.

At each sampling location, we collected multiple soil cores approximately 15 centimeters (cm) deep and 2 cm wide to obtain the 470 milliliters (ml) (ca. 2 cups) minimum required by industrial soils labs. We collected a smaller amount of soil in small ACIL populations to minimize damage to the clay lens. A&L Western Labs (Modesto, CA) processed all soil samples and conducted soil tests.

We evaluated soil texture by hand using a key simplified from Brewer and McCann (1982). This key divides soil into different texture classes based on physical properties such as its ability to stay together when squeezed into a ball, its plasticity when moistened, and the prevalence of smooth and gritty particles (Figure C-3). A&L Western Labs also measured soil texture using the hydrometer method (Gee and Bauder 1986).

**Figure C-3**. Assessing Soil Texture and Color in the Field.

We characterized soil color (both wet and dry) using a Munsell soil color book. The soil color book contains color chips against which we can compare soils visually (Figure C-3). Munsell characterizes each chip by a distinct hue, value, and chroma that can be cross-walked to a standardized description (e.g., *light brownish gray*) if desired. Unfortunately, there were too many color codes and descriptions to use a traditional chi-square ($X^2$) analysis to determine if soil color(s) was predictive of occupancy. We converted each color to red-green-blue (RGB) values to make the information more statistically manageable, but because a complete cross-walk between Munsell and RGB isn't publicly available, we estimated some of these values.

At each sampling location, we estimated the cover of plant species within a 10 m radius using a printed guide. We also assessed the position of target species occurrences on a topographic scale (e.g., top, bottom, middle, or upper or lower portion of a slope), and recorded the microtopography or approximate shape of the soil surface (e.g., convex, concave, flat, or undulating).

## Data Analysis

Data analysis took place in several phases. We conducted an exploratory phase in preparation for later phases, and set up our study design to be analyzed using repeated-measures ANOVA (RANOVA) and an equality of variance test (Bartlett's). We added a principle components analysis (PCA) to address multicollinearity (correlations) among the soils data and contextualize our results. We added additive logistic modeling as a means of inferring which of numerous significant results were most important. Note that our study design and the multicollinearity of the data are not ideal for this kind of modeling, and these results for clarification only.

### Exploratory Phase

The exploratory phase focused on characterizing the shape of the soils data distribution and identifying skewed variables or contained influential or unrealistic outliers. This phase is necessary in order to meet the assumption of normality for RANOVA, logistic regression, and other statistical tests which compare the mean and variance of different groups.

Biological data sets are often right-skewed (with many zeros or small values and few large values), and may possess influential outliers (extreme values). Skewed data can affect test results, often inflating the false-positive rate. Distributions were assessed visually using dot histograms, and in borderline cases skewness and kurtosis (measures of symmetry and the prevalence of outliers) were calculated. Distributions with skewness or kurtosis values greater than 2 (or less than -2) are significantly non-normal.

Skew and influential (but realistic) outliers were addressed by using a log(X+1) transformation. Log transformations normalize data with a preponderance of small or large values by shortening the distance between values on the tails. They are useful only in cases where the original data distribution approximates a log distribution. We reevaluated the distribution, skewness, and kurtosis of logged data to ensure the transformation yielded reasonable results.

We removed unrealistic outliers that were many standard deviations from the mean based on the assumption that something went wrong during soil processing or that some uncharacteristic perturbation had occurred at the sample location in the past (e.g., application of fertilizer, bodily elimination, urban runoff, dumping). Overall, there were few outliers in the data.

## Principle Components Analysis

Principal Components Analysis (PCA) is a statistical procedure that converts correlated variables into a single synthetic variable (a principle component) representative of the group. During PCA, we calculate several synthetic variables such that the first principal component explains the most variability in the data, and each following component picks up as much leftover variance as possible, while keeping the principle components uncorrelated and orthogonal. The strength of the relationship between the original variables and a principle component is expressed with factor loading ranging between -1 (perfect negative relationship) to 1 (perfect positive relationship), with zero indicating no relationship. The procedure yields a smaller set of uncorrelated synthetic variables, which we then analyze like any other data set. This is particularly useful for statistical modeling since multicollinearity among variables splits the explanatory power between them, undermining their apparent statistical significance. For our purposes, we used PCA as an exploratory tool to identify and characterize sets of variables as a group with strong relationships. This helped contextualize our RANOVA and Bartlett's test results. It also provided a road map for variable selection during additive logistic modeling.

PCA assumes a normal data distribution, so we used a log(X+1) transformation on all variables to eliminate skew. We performed the PCA with pairwise deletions to minimize the impact of missing values to the extent possible; however, we excluded phosphorous and color variables from final results due to missing data. We used a varimax rotation to minimize the number of variables with high factor loadings on each synthetic variable, which simplifies the interpretation.

## Repeated Measures ANOVA

We used RANOVA tests to detect differences between related means. In this study, the relating variable is the plant occurrence and the means being compared are those for the *in*, *near*, and *far* locations. RANOVA acknowledges the relationship between the three locations in a triad, reducing intra-subject variability and increasing statistical power.

RANOVA presents an advantage over making multiple comparisons (e.g., *in* vs. *near*, *in* vs. *far*, *near* vs. *far*) because the false positive (Type I error) rate is fixed at the significance level ($\alpha$, usually set at 5%), instead of inflating with each additional test performed. RANOVA does this by testing the differences between related sampling locations simultaneously. We then performed multiple comparisons (in this case paired t-tests) as a post-hoc test to tell which of the sampling locations are different from the others.

## Equality of Variances

RANOVA also assumes that the variance of each related group (e.g., location) is equal. We used a Bartlett's equality of variance test to verify this assumption throughout the data analysis process.

We use equality of variance tests to identify phenomena that affect the sample variance without changing the sample mean. Edaphic endemic plants are soil specialists that are often adapted to higher or lower levels of a given soil property; this can be captured by statistical tests against the means. In other cases, they may be restricted to a range of conditions that is narrower than the surrounding environment. For instance, a plant may occur only on soils with between 4 and 6 ppm zinc (Zn) on a larger landscape with Zn concentrations between 1 and 10 ppm. The average of soils around the plant won't be significantly different from the rest of the landscape, yet we expect to see less variance in soils collected around the species (Figure C-4). Equality of variance testing captures these instances which would be lost entirely by tests against the mean.

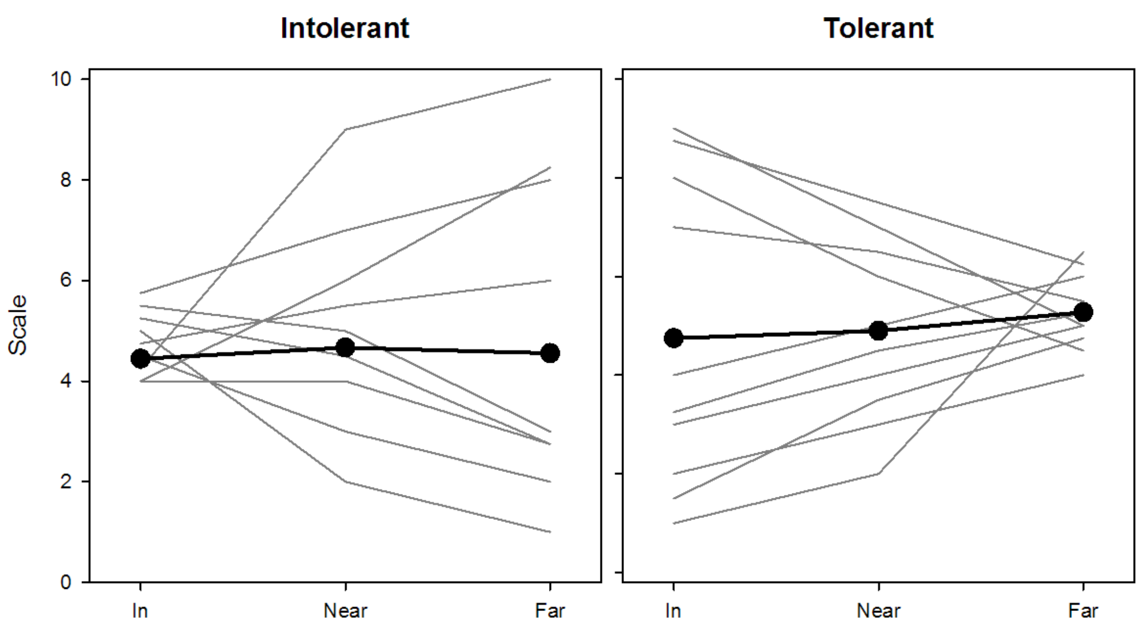


**Figure C-4**. Testing for Unequal Variance. In both figures, the mean remains constant at all three positions (indicating no relationship); however, the variance increases or decreases as one moves away from a species occurrence (indicating tolerance or intolerance of the species for a range of conditions).

We conducted Bartlett's tests on each soil variable for each species to capture such relationships. While we used raw data to determine if the three sampling positions had different variances, we used RANOVA's transformed data to verify equal variance, where appropriate.

## Additive Logistic Modeling

Logistic regression is a technique used to describe the relationship between a categorical dependent variable, and one or more nominal or ordinal independent variables. In this study, our dependent variable is the presence or absence of one of our rare plant species, and the independent variables are the aspects of soil chemistry we measured. We used data from *in* points as our "present" data, and we used *far* points as "absent" data. Logistic regression assumes that the samples analyzed are independent of one another, which is not the case due to our spatially matched sampling design. However, we actively sought dissimilar areas for our *far* samples so this should not present a problem, particularly if the interpretation recognizes the importance of spatial scale and the absence of *near* samples from the analysis.

Logistic regression allows us to add more than one explanatory variable to the model and consider the change in the test statistic (approximated on a chi-square [$X^2$] distribution). This lets us assess if the second variable is important after we account for the first variable. For example, RANOVA may indicate that BRFI is associated with clay, pH, and several other related variables. However, RANOVA forces us to test each variable separately, so we are unable to determine if pH plays a role after we account for clay content. Logistic modeling allows us to compare the single-variable "clay" model, to the two-variable "clay + pH" model, and determine if there is a significant, explanatory change. We do so by subtracting the $X^2$ of the clay model from the $X^2$ of the clay+ pH model and looking up the probability (p)-value on a 1 degrees of freedom (df) $X^2$ distribution (1 df because one variable was added). If the p-value is less than 5% ($P<0.05$), the addition of pH was a significant improvement to the model.

We must manage this approach carefully when working with correlated data. Adding independent variables to a logistic regression model will always increase the amount of variance explained by the model. In fact, many statistical programs have automated features that add and subtract variables until they arrive at an optimal solution. However, our soils data are not independent, and multicollinearity among variables breaks one of the fundamental assumptions of regression techniques. Correlation between variables splits the explanatory power between them; thus, undermining their apparent statistical significance. Two correlated variables that were powerful individually can begin to behave in odd ways when entered into a model together. To guard against this, we performed the addition of variables to the model by hand. We first estimated the $X^2$ values for individual variables identified as important by RANOVA. We then selected the most powerful single variable model, and added the remaining variables one at a time, calculating the change in $X^2$ values and their significance. If a two-variable model represented a significant improvement over the single variable model, we kept that model and repeated the process, adding a third variable, and so on. This allowed us to remove colinear variables from the model when they did not make a significant contribution while controlling for unusual behavior.

# Results

## Principle Components Analysis

Many of the soil variables measured in this study covaried in expected ways. Our PCA identifies three primary dimensions or categories for our variables.

PC1 (texture and pH) was positively correlated with clay, which drives increases in cation exchange capacity (CEC) and cations. In addition, pH increases with PC1, driving negative correlations with metals such as iron and manganese, which are more soluble with low pH.

PC1 explained 27% of the variance contained in the data set. Refer to Appendix C-1 for the full list of correlated variables with their factor loadings, and Appendix C-2 for a master correlation matrix.

PC2 (calcium [Ca] to Mg ratio) relates mainly to the relative availability of Ca and Mg. This ratio can be important for plant nutrition, as these cations can interfere with each other during plant uptake. PC2 explained 20% of the variation in the data set; refer to Appendix C-1 for factor loadings.

PC3 (fertility) is driven by organic matter (OM) and reflects aspects of soil fertility related to nutrient cycling, such as N, sulfur (S), and potassium (K). Copper (Cu) and Zn were also positively associated with this component because OM helps solubilize (chelate) metals. PC3 explained 13% of the variance in our soil data.

**Element or Soil Property**

| | |
|---|---|
| B | Boron |
| C | Carbon |
| Ca | Calcium |
| CEC | Cation Exchange Capacity |
| Cr | Chromium |
| Cu | Copper |
| Fe | Iron |
| Mg | Magnesium |
| Mn | Manganese |
| N | Nitrogen |
| Na | Sodium |
| Ni | Nickel |
| P | Phosphorus |
| S | Sulfur |
| Zn | Zinc |

Our five species fall out in different areas in this parameter space, and the two gabbro-associated species separate from the three clay-associated species (Figure C-5).

## Soil Chemistry and Texture

In the following sections, we discuss the distributions of our target species with respect to specific soil properties and interpret them in terms of soil science and biology.

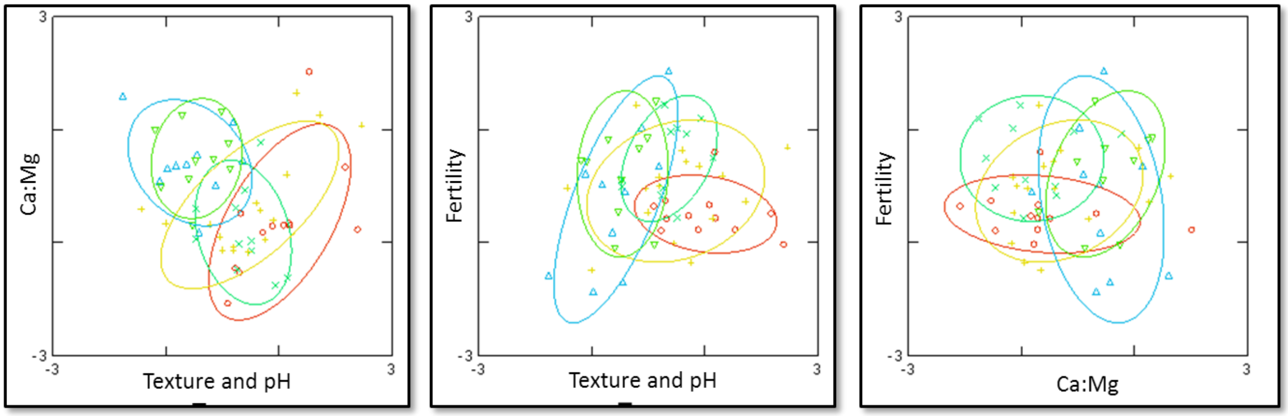


**Figure C-5**. Principle Components Analysis. Soil sample values are plotted on two PC axes to assess how closely related the soils associated with each sample are to one another. Confidence ellipses characterize typical soils associated with the species. Diverging ellipses indicate that species occupy different soil types as described by the principle components on the axes. Red circles = ACIL, green "X"s = BRFI, yellow "+"s = DECO, blue triangles = NOIN and green triangles = TEDI.

## San Diego Thornmint

Our data support the common understanding that ACIL occurs on clay soils (Figure C-6). Of the clay-loving species in this study, ACIL soils have the highest clay to sand ratio. The requirement for clay-rich substrates may drive the high pH, CEC, Mg, and Ca levels under these plants, as this suite of variables covaries positively with clay, though they also may be part of the underlying cause of this preference (Figure C-6). RANOVA results indicate that ACIL is strongly associated with several other variables which covary on the texture and pH (PC1) principle component (Appendix C-3). Similarly, a preference for higher pH and/or clay may drive avoidance of Zn and Iron (Fe)-rich sites (Figure C-6).

Although we know ACIL associates with clay, sand was a stronger predictor in both the RANOVA and logistic regression analysis (Appendix C-4). The proportion of clay in soils naturally correlates to the proportion of sand (and silt). Initially, we believed the relative strength of the sand signal over the clay signal was an artifact of laboratory technique (sand is sieved out of soils directly, but silt and clay are measured using the hydrometer technique). As an aggregate, though, our data show that estimates of sand are slightly more variable than clay. A Bartlett's test showed there was not a significant difference in the variance of sand or clay at the three different sampling locations. However, we did find that standard deviations associated with sand, clay, and silt were relatively low and nearly equivalent in ACIL (8.6, 8.5, 8.0). This was not the case with the other four species, which tended to have more variance in their sand fractions. The relevance of this observation is unclear, but could indicate that ACIL has more specific soil structure and texture requirements than do other clay species. Follow up work (e.g.,

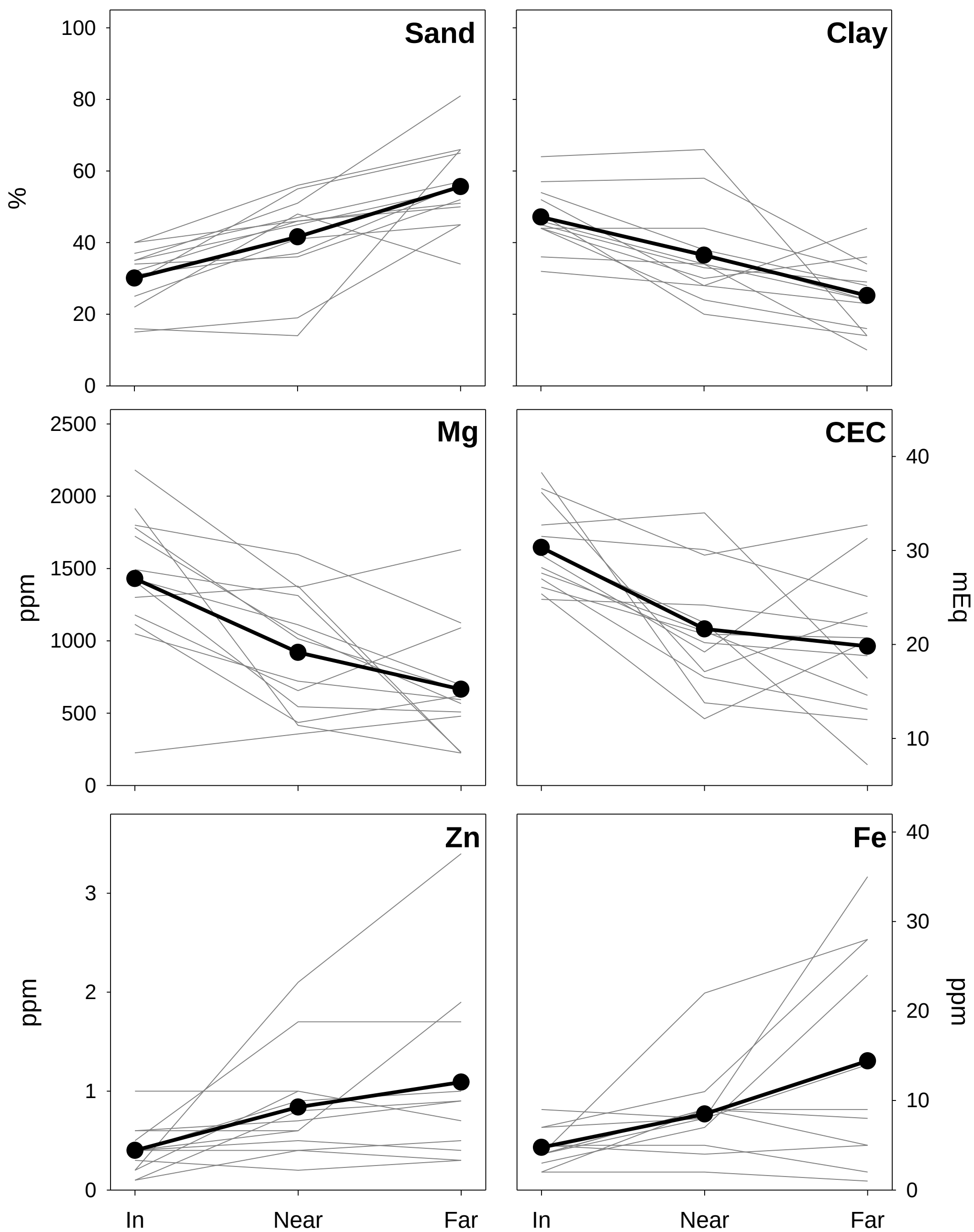


**Figure C-6**. ACIL Soil Test Results. A subset of significant soil variables associated with ACIL. Thin, grey lines represent a set of samples (*in, near, far*); heavy black lines indicate averages. Averages were assessed using RANOVA while variances (separation) of grey lines were tested using a Bartlett's test.

more samples to examine the means and variance of the three soil components as an aggregate) could prove interesting.

### Thread-leaved Brodiaea

BRFI was positively associated with clay and negatively associated with sand (Figure C-7, Appendix C-5). The positive association of BRFI with Na could be a spurious correlation resulting from the positive relationship between cation concentration and clay content (Figure C-7, Appendix C-5). RANOVA showed BRFI responded more strongly to Na than to Mg or Ca (Figure C-7, Appendix C-5), so this pattern may genuinely indicate Na-tolerance in this species. If this is the case, the pattern would likely result from improved competitive success in microsites with higher Na. The Na levels in this study are moderate but could still contribute to competitive effects between species varying in salinity tolerance. Another possible interpretation of the Na affinity of this species is that Na indicates swelling clays, such as Na montmorillonite (or smectite), which expand and contract more than Ca or Mg forms (Foster 1954). In BRFI, seedlings have a specialized contractile root that facilitates downward movement in the soil profile to the optimum depth (USFWS 2005). This process relies on soil contracting while drying, so Na-rich, swelling clays may be ideal for this species.

BRFI occurred in a relatively narrow pH range (Figure C-7, Appendix C-5) that was much lower than the other clay species in this study. Soil pH controls many aspects of soil biology and chemistry, so this pattern could represent direct physiological effects of pH or various indirect effects not measured in this study. For example, pH can influence the dominant form of N (ammonium vs. nitrate) and the availability of phosphorus (P) and various micronutrients, some of which are maximally available at intermediate pH levels.

### Otay Tarplant

Our data reinforced that DECO has an affinity for clay (Figure C-8, Appendix C-7). In addition, we found that DECO occurs on soils with the silt fraction restricted to a narrow range (less variable) (Figure C-8). It is unclear if this phenomenon is directly related to silt itself, or to the sand and clay requirements of the species. The high Na and Mg in DECO patches (Figure C-8) could be driven by clay preference and merely reflect the pH and texture principle component (PC1, Appendix C-1). However, as noted above for BRFI, it is worth considering the salinity tolerance of this species and the specific requirement for expanding Na-smectite clays. Similarly, the low P and Zn concentrations in DECO patches could be driven by the clay soil type or indicate restriction to relatively low fertility areas due to competitive effects (Figure C-8). P is an important macronutrient for plants and Zn is among several variables associated with

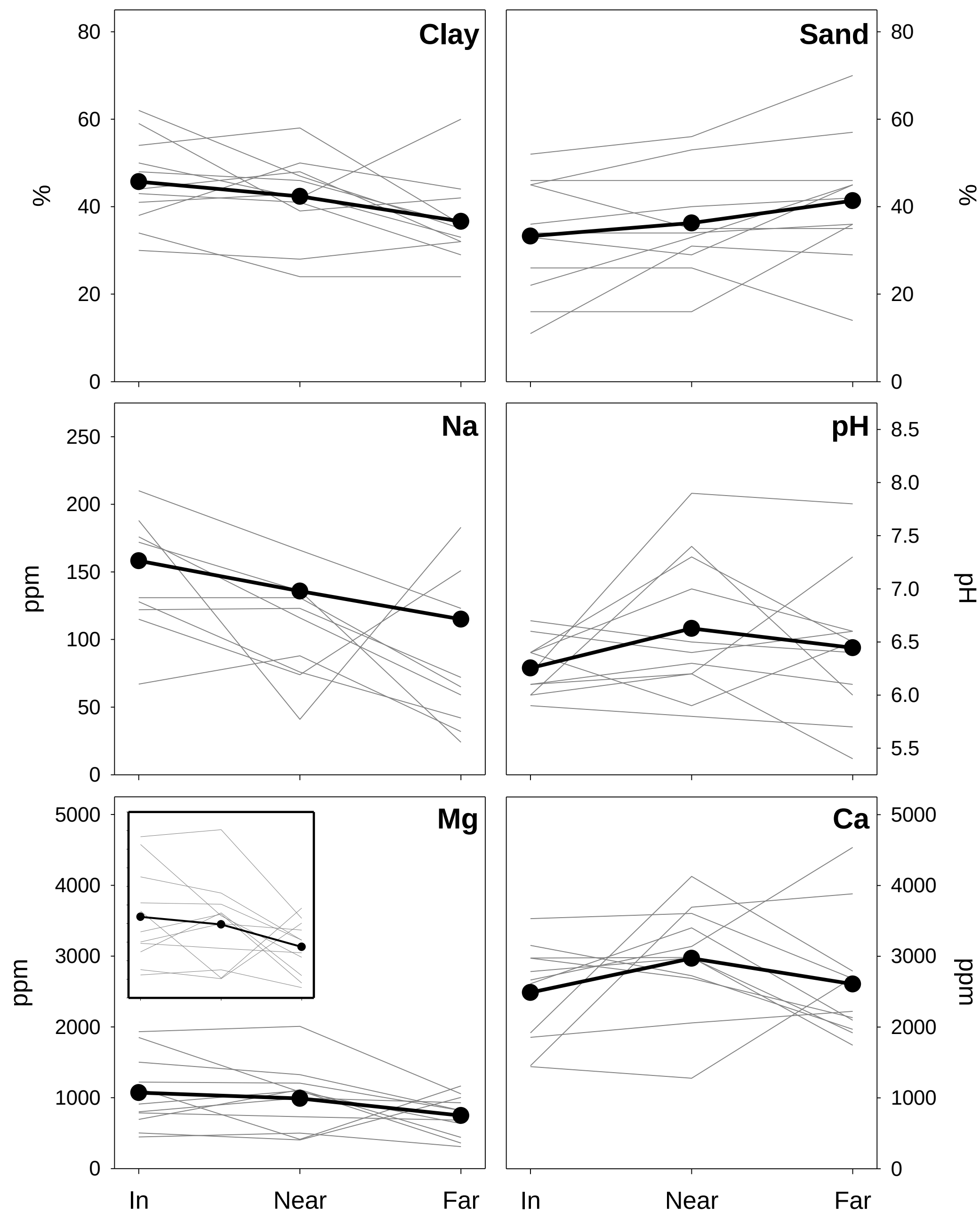


**Figure C-7**. BRFI Soil Test Results. A subset of significant soil variables associated with BRFI. Thin, grey lines represent a set of samples (*in, near, far*); heavy black lines indicate averages. Averages were assessed using RANOVA while variances (separation) of grey lines were tested using a Bartlett's test.

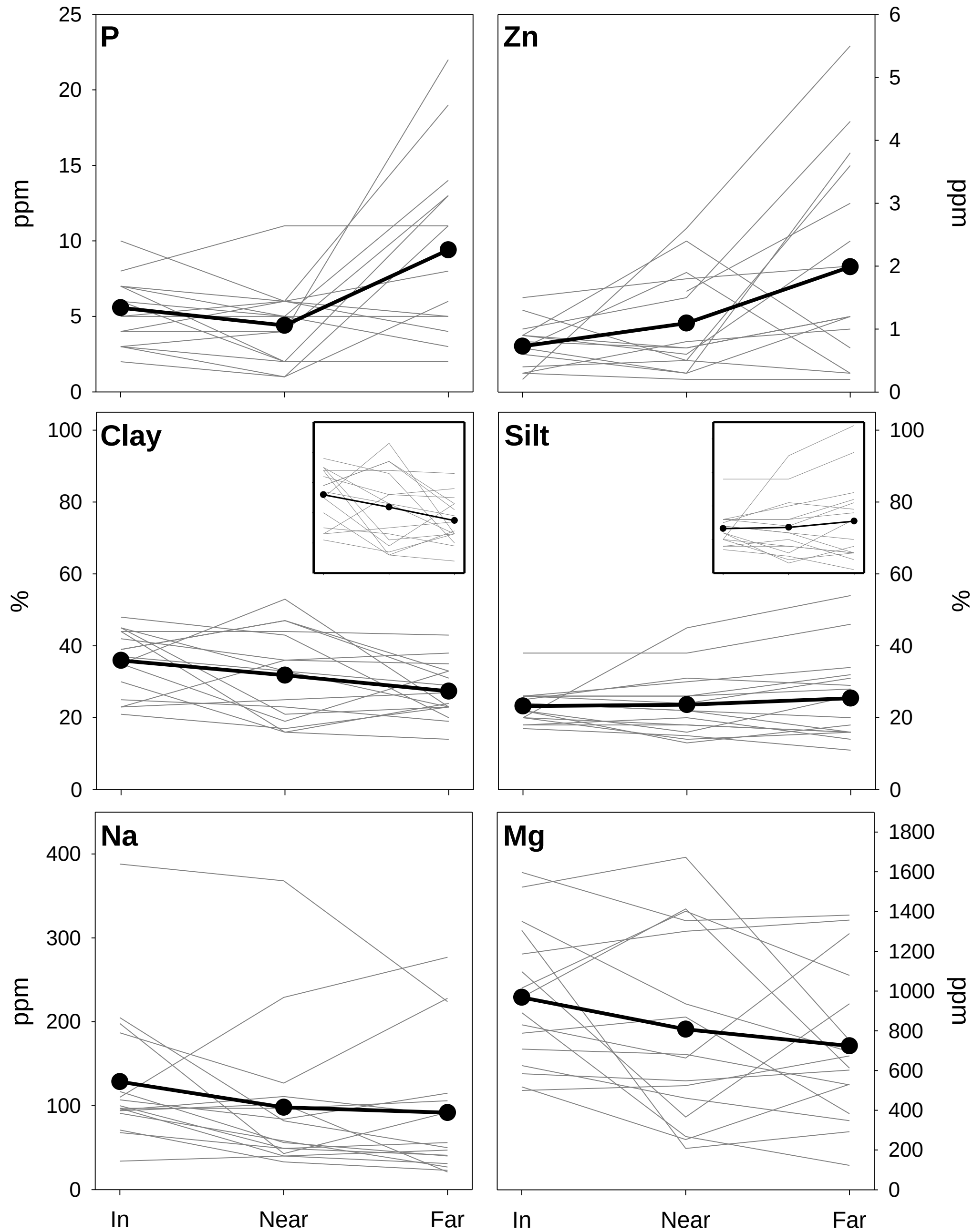


**Figure C-8**. DECO Soil Test Results. A subset of significant soil variables associated with DECO. Thin, grey lines represent a set of samples (*in*, *near*, *far*); heavy black lines indicate averages. Averages were assessed using RANOVA while variances (separation) of grey lines were tested using a Bartlett's test.

soil organic matter and other indicators of fertility (PC3). The occurrence of DECO on locally low fertility soils suggests an ecological strategy of stress tolerance and competition avoidance.

## Dehesa Nolina

The strongest pattern for NOIN across sampling triads was a preference for higher pH soils (Figure C-9, Appendix C-9). Relatively high boron (B), high Ca, and low manganese (Mn) concentrations associated with this species could be driven by pH (or vice versa), as these elements covary strongly with pH (PC1) (Appendix C-1). However, the relatively low Cu levels compared to nearby sites not occupied by this species are likely independent of pH (Figure C-9). Gabbro soils are similar in some respects to serpentine soils, which select for endemic plant species by a combination of low fertility and high concentrations of toxic metals. Gabbro can be relatively enriched in Cu (Medeiros et al. 2015), and so this species may require microsites within gabbroic soils with low Cu levels. Alternatively, this species may remediate Cu levels by bioaccumulation, as some serpentine soil endemics hyper-accumulate nickel (Ni).

Gabbro soils are formed from mafic (high Fe and Mg) lava, but tend to have more Ca than ultramafic soils, such as serpentine soils, where high Mg/Ca ratios can interfere with plant Ca uptake. However, the gabbro sites in this study had relatively low Ca concentrations compared to the other sites (see Appendices C-1 – C12), so the significantly higher Ca associated with NOIN compared to surrounding areas could indicate selection for Ca-rich microsites within a generally Ca-depleted landscape (Figure C-9, Appendix C-9). Logistic regression (comparing *in* and *far* points) suggested that Ca was the dominant variable at play, with pH adding little explanatory power to the model (Appendix C-10).

There is also a marginally significant trend towards higher soil organic matter (OM) content under this species, which could indicate their affinity for “fertility islands,” or their ability to help sequester carbon (C) into these soils (Figure C-9).

While these data do not clearly address the factors of gabbro soils that lead to endemism in NOIN, they do suggest local conditions this species may require within this broader soil type. As with other gabbro endemics, the former question may go beyond soil factors into the realm of biotic interactions (Gogol-Prokurat 2014), but simple experiments informed by data in this study could address smaller-scale patterns.

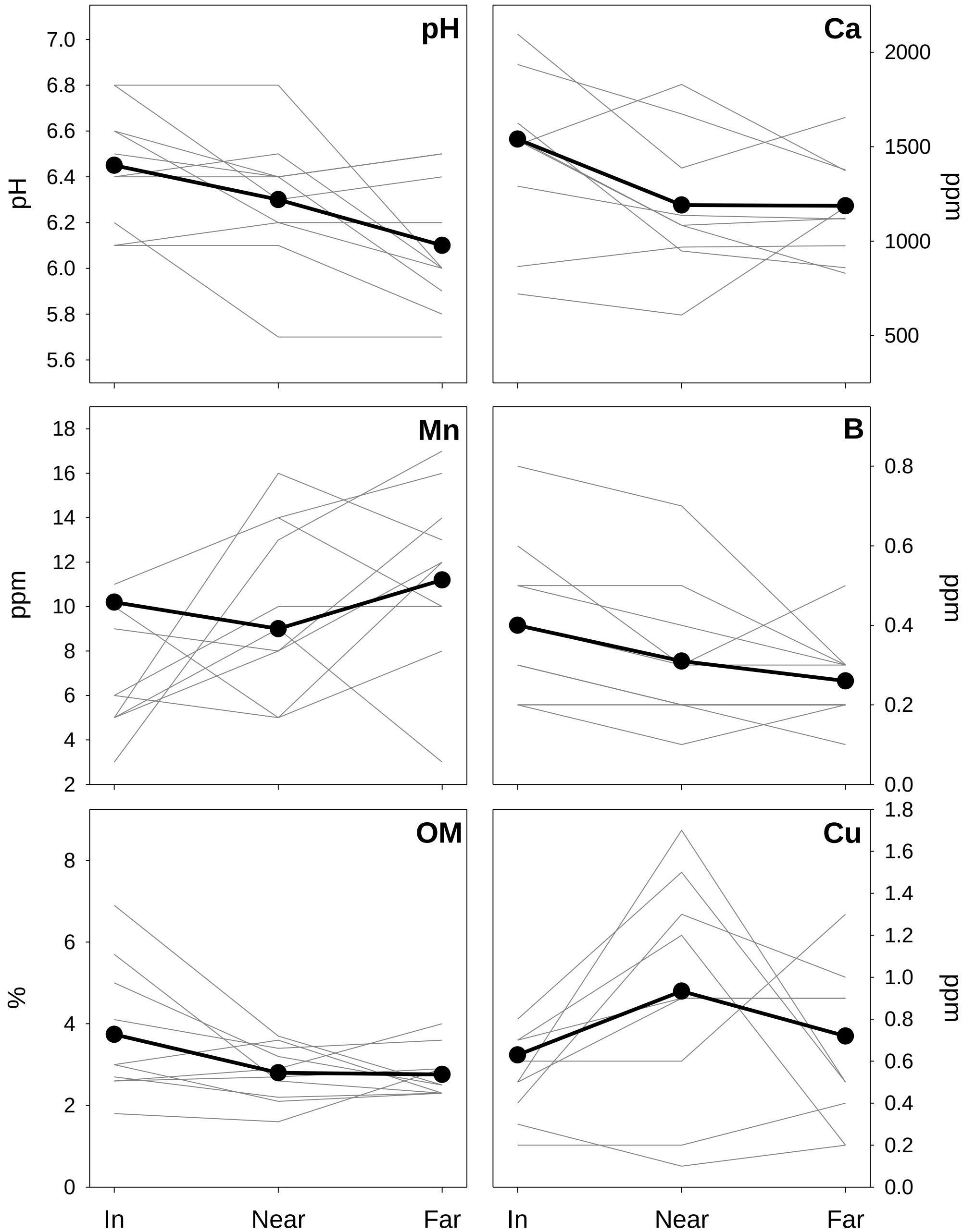


**Figure C-9**. NOIN Soil Test Results. A subset of significant soil variables associated with NOIN. Thin, grey lines represent a set of samples (*in*, *near*, *far*); heavy black lines indicate averages. Averages were assessed using RANOVA while variances (separation) of grey lines were tested using a Bartlett's test.

## Parry's Tetracoccus

Overall, TEDI shared similar soil characteristics with NOIN, as seen by their overlapping ellipses on the PCA plots (Figure C-5). This is consistent with the affinity of both species for gabbro soils. TEDI occurred within a wider range (higher variance) of Cu concentrations than observed in surrounding areas (Figure C-10), which could indicate Cu tolerance relative to the apparent sensitivity of NOIN to this metal. TEDI showed distinctive patterns, growing in areas with relatively high Fe and Zn compared to surrounding areas (Figure C-10). These patterns are subtle and given their moderate concentrations, probably do not directly represent the importance of these elements as either nutrients or toxins. However, they may be indicators of other associated metals not measured in this study.

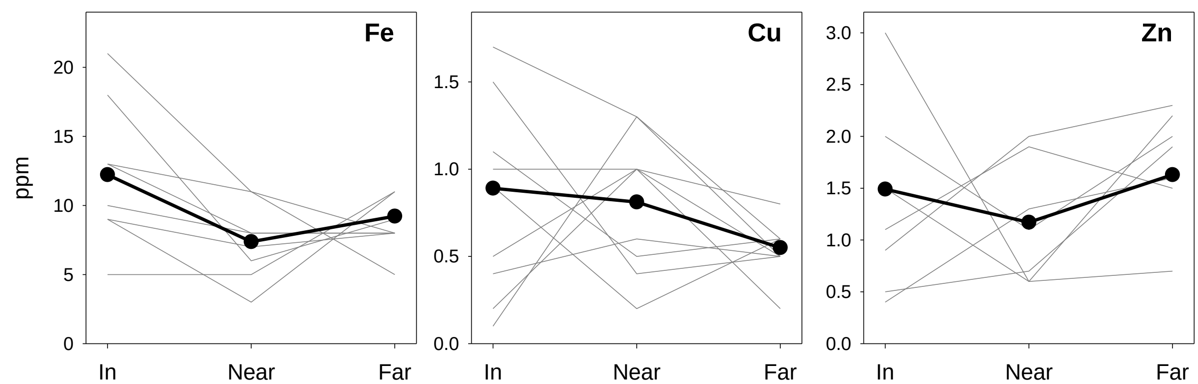


**Figure C-10**. TEDI Soil Test Results. A subset of significant soil variables associated with TEDI. Thin, grey lines represent a set of samples (*in*, *near*, *far*); heavy black lines indicate averages. Averages were assessed using RANOVA while variances (separation) of grey lines were tested using a Bartlett's test.

## Soil Color, Microsites, and Hand Texture

The target species occur on a broad spectrum of colors described in the Munsell color chart (Table C-1). As a result, our color sample size is too small to support a valid hypothesis test (e.g., Pearson's $X^2$), so we restricted our assessment of soil color to descriptions. All five species have a strong tendency to occur on "brown" soils (Table C-1). There is a great deal of overlap between soil colors associated with clay and gabbro species; however, gray soils were associated only with clay species and red or yellow soils were associated only with gabbro species. ACIL ranges across the largest number of colors and has the most variance in Red-Green-Blue (RGB) values compared to the other species (Figure C-11).

**Table C-1**. Range of Soil Colors for Target Species (from Munsell Color Chart).

| Color | Target Species[1,2] | | | | |
|---|---|---|---|---|---|
| | ACIL | BRFI | DECO | NOIN | TEDI |
| Brown | 15% | 27% | 38% | 40% | 56% |
| Strong Brown | 15% | 9% | 13% | - | 22% |
| Gray | 15% | 18% | 19% | - | - |
| Dark Grayish Brown | - | 27% | 6% | - | - |
| Yellowish Red | - | - | - | 20% | 11% |
| Dark Brown | 8% | 9% | - | 10% | - |
| Dark Gray | 8% | 9% | 6% | - | - |
| Dark Reddish Brown | - | - | - | 10% | 11% |
| Very Dark Brown | 8% | - | - | 10% | 0% |
| Grayish Brown | 8% | - | 6% | - | - |
| Pinkish Gray | 8% | - | 6% | - | - |
| Reddish Brown | 8% | - | - | - | - |
| Dark Yellowish Brown | - | - | - | 10% | - |
| Very Dark Grayish Brown | - | - | 6% | - | - |
| Black | 8% | - | - | - | - |
| Sample size: | 13 | 11 | 16 | 10 | 9 |

[1] Numbers represent the percentage (%) of soil samples that fall into color type.

[2] We color-coded cells by species, with color intensity increasing from white (no observations) to vivid as the percentage of observations increases. Values in each column help us assess how well Munsell colors identify potential habitat.

Similarly, it was not possible to perform hypothesis testing on hand texture data, due to small sample size. However, our observations reinforce other observations or data on texture for the target species. For example, both field and lab tests indicate that the clay species all occur on fine clay soils (Tables C-2, C-3). A large proportion of ACIL observations were on fine silty clay, which has the highest clay content when measured in the laboratory. Conversely, DECO occurs primarily on fine sandy clay (Table C-2), which has the most sand relative to other clays (Table 3). The gabbro species occur most frequently on moderately fine sandy clay loam or fine sandy clay (Table C-2).

We detected cracks in the soil at 100% of clay species occurrences, which was expected (Table C-4). Unfortunately, cracks on the soil surface were so prevalent elsewhere that the presence of cracks is not independently a reliable predictor of potential habitat (Table C-4). The gabbro species showed no association with the presence of cracks. Four of our five species occur most frequently on undulating terrain (Table E). This may be an artifact of the broad definition of

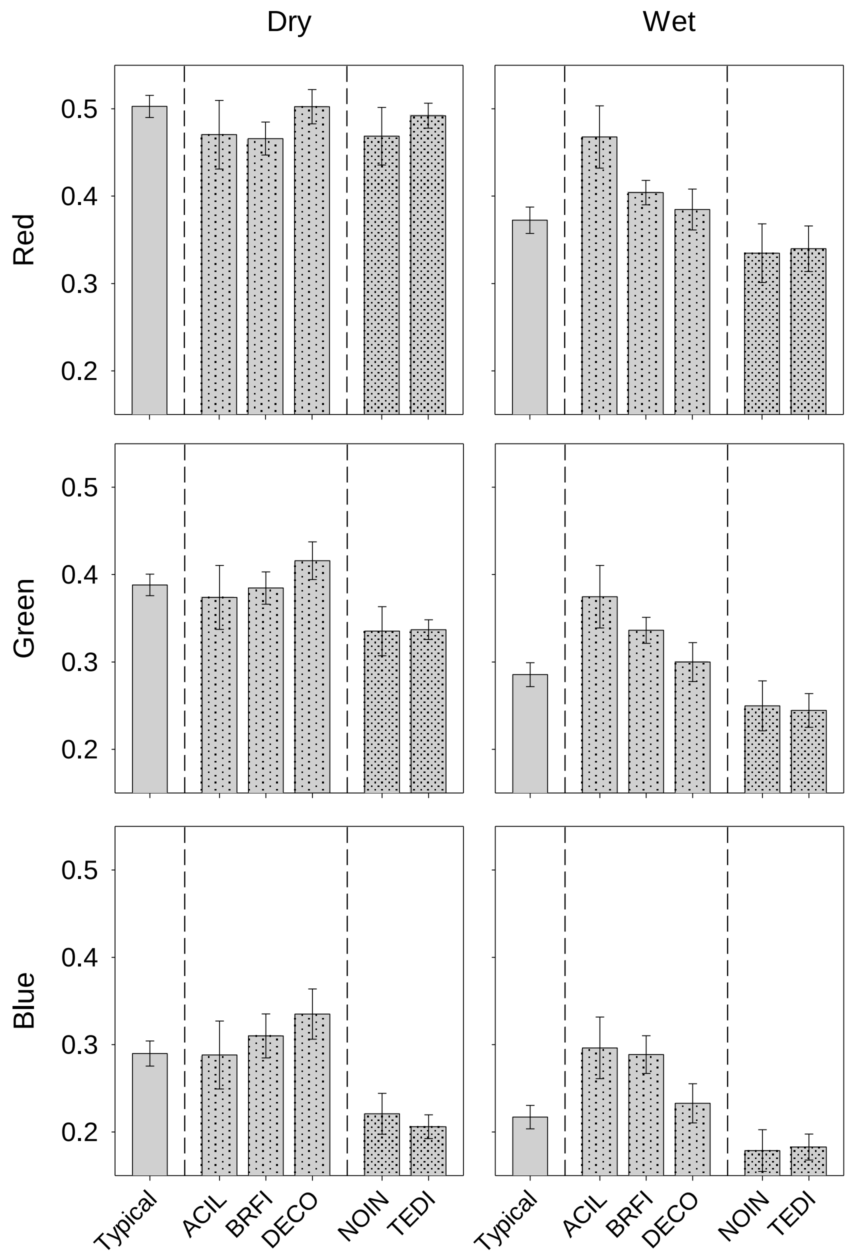


**Figure C-11**. RGB Values. Average RGB values for dry and wet soils for each species with a “typical” comparison. Typical values are averages of all *far* samples. Other values are averages of the *in* samples for each target species (indicated on the X axis). Dashed vertical lines separate the typical samples from the clay obligate species and the gabbro obligate species.

**Table C-2**. Summary of Soil Texture for Target Species[1]

| Soil Texture | Target Species[2,3] | | | | |
|---|---|---|---|---|---|
| | ACIL | BRFI | DECO | NOIN | TEDI |
| Fine silty clay | 38% | 18% | 6% | - | - |
| Fine clay | 54% | 55% | 38% | - | 11% |
| Fine sandy clay | 8% | 27% | 44% | 30% | 22% |
| Mod fine clay loam | - | - | - | 10% | - |
| Mod. fine sandy clay loam | - | - | 13% | 50% | 67% |
| Mod. coarse, sandy loam | - | - | - | 10% | - |
| Grand Total | 13 | 11 | 16 | 10 | 9 |

1 Results from field assessment of soil texture (i.e., hand texture).

2 Numbers represent the percentage (%) of soil samples that fall within soil texture type.

3 We color-coded cells by species, with color intensity increasing from white (no observations) to vivid as the percentage of observations increases. Values in each column help us assess how well we can use hand texture to identify potential habitat.

**Table C-3**. Cross-walk Between Soil Hand Texture and Particle Size Percentage.

| Soil Texture | % Sand | % Silt | % Clay |
|---|---|---|---|
| Fine silty clay | 24.8 (+/- 11.4) | 23.6 (+/- 6.7) | 51.8 (+/- 9.1) |
| Fine clay | 33.1 (+/- 9.4) | 23.6 (+/- 7.4) | 43.4 (+/- 8) |
| Fine sandy clay | 43.7 (+/- 7.5) | 21.8 (+/- 4.8) | 34.8 (+/- 7.9) |
| Moderately fine clay loam | 72.0 (n/a) | 17.0 (n/a) | 12.0 (n/a) |
| Moderately fine sandy clay loam | 54.5 (+/-6.8) | 25.4 (+/-4.8) | 20.4 (+/-4.9) |
| Moderately coarse, sandy loam | 67.0 (n/a) | 20.0 (n/a) | 13.0 (n/a) |

**Table C-4**. Presence of Cracks in Occupied and Unoccupied Habitat.

| Presence of Cracks | Target Species[1,2] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | ACIL | | BRFI | | DECO | | NOIN | | TEDI | |
| | Absent | Present | Absent | Present | Absent | Present | Absent | Present | Absent | Present |
| No Cracks | 23% | **0%** | 14% | **0%** | 37% | **0%** | 55% | 50% | 70% | 80% |
| Cracks | 77% | **100%** | 86% | **100%** | 63% | **100%** | 45% | 50% | 30% | 20% |

1 Absent = soil sample taken from *near* and *far* locations; Present = soil sample taken from IN location.

2 Numbers represent the percentage (%) of samples with or without cracks; bolded numbers indicate strong relationships. Comparing values in each species matrix lets us consider how well we can use the presence of cracks to identify potential habitat visually.

'undulating' relative to other microsite types. Nevertheless, a few potentially interesting patterns emerge. For example, ACIL occurred most frequently in concave hollows rather than on undulating terrain (Table C-5). This could be because these landscape features fill up with fine grain sediment (e.g., clay) over time. The two gabbro species, NOIN and TEDI, were never located on flat microsites. This is consistent with their occurrence on volcanic substrate that forms hills and mountains. As with soil color, our sample size is too small to support a valid hypothesis test on microsites, so we have no statistical basis for determining the significance of these observations, but they do match our understanding of the biology of these species.

**Table C-5**. Microtopography of Target Species Sites.

| Microtopography | Target Species[1,] | | | | |
|---|---|---|---|---|---|
| | ACIL | BRFI | DECO | NOIN | TEDI |
| Concave | 46% | 9% | 20% | 10% | 20% |
| Convex | 8% | 18% | 7% | 30% | 30% |
| Flat | 15% | 9% | 27% | - | - |
| Undulating | 31% | 64% | 47% | 60% | 50% |
| Sample Size: | 13 | 11 | 15 | 10 | 10 |

[1]Numbers represent the percentage (%) of *in* sample locations that fell within the microtopography type.
[2] We color-coded cells by species, with color intensity increasing from white (no observations) to vivid as the percentage of observations increases. Values allow us to consider how closely a particular microtopography type ties to each species.

## Associated Plants

### San Diego Thornmint

We recorded 77 species at ACIL occurrences, which is the highest diversity among our target species. However, we encountered only a few of these associates regularly at ACIL sites. Also, the ACIL clay lenses are often smaller than the 10 m vegetation sampling area; thus, species in Table C-6 represent those found in and immediately adjacent to ACIL patches. We found that the most frequent ACIL associates were tarplant (*Deinandra* spp.), tocalote (*Centaurea melitensis*), and filaree (*Erodium* spp.). Species often present at high or moderate cover included tarplant and the clay-loving nonnative grass purple falsebrome (*Brachypodium distachyon*). Despite the extensive species list, ACIL patches had the lowest total (absolute) vegetation cover (54%) relative to the other target species.

**Table C-6**. Associated Species at San Diego Thornmint Soil Sampling Sites.[1,2]

| Scientific Name | Common Name | No. of Sites Occupied | Average Cover (%) |
|---|---|---|---|
| *Adenostoma fasciculatum* | Chamise | 2 | 2.0 |
| *Apiastrum angustifolium* | Mock parsley | 5 | 0.4 |
| *Brachypodium distachyon* | Purple falsebrome | 6 | 4.2 |
| *Centaurea melitensis* | Tocalote | 9 | 3.6 |
| *Cryptantha* species | Cryptantha | 2 | 1.5 |
| *Deinandra* species | Tarplant | 9 | 13.0 |
| *Erodium* species | Filaree | 8 | 0.6 |
| *Lysimachia arvensis* | Scarlet pimpernel | 5 | 0.1 |
| *Plantago rhodosperma* | Red seed plantain | 4 | 1.2 |
| *Rhus integrifolia* | Lemonadeberry | 3 | 1.2 |
| *Sonchus oleraceus* | Common sow thistle | 7 | 0.2 |

[1] Includes the most common species detected only.
[2] Sample size = 13.

### Thread-leaved Brodiaea

We recorded 37 associated species at BRFI occurrences, which is the lowest number among our target species (Table C-7). This may be due to nonnative grass invasion. Wild oats (*Avena* spp.) and purple falsebrome were often found at high cover and can out-compete native forbs. Low species diversity could also be due to chemistry and texture of clays associated with BRFI, which pose a challenge to some species. We encountered bristly ox-tongue (*Helminthotheca echioides*) (often occurring on clays) regularly and in very high cover at one site. Another nonnative forb, black mustard (*Brassica nigra*), also occurred frequently, but typically at lower cover (Table C-7). Total vegetation cover averaged 68% at BRFI sites. Species associated with BRFI were extreme generalists, clay-loving species, grassland species, or a combination of all three.

### Otay Tarplant

We recorded 69 species within DECO populations (Table C-8). Total vegetation averaged 60% at DECO sites. We encountered tocalote and purple falsebrome at most populations, occasionally at high cover. We also encountered black mustard frequently, but typically at lower cover. We encountered species more typical of coastal sage scrub occasionally (such as California sagebrush [*Artemisia californica*] and San Diego County viguiera [*Bahiopsis laciniata*]), which is expected because native grasslands that support DECO often intergrade with coastal sage scrub (Table C-8).

**Table C-7**. Associated Species at Thread-leaved Brodiaea Soil Sampling Sites.[1,2]

| Scientific Name | Common Name | No. of Sites Occupied | Average Cover (%) |
|---|---|---|---|
| *Avena* species | Wild oats | 6 | 29.7 |
| *Brachypodium distachyon* | Purple falsebrome | 6 | 26.8 |
| *Brassica nigra* | Black mustard | 6 | 0.8 |
| *Calystegia macrostegia* | False bindweed | 1 | 0.3 |
| *Festuca perennis* | Italian rye grass | 4 | 2.4 |
| *Festuca myuros* | Rattail six-weeks grass | 1 | 5.5 |
| *Grindelia camporum* | Gum plant | 3 | 0.1 |
| *Helminthotheca echioides* | Bristly ox-tongue | 6 | 5.5 |
| *Rhus integrifolia* | Lemonadeberry | 1 | 0.5 |
| *Sonchus oleraceus* | Common sow thistle | 3 | 0.2 |
| *Stipa* species | Needlegrass | 4 | 0.6 |

1 Includes the most common species detected only.

2 Sample size = 11

**Table C-8**. Associated Species at Otay Tarplant Soil Sampling Sites.[1,2]

| Scientific Name | Common Name | No. of Sites Occupied | Average Cover (%) |
|---|---|---|---|
| *Artemisia californica* | California sagebrush | 6 | 1.2 |
| *Bahiopsis laciniata* | San Diego County viguiera | 4 | 0.7 |
| *Brachypodium distachyon* | Purple falsebrome | 10 | 17.1 |
| *Brassica nigra* | Black mustard | 10 | 0.7 |
| *Bromus madritensis* | Red brome | 5 | 1.3 |
| *Centaurea melitensis* | Tocalote | 14 | 4.7 |
| *Convolvulus simulans* | Small-flowered morning glory | 4 | 0.2 |
| *Deinandra* species | Tarplant species | 4 | 0.7 |
| *Erodium* species | Filaree species | 7 | 1.8 |
| *Festuca myuros* | Rattail six-weeks grass | 4 | 0.8 |
| *Stipa* species | Needlegrass | 4 | 0.8 |

1 Includes the most common species detected only.

2 Sample size = 16

## Dehesa Nolina

We recorded 54 species within NOIN populations (Table C-9). We found redberry (*Rhamnus crocea*) at over half of NOIN occurrences (6 of 10) (Table C-9). Other shrubs found at half of NOIN occurrences, including chamise (*Adenostoma fasciculatum*), California sagebrush, Cleveland sage (*Salvia clevelandii*), and the other gabbro endemic, Parry's tetracoccus (TEDI) (Table C-9). Preliminary logistic modeling (not presented) indicated that native shrub richness was the strongest predictor of NOIN, followed by the presence of TEDI. A preliminary PCA (also not presented) grouped NOIN and TEDI together consistently, along with native shrub richness (i.e., chamise, Cleveland sage, manzanita [*Arctostaphylos* spp.], and redberry). Together, these species represent a distinct assemblage associated with gabbro soils in southern San Diego County. When chamise and manzanita were absent, NOIN occurred with coastal sage scrub shrubs, such as California sagebrush and San Diego County viguiera. The nonnative grass, purple falsebrome has invaded NOIN populations at one site (South Crest) where we collected several soil samples. Nonnative grass is virtually absent from populations elsewhere, which may be due to low disturbance and relatively long fire intervals at those sites compared with South Crest. Total vegetation cover averaged 76% at NOIN sites.

**Table C-9**. Associated Species at Dehesa Nolina Soil Sampling Sites.[1,2]

| Scientific Name | Common Name | No. of Sites Occupied | Average Cover (%) |
|---|---|---|---|
| *Adenostoma fasciculatum* | Chamise | 5 | 11.9 |
| *Arctostaphylos* species | Manzanita species | 3 | 2.9 |
| *Artemisia californica* | California sagebrush | 5 | 2.3 |
| *Brachypodium distachyon* | Purple falsebrome | 4 | 12.3 |
| *Bromus madritensis* | Red brome | 5 | 1.0 |
| *Cneoridium dumosum* | Bush rue | 2 | 0.3 |
| *Dichelostemma capitatum* | Blue dicks | 5 | 0.1 |
| *Malosma laurina* | Laurel sumac | 2 | 1.3 |
| *Rhamnus crocea* | Redberry | 6 | 1.5 |
| *Salvia clevelandii* | Cleveland sage | 5 | 1.3 |
| *Tetracoccus dioicus* | Parry's tetracoccus | 5 | 1.9 |

[1] Includes the most common species detected only.

2 Sample size = 10.

### Parry's Tetracoccus

Total vegetation cover averaged 116% at TEDI occurrences. This is substantially higher than cover at NOIN occurrences (76%) despite the close spatial association of these two species (Table C-10, C-9). We recorded 51 species within TEDI populations (Table C-10). Like NOIN, TEDI is associated with high native shrub richness and frequently occurs near chamise, Cleveland sage, manzanita species, and redberry (Table C-10). TEDI and NOIN often co-occur and are good predictors of one another, even on a small spatial scale.

**Table C-10**. Associated Species at Parry's Tetracoccus Soil Sampling Sites.[1,2]

| Scientific Name | Common Name | No. of Sites Occupied | Average Cover (%) |
|---|---|---|---|
| *Adenostoma fasciculatum* | Chamise | 6 | 9.4 |
| *Arctostaphylos* species | Manzanita | 4 | 3.4 |
| *Hesperoyucca whipplei* | Chaparral yucca | 4 | 0.6 |
| *Heteromeles arbutifolia* | Toyon | 2 | 0.2 |
| *Hirschfeldia incana* | Short-podded mustard | 2 | 0.9 |
| *Malosma laurina* | Laurel sumac | 2 | 1.0 |
| *Nolina interrata* | Dehesa nolina | 4 | 3.2 |
| *Rhamnus crocea* | Redberry | 4 | 0.8 |
| *Salvia clevelandii* | Cleveland sage | 5 | 0.9 |
| *Salvia mellifera* | Black sage | 1 | 5.0 |
| *Xylococcus bicolor* | Mission manzanita | 2 | 1.0 |

[1] Includes the most common species detected only.
[2] Sample size = 10.

## Discussion

This study considered unseen factors in the soil, site characteristics, and vegetation to refine our understanding of five edaphic endemic plants. To advance our understanding of these species, we used a spatially explicit sampling design that allowed us to compare occupied and unoccupied soils and examine habitat requirements at a fine spatial scale.

Our results indicate that all five target species occur on nutrient poor soils, and that each species is associated with a unique suite of physical and chemical soil properties. Many of these properties correlate significantly to one another, which make identifying individual drivers difficult and potentially misleading (i.e., adapting to or exploiting any single factor necessitates adapting to the other related factors). Nevertheless, the fine-scale, multidimensional information we collected clarifies uncertainties about the species' requirements and elucidates several new pieces of information.

## San Diego Thornmint

The USFWS (2009a) 5-year review describes ACIL habitat as follows:

> "*Acanthomintha ilicifolia occurs on isolated patches of clay soils derived from gabbro and soft calcareous sandstone substrates. The soils derived from gabbro substrates are red to dark brown clay soils, and those derived from soft calcareous sandstone are gray clay soils. These patches of clay soils surrounded by non-clay soils are called 'clay lenses.'*"

Our study confirms that ACIL is restricted to clay soils but adds that these clays must be particularly low in sand (even relative to other clay-loving species). Our study also concurs with the description of soil color on clay lenses but discovered that these colors were much more variable than the other species we evaluated.

At a large scale ACIL is found on clays with 60% less iron relative to the global average (all *far* points across San Diego) and is much less tolerant of metals than the other clay obligates we studied. ACIL on gabbroic clays occurs in microsites with equally low metal content, even though gabbro is typically metal-rich. However, gabbro readily weathers into silt and clay (Medeiros et Al., 2015). We conclude, therefore, that the occurrence of ACIL on gabbroic clays is due to the weathering properties of the parent material rather than its chemical content.

## Thread-leaved Brodiaea

The USFWS (2009b) 5-year review describes BRFI habitat as follows:

> *"This species is usually found in herbaceous plant communities. These herbaceous communities occur in open areas on clay soils, soil with clay subsurface, or clay lenses within loamy, silty loam, loamy sand, or silty deposits with cobbles or alkaline soils."*

In 2011, when the USFWS revised the designated critical habitat, the following caveat was included:

> *"In some areas in northern San Diego County and southwestern Riverside County, the species is identified with mapped soils with no known clay component; however, closer study and site-specific sampling may show these soils contain clay in the specific areas supporting BRFI. Despite this issue and the diversity in named soil series, BRFI is considered a clay soils endemic."*

Our study was site-specific and designed to capture a smaller spatial scale than soils maps, a as suggested by USFWS in 2011. Although we did not sample in Riverside County, our data from northern San Diego County supports BRFI as a clay endemic. Our data also show that BRFI is tolerant to relatively high Na content in clays, yet avoids alkaline soils. Instead, BRFI stays within a relatively narrow pH range more typical of non-clay soils, even when more alkaline soils are available nearby. It therefore seems likely that those populations reported on “alkaline soils” are actually on smaller patches of unmapped clay which, while salty, are not alkaline. If confirmed, this piece of information will dramatically improve our ability to select appropriate sites for BRFI outplantings and restoration in the future.

## Otay Tarplant

DECO’s specific adaptation to clay soils is not well-known, other than its general affinity for clay soils, subsoils, and lenses. More attention has focused on its self-incompatible mating system and the problem that habitat fragmentation poses to pollination. Yet understanding DECO soils is a critical step for selecting appropriate sites for restoration or translocation, particularly where the species has been extirpated or has not been recorded previously (e.g., experimental translocation in response to a changing climate).

Our data show that DECO correlates positively to clay as expected. It also has a positive relationship with Na and Mg, which may be attributable to its preference for clay or possibly, tolerance to salt or preference for Na-smectite clay. Our data also show that DECO occurs on soils with relatively low fertility (as indicated by low levels of Zn and P) in comparison to the surrounding landscape. Drivers could be either clay’s inherent properties or an ecological strategy of stress tolerance and competition avoidance.

Our data show a much looser negative relationship to sand than the other clay species we examined. Further, the proportion of silt associated with DECO is less variable than it is elsewhere on the landscape. The importance and potential implications of this observation are unclear but point toward questions about physical characteristics of soils that we have not yet addressed.

## Dehesa Nolina

NOIN is generally restricted to gabbroic soils and clays within a small area of San Diego County and northern Baja California. Some populations occur on soil series where gabbro is not the primary parent material but is an inclusion in other soil types (CBI 2015). There are also a few populations on clay soils not derived from gabbro, although we base this information on the

SSURGO soils data set, which is spatially coarse and often inaccurate at finer scales relevant to plants.

Our data indicate that clay content does not significantly influence NOIN at the scale of our study. However, clay strongly influences pH and Ca, which were the two most significant factors associated with NOIN. The pH might drive the relatively high B, high Ca, and low Mn concentrations associated with this species (or vice versa). Logistic regression indicated that Ca was the strongest predictor of NOIN presence even when pH was included in the model. The gabbro sites in this study had relatively low Ca concentrations compared to a global average across all our *far* points, so the significantly higher Ca associated with NOIN could indicate selection for Ca-rich microsites within a generally Ca-depleted landscape.

NOIN also shows an interesting spatial relationship with Cu, occurring on soils with low Cu levels that appear embedded inside areas of locally high Cu. Gabbro soils are similar in some respects to serpentine soils, which select for endemic plant species by a combination of low fertility and high concentrations of toxic metals. Gabbro can be relatively rich in Cu (Medeiros et al. 2015), so this species may require microsites within gabbroic soils with low Cu levels. Alternatively, this species may remediate Cu levels by bioaccumulation, as some serpentine soil endemics hyper-accumulate Ni.

While these data do not clearly address the factors of gabbro soils that lead to endemism in NOIN, they do suggest local conditions this species may require within this broader soil type. Follow-up work should compare populations on gabbroic soils to those that appear to occur on clays derived from other material. As with other gabbro endemics, biotic interactions are also of interest (Gogol-Prokurat 2014).

## Parry's Tetracoccus

Other than its affinity for gabbroic soils on steep, rocky terrain, we know little about TEDI's habitat requirements. It shares similar soil characteristics with NOIN, but its relationship to those characteristics is quite different. For example, while NOIN appears to "avoid" Cu, TEDI occurs on a wide range of Cu concentrations. TEDI also occurs on soils containing more iron and Zn than the surrounding area. These patterns are subtle, and given their moderate concentrations, probably do not directly represent the importance of these elements as either nutrients or toxins. However, they may be indicators of other associated metals not measured in this study. TEDI may therefore be avoiding competition with other plants by tolerating metals in a metal-rich environment.

# Recommendations

Improving our understanding of the soils that support edaphic endemic plants allows us to (1) evaluate occurrences with low population size to determine if conditions are still appropriate to support the target species, particularly if the occurrence does not respond to enhancement measures, (2) evaluate extirpated occurrences to determine if they are salvageable through site remediation and/or species augmentation, (3) evaluate suitable but unoccupied sites for expansion or establishment, and (4) identify new areas of inquiry or potential management measures or experiments to expand the population beyond its current, realized niche (translocation or assisted migration).

In the previous section, we identified additional studies to further refine soil-plant relationships. In this section, we provide recommendations for species management based on study results.

- All five species occur on nutrient poor soils. We recommend testing soils to identify site fertility and chemistry, particularly for variables with strong relationships to species presence, prior to expanding existing occurrences into adjacent, unoccupied habitat, establishing new occurrences in unoccupied habitat to improve connectivity, or translocating the species into habitat outside its current range in response to changing climatic conditions. Soil testing would also benefit enhancement projects where the species is still present to ensure that soils are still suitable; we could then eliminate or remediate unsuitable sites with remnant populations before investing management funds.

- Since this study was descriptive in nature and because soils variables often correlated to one another, we recommend confirming causal links between soils and plants. Refer to Future Work (below) for appropriate experiments.

## San Diego Thornmint

- Test soil to ensure that the site is high in clay (42-52%), low in sand (25-35%), and low in metal content (3.5-6 ppm Fe, 0.5-1.1 ppm Cu, and 0.25-0.55 ppm Zn) before expanding, establishing, or translocating this species (note that different testing methods can yield different results). Where existing occurrences do not respond favorably to enhancement, consider testing the soil to ensure that the site retains suitable conditions to support this species.

- Unless new information becomes available it is reasonable to assume that the presence of ACIL on gabbroic clay is due to gabbro weathering into clay of the right texture, rather than the gabbro conferring important chemical properties.

## Thread-leaved Brodiaea

- Test soil for clay content (39-53%), pH (6.1-6.4) and Na (111-205 ppm) (at minimum) before expanding, establishing, or translocating this species. Where existing occurrences do not respond favorably to enhancement, consider testing the soil to ensure that the site retains suitable conditions to support this species.
- Contact the land manager (Center for Natural Lands Management) about the Rancho La Costa North occurrence (BRFI_6RLCO018) to inform them of extreme Na levels at that site. In the event of a population decline that does not appear tied to other factors (e.g., climatic fluctuations, direct disturbance, invasive species), the land manager may consider locating and eliminating the source of the Na, if possible, and remediating the site back to lower Na levels.

## Otay Tarplant

- Test soils for clay content (31-41%), Na (84-173 ppm), Zn (0.06-2.5 ppm), and P (0.06 ppm and 4-6.6 ppm, respectively as assayed by Weak Bray method) before expanding, establishing, or translocating this species. Where existing occurrences do not respond favorably to enhancement, consider testing the soil to ensure that the site retains suitable conditions to support this species.

## Dehesa Nolina

- Test soils for pH (6.1-6.6), Ca (1200-1900ppm), and Cu (0.4-1.1ppm) content before establishing or translocating this species.
- Select microsites with relatively high Ca (1200-1900ppm) over others, and avoid microsites with high Cu (>1.1ppm).

## Parry's Tetracoccus

- Test soils for Fe (8-15 ppm), Zn (1.2-2.1 ppm), and Cu (0.4-0.7ppm) content before establishing or translocating this species.

# Future Work

This study is descriptive, and so the mechanisms underlying the patterns we present, while well informed, are nevertheless speculative. Here we suggest experiments to test hypotheses implied by the observed patterns.

## San Diego Thornmint

Since there is a suite of variables that covary with the presence of these clay lenses, we recommend experiments to tease apart the driving variables. Previous competition studies varied light conditions (Bauder and Sakrison 1999), and N and water availability (Rice 2017), but there is currently no experimental data on how ACIL success is affected by soil type, clay content, pH and the other soil variables identified here. Potential experiments or investigations include

- Test whether the establishment of ACIL links to the abundance of base cations (Ca, Mg), direct effects of soil pH, or effects of clay on soil moisture, structure, or porosity.
- Test the performance of ACIL in response to soil variables (soil type, clay content, pH, and other variables) both in monoculture and in competition with exotics.
- Examine the bulk physical properties (structure, density, friability) of soils in clay lenses that support ACIL.
- Further explore the importance of sand, the sand to clay ratio, porosity, and bulk density of soils that support ACIL, and examine the vertical soil structure in a careful, fine-scale fashion.

## Thread-leaved Brodiaea

To isolate the potential effects of Na on habitat preferences of BRFI, we recommend experiments to differentiate between salinity and clay mineralogy effects. Potential experiments include:

- Test the effect of Na on competitive success by comparing establishment and growth of BRFI at a range of Na concentrations in monoculture or in competition with exotic annuals
- Test the role of clay mineralogy experimentally by comparing establishment of seedlings in soils that have identical clay content but vary in mineralogy
- Investigate the hypothesized link between BRFI and Na montmorillonite by analyzing the mineralogy of the soils associated with BRFI patches; this could include sprinkling seeds into vertisol cracks and comparing BRFI success (germination, establishment) to nearby reference sites without cracks.
- Test direct and indirect effects of pH with a factorial experiment varying pH and micronutrients, and adding N in two forms (nitrate vs. ammonium).

- Conduct pot experiments to confirm that BRFI selects for clays with relatively low pH (6.1-6.4) rather than creates these conditions.

## Otay Tarplant

We recommend testing Na and clay effects as described above for BRFI. Additional experiments include:

- Explore the importance of sand, silt, and clay fractions, as well as porosity and bulk density for this species. Examining the vertical soil structure in a careful, fine scale fashion could also be helpful.

- Test the hypothesis that DECO exhibits a low fertility strategy by comparing competitive performance along a fertility gradient where P and possibly micronutrients such as Zn are increased.
- Test DECO tolerance to deviations from the reported soil chemistry and texture. DECO appears to exist in a broader envelope of soil properties (in terms of chemistry and texture) than the other clay endemics. There might be habitat outside of DECO's historic distribution (its realized niche) that is suitable for establishing or translocating this species.

## Dehesa Nolina

The most compelling soil variables for NOIN are pH, Ca, and Cu. To distinguish whether pH, Ca, or both are important for NOIN success, and to determine the NOIN's relationship with Cu, we recommend the following:

- Conduct a factorial design greenhouse or field experiment that varies pH and Ca to test whether one or the other (or both) are important for NOIN success.
- Test the relationship of NOIN to Cu by measuring (1) plant growth response to a range of Cu levels and (2) final soil and tissue concentrations of Cu in these treatments for bioaccumulation.

NOIN doesn't demonstrate a particular affinity for the metals contained in gabbro, and seems to avoid Cu-rich microsites in particular. Since clay and gabbro both tend to have elevated pH, CEC, and other PC1 features, we may be able to expand our understanding of the fundamental niche of NOIN through an experiment:

- Compare populations on gabbroic soils to those which seem to occur on clays derived from other material by performing a transplantation experiment comparing success in gabbroic soils to clay soils with appropriate chemistry.

## Parry's Tetracoccus

TEDI may need higher than average Fe, Zn, and Cu, but it may simply be metal tolerant.

- Test whether TEDI can flourish off of gabbroic soils prior to establishing the species on non-gabbroic soils in gap areas or translocating the species onto non-gabbroic soils outside its current range in response to changing climatic conditions.
- Test the metal tolerance of TEDI to Cu and other metals not included in the present study but that might be present in mafic/ultramafic soils (e.g., Ni, Chromium [Cr]).

These experiments would be most effective if they also included important competing species, in both monoculture and co-culture. Because of the similarity in overall patterns for both TEDI and NOIN, it would be useful to include both species in the experiments suggested here and in the previous section, despite the differences in statistical significance of the variables.

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# Appendix C

# Supplemental Information

# Appendices C-1 through C-12

**Appendix C-1**. Final Principle Components Analysis.[1,2]

| Factor[3] | PC1: Texture & pH | PC2: Ca & Mg Balance | PC3: Fertility |
|---|---|---|---|
| B | 0.608 | 0.471 | 0.178 |
| Ca:Mg | -0.205 | 0.919 | -0.007 |
| Ca | 0.774 | 0.488 | 0.191 |
| Ca% | -0.011 | 0.931 | -0.062 |
| CEC | 0.895 | 0.076 | 0.247 |
| CLAY | 0.832 | -0.112 | 0.146 |
| Cu | 0.157 | -0.412 | 0.469 |
| Fe | -0.553 | -0.434 | 0.476 |
| K | 0.274 | 0.369 | 0.487 |
| K% | -0.444 | 0.321 | 0.299 |
| Mg | 0.799 | -0.48 | 0.144 |
| Mg% | 0.329 | -0.85 | -0.037 |
| Mn | -0.687 | -0.366 | 0.376 |
| Na | 0.731 | -0.368 | 0.104 |
| Na% | 0.35 | -0.453 | -0.051 |
| $NO_3$ | 0.096 | 0.086 | 0.493 |
| OM% | -0.052 | 0.118 | 0.649 |
| pH | 0.671 | 0.492 | -0.217 |
| SAND | -0.666 | 0.081 | -0.303 |
| SILT | -0.073 | -0.079 | 0.402 |
| $SO_4$ | -0.044 | 0.109 | 0.58 |
| SOLSALT | 0.03 | 0.371 | 0.412 |
| Zn | -0.561 | 0.045 | 0.607 |

[1] All values log(X+1) transformed to meet assumption of normality.

[2] Factor loadings of soils variables on three principle components (PC). Factor loadings indicate how strongly a variable is related to a principle component. Like correlation values, factor loadings range from -1, indicating a perfect negative relationship, to 1 indicating a perfect positive relationship, and 0 indicating no relationship. In

this figure factor loadings have been color coded on a gradient with dark blue indicating a negative value, white indicating a value close to 0, and dark orange indicating values close to 1.

[3] B = boron, Ca = calcium, Mg = magnesium, CEC = cation exchange capacity, Cu = copper, Fe = iron, K = potassium, Mn = manganese, Na = sodium, $NO_3$ = nitrate, OM = organic matter, SO4 = sulfate, SOLSALT = soluble salts, Zn = zinc.

Appendix C-2. Master Correlation Matrix.[1,2]

| | R_DRY | G_DRY | B_DRY | R_WET | G_WET | B_WET | OM_% | P1 | PO | K_PPM | MG_PPM | CA_PPM | CA_MG | NA_PPM | PH | CEC | K% | MG% | CA% | NA_% | NO3 | SO4 | ZN | MN | FE | CU | B | SOLSALT | SAND | SILT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| G_DRY | 0.849 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| B_DRY | 0.447 | 0.836 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| R_WET | 0.376 | 0.407 | 0.3 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G_WET | 0.285 | 0.437 | 0.427 | 0.944 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| B_WET | 0.14 | 0.374 | 0.474 | 0.789 | 0.935 | | | | | | | | | | | | | | | | | | | | | | | | | |
| OM_% | -0.299 | -0.36 | -0.286 | -0.258 | -0.227 | -0.156 | | | | | | | | | | | | | | | | | | | | | | | | |
| P_WB | -0.039 | 0.089 | 0.172 | -0.077 | 0.017 | 0.09 | 0.105 | | | | | | | | | | | | | | | | | | | | | | | |
| PO | 0.07 | 0.12 | 0.129 | -0.11 | -0.063 | -0.021 | 0.019 | 0.593 | | | | | | | | | | | | | | | | | | | | | | |
| K_PPM | -0.228 | 0.031 | 0.271 | -0.022 | 0.151 | 0.299 | 0.358 | 0.352 | 0.174 | | | | | | | | | | | | | | | | | | | | | |
| MG_PPM | -0.117 | 0.035 | 0.183 | 0.273 | 0.287 | 0.283 | -0.009 | 0.015 | -0.078 | 0.062 | | | | | | | | | | | | | | | | | | | | |
| CA_PPM | -0.366 | -0.16 | 0.068 | 0.25 | 0.359 | 0.395 | 0.323 | 0.087 | -0.016 | 0.415 | 0.489 | | | | | | | | | | | | | | | | | | | |
| CA:MG | -0.126 | -0.149 | -0.157 | -0.096 | -0.032 | -0.007 | 0.239 | 0.058 | 0.081 | 0.247 | -0.751 | 0.201 | | | | | | | | | | | | | | | | | | |
| NA_PPM | -0.095 | 0.143 | 0.345 | 0.331 | 0.385 | 0.399 | -0.19 | 0.091 | -0.023 | 0.228 | 0.705 | 0.384 | -0.501 | | | | | | | | | | | | | | | | | |
| PH | -0.067 | -0.015 | 0.033 | 0.262 | 0.254 | 0.199 | 0.089 | 0.006 | -0.013 | 0.107 | 0.479 | 0.498 | -0.15 | 0.285 | | | | | | | | | | | | | | | | |
| CEC | -0.281 | -0.063 | 0.159 | 0.319 | 0.404 | 0.428 | 0.169 | 0.09 | -0.038 | 0.336 | 0.831 | 0.873 | -0.263 | 0.647 | 0.507 | | | | | | | | | | | | | | | |
| K% | -0.041 | 0.06 | 0.144 | -0.254 | -0.143 | -0.011 | 0.234 | 0.282 | 0.199 | 0.742 | -0.528 | -0.207 | 0.433 | -0.245 | -0.238 | -0.374 | | | | | | | | | | | | | | |
| MG% | 0.109 | 0.128 | 0.135 | 0.12 | 0.052 | 0.017 | -0.207 | -0.075 | -0.091 | -0.263 | 0.796 | -0.12 | -0.991 | 0.492 | 0.261 | 0.325 | -0.492 | | | | | | | | | | | | | |
| CA% | -0.205 | -0.205 | -0.166 | -0.101 | -0.041 | -0.013 | 0.324 | 0.005 | 0.045 | 0.199 | -0.599 | 0.358 | 0.915 | -0.464 | 0.036 | -0.143 | 0.298 | -0.868 | | | | | | | | | | | | |
| NA_% | 0.048 | 0.216 | 0.34 | 0.212 | 0.232 | 0.238 | -0.364 | 0.074 | 0.001 | 0.075 | 0.336 | -0.076 | -0.44 | 0.855 | 0.029 | 0.168 | -0.061 | 0.386 | -0.48 | | | | | | | | | | | |
| NO3 | -0.149 | -0.046 | 0.048 | -0.121 | -0.053 | -0.001 | 0.2 | 0.361 | 0.235 | 0.215 | 0.097 | 0.151 | -0.007 | 0.084 | -0.013 | 0.146 | 0.123 | 0.002 | 0.022 | 0.014 | | | | | | | | | | |

Appendix C-2. Master Correlation Matrix.[1,2]

| | R_DRY | G_DRY | B_DRY | R_WET | G_WET | B_WET | OM_% | P1 | PO | K_PPM | MG_PPM | CA_PPM | CA_MG | NA_PPM | PH | CEC | K% | MG% | CA% | NA_% | NO3 | SO4 | ZN | MN | FE | CU | B | SOLSALT | SAND | SILT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SO4 | 0.009 | -0.026 | -0.058 | 0.064 | 0.046 | 0.042 | 0.195 | 0.191 | 0.08 | 0.218 | 0.013 | 0.108 | 0.056 | 0.165 | -0.023 | 0.079 | 0.158 | -0.068 | 0.059 | 0.154 | 0.34 | | | | | | | | | |
| ZN | -0.124 | -0.174 | -0.149 | -0.45 | -0.405 | -0.289 | 0.576 | 0.418 | 0.312 | 0.266 | -0.256 | -0.149 | 0.145 | -0.234 | -0.186 | -0.258 | 0.429 | -0.164 | 0.18 | -0.14 | 0.344 | 0.338 | | | | | | | | |
| MN | 0.134 | 0.066 | -0.006 | -0.325 | -0.338 | -0.276 | 0.089 | 0.252 | 0.274 | 0.178 | -0.255 | -0.54 | -0.123 | -0.229 | -0.404 | -0.449 | 0.477 | 0.054 | -0.236 | -0.004 | 0.077 | 0.206 | 0.558 | | | | | | | |
| FE | -0.148 | -0.083 | -0.019 | -0.374 | -0.276 | -0.161 | 0.27 | 0.266 | 0.232 | 0.027 | -0.117 | -0.193 | -0.03 | -0.025 | -0.43 | -0.164 | 0.139 | -0.024 | -0.078 | 0.081 | 0.329 | 0.002 | 0.503 | 0.382 | | | | | | |
| CU | 0.16 | 0.268 | 0.252 | 0.29 | 0.342 | 0.35 | 0.003 | 0.04 | -0.092 | 0.124 | 0.39 | 0.175 | -0.303 | 0.342 | -0.008 | 0.332 | -0.146 | 0.3 | -0.284 | 0.196 | 0.074 | 0.096 | 0.004 | -0.006 | 0.185 | | | | | |
| B | -0.108 | -0.016 | 0.084 | 0.172 | 0.218 | 0.236 | 0.286 | 0.12 | 0.06 | 0.449 | 0.306 | 0.476 | 0.007 | 0.4 | 0.594 | 0.431 | 0.142 | 0.046 | 0.136 | 0.216 | 0.224 | 0.375 | 0.163 | -0.198 | -0.179 | 0.101 | | | | |
| SOLSALT | 0.063 | 0.107 | 0.121 | -0.112 | -0.073 | -0.027 | 0.096 | 0.39 | 0.257 | 0.101 | -0.048 | -0.029 | 0.026 | 0.037 | -0.127 | -0.039 | 0.119 | -0.045 | 0.008 | 0.076 | 0.58 | 0.415 | 0.352 | 0.268 | 0.218 | 0.032 | 0.074 | | | |
| SAND | 0.153 | 0.067 | -0.002 | -0.379 | -0.422 | -0.419 | -0.207 | 0.182 | 0.167 | -0.251 | -0.592 | -0.673 | 0.157 | -0.429 | -0.356 | -0.736 | 0.269 | -0.208 | 0.038 | -0.041 | -0.046 | -0.043 | 0.204 | 0.338 | 0.11 | -0.446 | -0.423 | 0.156 | | |
| SILT | -0.044 | -0.178 | -0.27 | -0.138 | -0.206 | -0.203 | 0.331 | -0.047 | -0.03 | -0.067 | 0.129 | -0.027 | -0.181 | -0.152 | 0.029 | 0.013 | -0.067 | 0.201 | -0.086 | -0.239 | 0.221 | 0.086 | 0.343 | 0.207 | 0.131 | 0.247 | 0.101 | 0.081 | -0.373 | |
| CLAY | -0.172 | -0.011 | 0.125 | 0.369 | 0.438 | 0.444 | 0.127 | -0.079 | -0.191 | 0.303 | 0.69 | 0.734 | -0.212 | 0.611 | 0.459 | 0.835 | -0.297 | 0.265 | -0.109 | 0.219 | 0.044 | 0.065 | -0.245 | -0.404 | -0.14 | 0.42 | 0.502 | -0.119 | -0.85 | 0.074 |
| | R_DRY | G_DRY | B_DRY | R_WET | G_WET | B_WET | OM_% | P1 | PO | K_PPM | MG_PPM | CA_PPM | CA_MG | NA_PPM | PH | CEC | K% | MG% | CA% | NA_% | NO3 | SO4 | ZN | MN | FE | CU | B | SOLSALT | SAND | SILT |

[1] All data log(X+1) transformed to ensure normality.

[2] Correlation values of soils variables with one another. The correlation of any soil variable we measured with another can be looked by following the row of one variable to the column of the other variable of interest. Correlation values range from -1, indicating a perfect negative relationship, to 1 indicating a perfect positive relationship, and 0 indicating no relationship. In this correlation values have been color coded on a gradient with dark blue indicating a negative value, white indicating a value close to 0, and dark orange indicating values close to 1

**Appendix C-3**. Principle Components Analysis for San Diego Thornmint (*Acanthomintha ilicifolia*).

| Principle Component | Variable[1] | In Average | Near Average | Far Average | RANOVA F | RANOVA P | In v Near Post-hoc P | In v Far Post-hoc P | In v Near Post-hoc P | Bartlett's Test $x^2$ | Bartlett's Test P |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Texture & pH | B** | 0.58 | 0.42 | 0.36 | 0.46 | 0.64 | - | - | - | **15.88** | **<0.001** |
| Texture & pH | Ca | 3185.92 | 2298.00 | 2280.92 | **6.08** | **0.01** | 0.01 | 0.02 | 0.78 | 0.81 | 0.67 |
| Texture & pH | CEC | 30.32 | 21.65 | 19.82 | **12.42** | **<0.001** | 0.00 | 0.00 | 0.55 | 2.79 | 0.25 |
| Texture & pH | Clay | 47.15 | 36.46 | 25.23 | **14.26** | **<0.001** | 0.00 | 0.00 | 0.05 | 3.67 | 0.16 |
| Texture & pH | Fe** | 4.77 | 12.31 | 17.77 | **7.62** | **0.00** | 0.01 | 0.01 | 0.14 | **33.21** | **<0.001** |
| Texture & pH | K%** | 2.11 | 2.97 | 2.85 | **3.34** | **0.05** | 0.02 | 0.43 | 0.14 | **10.59** | **0.01** |
| Texture & pH | Mg | 1430.92 | 919.92 | 665.23 | **15.10** | **<0.001** | 0.00 | 0.00 | 0.12 | 0.51 | 0.77 |
| Texture & pH | Mn** | 4.85 | 10.38 | 12.38 | **4.89** | **0.02** | 0.03 | 0.02 | 0.50 | 11.88 | 0.003 |
| Texture & pH | Na** | 141.75 | 124.92 | 68.00 | 3.16 | 0.06 | 0.13 | 0.07 | 0.24 | 5.07 | 0.08 |
| Texture & pH | pH** | 6.96 | 6.56 | 6.38 | **5.45** | **0.01** | 0.02 | 0.03 | 0.49 | 2.41 | 0.30 |
| Texture & pH | Sand | 30.08 | 41.62 | 55.62 | **27.83** | **<0.001** | 0.00 | <0.001 | 0.01 | 2.16 | 0.34 |
| Ca & Mg Balance | Ca:Mg ratio** | 2.13 | 2.00 | 2.57 | 2.97 | 0.07 | 0.73 | 0.07 | 0.08 | 1.43 | 0.49 |
| Ca & Mg Balance | Ca% | 51.95 | 50.77 | 56.72 | 1.50 | 0.25 | - | - | - | 1.25 | 0.54 |
| Ca & Mg Balance | Mg% | 39.13 | 36.00 | 26.65 | **7.05** | **0.01** | 0.31 | 0.00 | 0.04 | 3.02 | 0.22 |
| Ca & Mg Balance | Na%** | 2.06 | 1.87 | 1.72 | 2.42 | 0.09 | 0.36 | 0.04 | 0.19 | **26.96** | **<0.001** |

**Appendix C-3**. Principle Components Analysis for San Diego Thornmint (*Acanthomintha ilicifolia*).

| Principle Component | Variable[1] | In Average | Near Average | Far Average | RANOVA F | RANOVA P | In v Near Post-hoc P | In v Far Post-hoc P | In v Near Post-hoc P | Bartlett's Test $x^2$ | Bartlett's Test P |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Fertility | Cu | 0.82 | 1.05 | 0.68 | **3.49** | **0.05** | 0.04 | 0.42 | 0.04 | 1.62 | 0.44 |
| Fertility | K | 245.77 | 252.23 | 197.69 | 1.85 | 0.18 | - | - | - | 1.41 | 0.49 |
| Fertility | $NO_3$** | 3.38 | 2.69 | 2.83 | 0.57 | 0.57 | - | - | - | **12.73** | **0.004** |
| Fertility | OM** | 2.82 | 2.68 | 2.94 | 0.32 | 0.73 | - | - | - | **7.16** | **0.002** |
| Fertility | Silt** | 22.85 | 22.00 | 19.38 | 2.51 | 0.11 | 0.96 | 0.15 | 0.03 | 5.32 | 0.07 |
| Fertility | $SO_4$** | 2.92 | 3.54 | 4.31 | **3.67** | **0.04** | 0.31 | 0.05 | 0.09 | 4.84 | 0.09 |
| Fertility | Soluble salt** | 0.17 | 0.18 | 0.23 | **4.26** | **0.03** | 0.45 | 0.02 | 0.09 | 2.41 | 0.30 |
| Fertility | Zn | 0.40 | 0.84 | 1.93 | **9.10** | **0.00** | 0.01 | 0.01 | 0.18 | **48.18** | **<0.001** |
| Fertility* | P_olsen** | 3.23 | 3.82 | 3.43 | 1.85 | 0.18 | - | - | - | **6.73** | **0.04** |
| Fertility* | P_WB** | 3.73 | 4.08 | 5.50 | 1.28 | 0.30 | - | - | - | **7.67** | **0.02** |
| Color* | Red (Dry)** | 0.47 | 0.55 | 0.49 | 2.68 | 0.09 | 0.07 | 0.40 | 0.13 | **9.83** | **0.01** |
| Color* | Green (Dry)** | 0.37 | 0.46 | 0.39 | 3.03 | 0.07 | 0.06 | 0.60 | 0.07 | **8.87** | **0.01** |
| Color* | Blue (Dry)** | 0.29 | 0.36 | 0.29 | 2.57 | 0.10 | 0.07 | 0.81 | 0.06 | 4.20 | 0.12 |
| Color* | Red (Wet)** | 0.47 | 0.42 | 0.39 | 1.79 | 0.19 | - | - | - | 0.83 | 0.66 |

**Appendix C-3**. Principle Components Analysis for San Diego Thornmint (*Acanthomintha ilicifolia*).

| Principle Component | Variable[1] | In Average | Near Average | Far Average | RANOVA F | RANOVA P | In v Near Post-hoc P | In v Far Post-hoc P | In v Near Post-hoc P | Bartlett's Test $x^2$ | Bartlett's Test P |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Color* | Green (Wet)** | 0.37 | 0.33 | 0.30 | 1.97 | 0.16 | - | - | - | 0.35 | 0.84 |
| Color* | Blue (Wet)** | 0.30 | 0.25 | 0.21 | 2.23 | 0.13 | - | - | - | 0.17 | 0.92 |

[1] B = boron, Ca = calcium, Mg = magnesium, CEC = cation exchange capacity, Cu = copper, Fe = iron, K = potassium, Mn = manganese, Na = sodium, $NO_3$ = nitrate, OM = organic matter, SO4 = sulfate, SOLSALT = soluble salts, Zn = zinc.

* Excluded from Final PCA due to missing cases.

** RANOVA performed with log(X+1) transformed data to meet assumption of normality/reduce skew. Data not transformed for Bartlett's test.

**Appendix C-4**. Logistic Regression Analysis for San Diego Thornmint (*Acanthomintha ilicifolia*).[1,2,3]

| Dependent | Model[4] | aic | bic | df | $X^2$ | P | Rho | df diff | $X^2$diff | Diff P |
|---|---|---|---|---|---|---|---|---|---|---|
| ACIL | *Sand* | *13.54* | *16.06* | *1* | *26.5* | *<0.001* | *0.735* | - | - | - |
| ACIL | Clay | 17.32 | 19.83 | 1 | 22.73 | <0.001 | 0.631 | - | - | - |
| ACIL | CEC | 24.881 | 27.397 | 1 | 15.163 | <0.001 | 0.421 | - | - | - |
| ACIL | Mg | 26.5 | 29.02 | 1 | 13.5 | <0.001 | 0.376 | - | - | - |
| ACIL | Zn | 28.49 | 31 | 1 | 11.56 | 0.001 | 0.321 | - | - | - |
| ACIL | Fe ** | 32.604 | 35.12 | 1 | 7.44 | 0.006 | 0.206 | - | - | - |
| ACIL | Mg% | 33.55 | 36.07 | 1 | 6.492 | 0.011 | 0.18 | - | - | - |
| ACIL | Mn ** | 33.74 | 36.25 | 1 | 6.31 | 0.012 | 0.175 | - | - | - |
| ACIL | pH ** | 34.28 | 36.94 | 1 | 5.77 | 0.016 | 0.16 | - | - | - |
| ACIL | SO4 ** | 33.89 | 36.33 | 1 | 4.73 | 0.03 | 0.136 | - | - | - |
| ACIL | Ca | 35.55 | 38.07 | 1 | 4.5 | 0.034 | 0.125 | - | - | - |
| ACIL | Sol_salt ** | 36.4 | 38.84 | 1 | 2.219 | 0.136 | 0.064 | - | - | - |
| ACIL | K% | 37.991 | 40.51 | 1 | 2.05 | 0.152 | 0.057 | - | - | - |
| ACIL | Cu | 39.37 | 41.89 | 1 | 0.672 | 0.412 | 0.019 | - | - | - |
| ACIL | ***Sand + CEC*** | ***6*** | ***9.774*** | ***2*** | ***36.04*** | ***<0.001*** | ***1*** | ***1*** | ***9.54*** | ***0.00201042*** |
| ACIL | Sand+Mg | 12.5 | 16.27 | 2 | 29.55 | <0.001 | 0.82 | ***1*** | ***3.05*** | 0.08073714 |
| ACIL | Sand+SO4** | 13 | 16.66 | 2 | 27.62 | <0.001 | 0.798 | ***1*** | ***1.12*** | 0.28991845 |

**Appendix C-4**. Logistic Regression Analysis for San Diego Thornmint (*Acanthomintha ilicifolia*).[1,2,3]

| Dependent | Model[4] | aic | bic | df | $X^2$ | P | Rho | df diff | $X^2$diff | Diff P |
|---|---|---|---|---|---|---|---|---|---|---|
| ACIL | Sand+pH** | 14.63 | 18.4 | 2 | 27.416 | <0.001 | 0.761 | ***1*** | ***0.916*** | 0.33852744 |
| ACIL | Sand+Clay | 14.794 | 18.569 | 2 | 27.25 | <0.001 | 0.756 | ***1*** | ***0.75*** | 0.38647623 |
| ACIL | Sand+Fe** | 15.235 | 19.01 | 2 | 26.81 | <0.001 | 0.744 | ***1*** | ***0.31*** | 0.57768019 |
| ACIe | Sand+Mn** | 15.47 | 19.24 | 2 | 26.58 | <0.001 | 0.737 | ***1*** | ***0.08*** | 0.77729741 |
| ACIL | Sand+Ca | 15.48 | 19.26 | 2 | 26.56 | <0.001 | 0.737 | ***1*** | ***0.06*** | 0.80649594 |
| ACIL | Sand+Mg% | 15.49 | 19.3 | 2 | 26.55 | <0.001 | 0.737 | ***1*** | ***0.05*** | 0.82306327 |
| ACIL | Sand+Zn | 15.53 | 19.3 | 2 | 26.51 | <0.001 | 0.736 | ***1*** | ***0.01*** | 0.92034433 |
| ACIL | Sand+CEC+Mg | 8 | 13.03 | 3 | 36.04 | <0.001 | 1 | ***1*** | 0 | 1 |
| ACIL | Sand+CEC+SO4** | 8 | 12.88 | 3 | 34.617 | <0.001 | 1 | ***1*** | -1.423 | #NUM! |
| ACIL | Sand+Mg+SO4** | 14.29 | 19.17 | 3 | 28.32 | <0.001 | 0.818 | 1 | -1.23 | #NUM! |
| ACIL | Sand+Mg+Mn** | 14.47 | 19.5 | 3 | 29.57 | <0.001 | 0.821 | 1 | 0.02 | 0.88753708 |
| ACIL | Sand+Mg+pH** | 14.23 | 19.26 | 3 | 29.813 | <0.001 | 0.827 | 1 | 0.263 | 0.60806657 |
| ACIL | *Sand+Mg+Clay* | *8* | *13.03* | *3* | *36.044* | *<0.001* | *1* | 1 | 6.494 | *0.01082392* |
| ACIL | Sand+Mg+Fe** | 14.21 | 19.24 | 3 | 29.84 | <0.001 | 0.828 | 1 | 0.29 | 0.59022053 |
| ACIL | *Sand+Mg+Ca* | *8* | *13.03* | *3* | *36.04* | *<0.001* | *1* | 1 | 6.49 | *0.0108483* |
| ACIL | *Sand+Mg+Mg%* | *8* | *13.03* | *3* | *36.04* | *<0.001* | *1* | 1 | 6.49 | *0.0108483* |
| ACIL | Sand+Mg+Zn | 14.45 | 19.49 | 3 | 29.59 | <0.001 | 0.821 | 1 | 0.04 | 0.84148058 |

[1] Logistic regression run with *in* points as present and *far* points as absent.
[2] Italics indicate an intermediate step, bold indicates the preferred model.
[3] Values in red are suspect.
[4] B = boron, Ca = calcium, Mg = magnesium, CEC = cation exchange capacity, Cu = copper, Fe = iron, K = potassium, Mn = manganese, Na = sodium, $NO_3$ = nitrate, OM = organic matter, SO4 = sulfate, SOLSALT = soluble salts, Zn = zinc.
** RANOVA performed with log(X+1) transformed data to meet assumption of normality/reduce skew. Data not transformed for Bartlett's test.

**Appendix C-5**. Principle Components Analysis for Thread-leaved Brodiaea (*Brodiaea filifolia*).

| Principle Component | Variable[1] | In Average | Near Average | Far Average | RANOVA F | RANOVA P | In v Near Post-hoc P | In v Far Post-hoc P | In v Near Post-hoc P | Bartlett's Test $x^2$ | Bartlett's Test P |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Texture & pH | B | 0.37 | 0.59 | 0.51 | 1.35 | 0.29 | - | - | - | 2.22 | 0.33 |
| Texture & pH | Ca | 2487.09 | 2970.18 | 2606.64 | 1.16 | 0.33 | - | - | - | 0.42 | 0.81 |
| Texture & pH | CEC | 25.30 | 26.44 | 22.74 | 1.41 | 0.27 | - | - | - | 1.00 | 0.61 |
| Texture & pH | Clay | 45.73 | 42.36 | 36.64 | **4.19** | **0.03** | 0.26 | 0.02 | 0.12 | 0.03 | 0.98 |
| Texture & pH | Fe** | 13.82 | 13.82 | 15.09 | 0.87 | 0.43 | - | - | - | 1.94 | 0.38 |
| Texture & pH | K% | 3.01 | 2.55 | 3.60 | 2.53 | 0.11 | 0.19 | 0.33 | 0.05 | 0.36 | 0.83 |
| Texture & pH | Mg | 1071.09 | 989.73 | 747.64 | 2.84 | 0.08 | 0.48 | 0.05 | 0.16 | 3.17 | 0.21 |
| Texture & pH | Mn | 4.55 | 3.82 | 7.00 | **3.68** | **0.04** | 0.46 | 0.13 | 0.03 | 4.13 | 0.13 |
| Texture & pH | Na** | 158.18 | 135.80 | 115.00 | **3.53** | **0.05** | 0.11 | 0.02 | 0.29 | 3.11 | 0.21 |
| Texture & pH | pH | 6.25 | 6.63 | 6.45 | 1.62 | 0.22 | - | - | - | **8.58** | **0.01** |
| Texture & pH | Sand | 33.27 | 36.27 | 41.36 | **3.75** | **0.04** | 0.24 | 0.05 | 0.10 | 0.41 | 0.81 |
| Ca & Mg Balance | Ca:Mg ratio** | 1.64 | 2.25 | 2.56 | 1.96 | 0.17 | - | - | - | 1.42 | 0.49 |
| Ca & Mg Balance | Ca% | 49.21 | 56.62 | 57.45 | 2.10 | 0.15 | 0.10 | 0.10 | 0.86 | 3.79 | 0.15 |
| Ca & Mg Balance | Mg% | 33.62 | 29.75 | 26.81 | 2.52 | 0.11 | 0.21 | 0.03 | 0.42 | 0.11 | 0.95 |
| Ca & Mg | Na%** | 2.83 | 2.34 | 1.99 | 2.22 | 0.14 | 0.12 | 0.06 | 0.59 | **8.76** | **0.01** |

**Appendix C-5**. Principle Components Analysis for Thread-leaved Brodiaea (*Brodiaea filifolia*).

| Principle Component | Variable[1] | In Average | Near Average | Far Average | RANOVA F | RANOVA P | In v Near Post-hoc P | In v Far Post-hoc P | In v Near Post-hoc P | Bartlett's Test $x^2$ | Bartlett's Test P |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Balance | | | | | | | | | | | |
| Fertility | Cu | 1.35 | 1.14 | 1.18 | 1.03 | 0.37 | - | - | - | 0.74 | 0.69 |
| Fertility | K | 272.91 | 250.45 | 274.55 | 0.72 | 0.50 | - | - | - | 1.80 | 0.41 |
| Fertility | $NO_3$** | 5.73 | 7.09 | 6.36 | 0.20 | 0.82 | - | - | - | 3.14 | 0.21 |
| Fertility | OM** | 3.38 | 3.42 | 3.48 | 0.06 | 0.94 | - | - | - | 0.44 | 0.81 |
| Fertility | Silt | 21.09 | 21.73 | 22.18 | 0.20 | 0.82 | - | - | - | 0.88 | 0.65 |
| Fertility | $SO_4$** | 4.09 | 5.09 | 3.89 | 2.76 | 0.09 | 0.06 | 0.66 | 0.02 | 0.29 | 0.87 |
| Fertility | Soluble salt | 0.19 | 0.25 | 0.25 | 1.31 | 0.29 | - | - | - | **36.28** | **<0.001** |
| Fertility | Zn** | 0.78 | 0.75 | 1.04 | 1.88 | 0.18 | - | - | - | 3.19 | 0.20 |
| Fertility* | P_olsen** | 5.00 | 7.00 | 6.00 | 0.97 | 0.40 | - | - | - | 5.04 | 0.08 |
| Fertility* | P_WB** | 3.50 | 5.78 | 8.44 | 1.95 | 0.17 | - | - | - | **6.27** | **0.04** |
| Red (Dry)** | Red (Dry) | 0.47 | 0.45 | 0.50 | 0.71 | 0.50 | - | - | - | 2.26 | 0.32 |
| Green (Dry)** | Green (Dry) | 0.38 | 0.38 | 0.43 | 0.81 | 0.46 | - | - | - | 2.84 | 0.24 |
| Blue (Dry)** | Blue (Dry) | 0.31 | 0.33 | 0.36 | 0.70 | 0.51 | - | - | - | 2.09 | 0.35 |

**Appendix C-5**. Principle Components Analysis for Thread-leaved Brodiaea (*Brodiaea filifolia*).

| Principle Component | Variable[1] | In Average | Near Average | Far Average | RANOVA F | RANOVA P | In v Near Post-hoc P | In v Far Post-hoc P | In v Near Post-hoc P | Bartlett's Test $x^2$ | Bartlett's Test P |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Red (Wet)** | Red (Wet) | 0.40 | 0.39 | 0.41 | 0.33 | 0.72 | - | - | - | **7.15** | **0.03** |
| Green (Wet)** | Green (Wet) | 0.34 | 0.33 | 0.35 | 0.22 | 0.81 | - | - | - | **5.95** | **0.05** |
| Blue (Wet)** | Blue (Wet) | 0.29 | 0.30 | 0.30 | 0.03 | 0.97 | - | - | - | 2.16 | 0.34 |

[1] B = boron, Ca = calcium, Mg = magnesium, CEC = cation exchange capacity, Cu = copper, Fe = iron, K = potassium, Mn = manganese, Na = sodium, $NO_3$ = nitrate, OM = organic matter, SO4 = sulfate, SOLSALT = soluble salts, Zn = zinc.

* Excluded from Final PCA due to missing cases.

** RANOVA performed with log(X+1) transformed data to meet assumption of normality/reduce skew. Data not transformed for Bartlett's test.

**Appendix C-6**. Logistic Regression Analysis for Thread-leaved Brodiaea (*Brodiaea filifolia*).[1,2]

| Dependent | Model[3] | aic | bic | df | $X^2$ | P | Rho | df diff | $X^2$diff | Diff P |
|---|---|---|---|---|---|---|---|---|---|---|
| BRFI | ***Clay*** | ***29.903*** | ***32.085*** | ***1*** | ***4.5*** | ***0.032*** | ***0.151*** | - | - | - |
| BRFI | Na ppm ** | 30.045 | 32.227 | 1 | 4.45 | 0.035 | 0.146 | - | - | - |
| BRFI | Mn | 32 | 34.138 | 1 | 2.543 | 0.111 | 0.083 | - | - | - |
| BRFI | Sand | 32.547 | 34.729 | 1 | 1.95 | 0.162 | 0.064 | - | - | - |
| BRFI | Clay+Na ** | 30.28 | 33.51 | 2 | 6.26 | 0.044 | 0.205 | 1 | 1.76 | 0.184624516 |
| BRFI | Clay+Mn | 29.407 | 32.68 | 2 | 7.09 | 0.029 | 0.233 | 1 | 2.59 | 0.107540336 |
| BRFI | Clay+Sand | 30.34 | 33.61 | 2 | 6.16 | 0.046 | 0.202 | 1 | 1.66 | 0.197603324 |

[1] Logistic regression run with *in* points as present and *far* points as absent.

[2] Italics indicate an intermediate step, bold indicates the preferred model.

[3] Na = sodium, Mn = manganese.

** RANOVA performed with log(X+1) transformed data to meet assumption of normality/reduce skew. Data not transformed for Bartlett's test.

**Appendix C-7**. Principle Components Analysis for Otay tarplant (*Deinandra conjugens*).

| Principle Component | Variable[1] | In Average | Near Average | Far Average | RANOVA F | RANOVA P | In v Near Post-hoc P | In v Far Post-hoc P | In v Near Post-hoc P | Bartlett's Test $x^2$ | Bartlett's Test P |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Texture & pH | B | 0.52 | 0.51 | 0.49 | 0.06 | 0.94 | - | - | - | 1.07 | 0.59 |
| Texture & pH | Ca** | 2709.94 | 2457.94 | 2295.44 | 0.44 | 0.65 | - | - | - | 0.34 | 0.84 |
| Texture & pH | CEC | 23.92 | 21.01 | 20.08 | 1.35 | 0.27 | - | - | - | 0.71 | 0.70 |
| Texture & pH | Clay | 35.94 | 31.81 | 27.38 | **4.15** | **0.03** | 0.21 | 0.01 | 0.15 | 3.72 | 0.16 |
| Texture & pH | Fe** | 8.25 | 10.81 | 13.88 | 1.33 | 0.28 | - | - | - | 4.09 | 0.13 |
| Texture & pH | K%** | 2.63 | 2.77 | 3.83 | 2.95 | 0.07 | 0.99 | 0.05 | 0.10 | 3.05 | 0.22 |
| Texture & pH | Mg** | 967.94 | 807.44 | 723.94 | **3.66** | **0.04** | 0.06 | 0.03 | 0.60 | 1.61 | 0.45 |
| Texture & pH | Mn** | 7.75 | 9.69 | 11.69 | 0.20 | 0.82 | - | - | - | **6.02** | **0.05** |
| Texture & pH | Na** | 128.69 | 98.00 | 91.69 | **6.42** | **0.01** | 0.02 | 0.01 | 0.30 | 0.07 | 0.97 |
| Texture & pH | pH | 6.76 | 6.59 | 6.55 | 0.69 | 0.51 | - | - | - | 2.04 | 0.36 |
| Texture & pH | Sand | 40.88 | 44.50 | 47.19 | 2.80 | 0.08 | 0.18 | 0.02 | 0.38 | 0.59 | 0.75 |
| Ca & Mg Balance | Ca:Mg ratio** | 1.92 | 2.84 | 2.49 | 1.13 | 0.34 | - | - | - | 1.59 | 0.45 |
| Ca & Mg Balance | Ca%** | 54.02 | 56.45 | 55.29 | 0.23 | 0.80 | - | - | - | 0.11 | 0.95 |
| Ca & Mg Balance | Mg%** | 34.64 | 31.31 | 29.31 | 2.02 | 0.15 | 0.20 | 0.01 | 0.70 | 0.93 | 0.63 |
| Ca & Mg | Na%** | 2.70 | 2.08 | 2.10 | 1.59 | 0.22 | - | - | - | 2.80 | 0.25 |

**Appendix C-7**. Principle Components Analysis for Otay tarplant (*Deinandra conjugens*).

| Principle Component | Variable[1] | In Average | Near Average | Far Average | RANOVA F | RANOVA P | In v Near Post-hoc P | In v Far Post-hoc P | In v Near Post-hoc P | Bartlett's Test $x^2$ | Bartlett's Test P |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Balance | | | | | | | | | | | |
| Fertility | Cu** | 0.76 | 0.71 | 0.76 | 0.24 | 0.79 | - | - | - | 2.52 | 0.28 |
| Fertility | K** | 237.63 | 200.75 | 253.80 | 2.32 | 0.12 | 0.21 | 0.52 | 0.05 | 0.16 | 0.92 |
| Fertility | $NO_3$** | 5.75 | 5.00 | 5.36 | 1.52 | 0.24 | - | - | - | 0.87 | 0.65 |
| Fertility | OM** | 2.40 | 2.99 | 2.98 | 3.17 | 0.06 | 0.07 | 0.00 | 0.97 | **5.85** | **0.05** |
| Fertility | Silt | 23.25 | 23.63 | 25.44 | 0.71 | 0.50 | - | - | - | **9.96** | **0.01** |
| Fertility | $SO_4$** | 3.81 | 4.69 | 4.73 | 1.08 | 0.35 | - | - | - | 3.22 | 0.20 |
| Fertility | Soluble salt | 0.28 | 0.31 | 0.31 | 0.85 | 0.44 | - | - | - | 4.49 | 0.11 |
| Fertility | Zn** | 1.30 | 1.09 | 1.99 | **4.44** | **0.02** | 0.31 | 0.02 | 0.10 | **13.52** | **<0.001** |
| Fertility* | P_olsen** | 4.64 | 4.33 | 5.90 | 3.11 | 0.06 | 0.67 | 0.08 | 0.05 | **16.81** | **0.00** |
| Fertility* | P_WB** | 5.31 | 4.33 | 9.18 | **6.50** | **0.01** | 0.12 | 0.04 | 0.01 | **15.64** | **0.00** |
| Color* | Red (Dry)** | 0.50 | 0.46 | 0.48 | 0.61 | 0.55 | - | - | - | 2.48 | 0.29 |
| Color* | Green (Dry)** | 0.42 | 0.37 | 0.38 | 0.82 | 0.45 | - | - | - | 1.46 | 0.48 |
| Color* | Blue (Dry)** | 0.33 | 0.30 | 0.30 | 0.70 | 0.51 | - | - | - | 1.64 | 0.44 |

**Appendix C-7**. Principle Components Analysis for Otay tarplant (*Deinandra conjugens*).

| Principle Component | Variable[1] | In Average | Near Average | Far Average | RANOVA F | RANOVA P | In v Near Post-hoc P | In v Far Post-hoc P | In v Near Post-hoc P | Bartlett's Test $x^2$ | Bartlett's Test P |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Color* | Red (Wet)** | 0.38 | 0.34 | 0.37 | 0.64 | 0.54 | - | - | - | 0.59 | 0.75 |
| Color* | Green (Wet)** | 0.30 | 0.27 | 0.29 | 0.41 | 0.67 | - | - | - | 0.58 | 0.75 |
| Color* | Blue (Wet)** | 0.23 | 0.22 | 0.22 | 0.28 | 0.76 | - | - | - | 0.13 | 0.94 |

1 B = boron, Ca = calcium, Mg = magnesium, CEC = cation exchange capacity, Cu = copper, Fe = iron, K = potassium, Mn = manganese, Na = sodium, $NO_3$ = nitrate, OM = organic matter, SO4 = sulfate, SOLSALT = soluble salts, Zn = zinc.

* Excluded from Final PCA due to missing cases.

** RANOVA performed with log(X+1) transformed data to meet assumption of normality/reduce skew. Data not transformed for Bartlett's test.

**Appendix C-8**. Logistic Regression Analysis for Otay Tarplant (*Deinandra conjugens*).[1,2]

| Dependent | Model[3] | aic | bic | df | $X^2$ | P | Rho | df diff | $X^2$diff | Diff P |
|---|---|---|---|---|---|---|---|---|---|---|
| *DECO* | *Clay* | *40.828* | *43.76* | *1* | *7.533* | *0.006* | *0.17* | - | - | - |
| DECO | P1 ** | 32.12 | 34.476 | 1 | 4.984 | 0.026 | 0.151 | - | - | - |
| DECO | Mg ** | 43.79 | 46.72 | 1 | 4.57 | 0.033 | 0.103 | - | - | - |
| DECO | Na ** | 44.089 | 47.02 | 1 | 4.272 | 0.039 | 0.096 | - | - | - |
| DECO | Zn ** | 45.251 | 48.18 | 1 | 3.11 | 0.078 | 0.07 | - | - | - |
| DECO | Clay+P1 ** | 28.883 | 32.417 | 2 | 10.221 | 0.006 | 0.309 | 1 | 2.688 | 0.10110665 |
| DECO | Clay+Mg ** | 42.709 | 47.11 | 2 | 7.652 | 0.022 | 0.172 | 1 | 0.119 | 0.73012161 |
| DECO | Clay+Na ** | 41.98 | 46.38 | 2 | 8.381 | 0.015 | 0.015 | 1 | 0.848 | 0.35711874 |
| DECO | Clay+Zn ** | 42.73 | 47.131 | 2 | 7.628 | 0.022 | 0.172 | 1 | 0.095 | 0.7579144 |
| ***DECO*** | ***P1**+Clay*** | ***28.883*** | ***32.417*** | ***2*** | ***10.221*** | ***0.006*** | ***0.309*** | ***1*** | ***5.237*** | ***0.02211137*** |
| DECO | P1**+Zn** | 29.45 | 32.98 | 2 | 9.66 | 0.008 | 0.292 | 1 | 4.676 | 0.03058689 |
| DECO | P1**+Na** | 30.81 | 34.35 | 2 | 8.29 | 0.016 | 0.25 | 1 | 3.306 | 0.06902732 |
| DECO | P1**+Mg** | 31.56 | 35.1 | 2 | 7.5 | 0.023 | 0.228 | 1 | 2.516 | 0.11269612 |
| DECO | P1**+Clay+Zn** | 29.399 | 34.111 | 3 | 11.705 | 0.008 | 0.354 | 1 | 1.484 | 0.22314973 |
| DECO | P1**+Clay+Na** | 29.787 | 34.499 | 3 | 11.318 | 0.01 | 0.342 | 1 | 1.097 | 0.29492542 |
| DECO | P1**+Clay+Mg** | 30.861 | 35.573 | 3 | 10.243 | 0.017 | 0.309 | 1 | 0.022 | 0.8820871 |

1 Logistic regression run with *in* points as present and *far* points as absent.

2 Italics indicate an intermediate step, bold indicates the preferred model.

3 P1 = phosphorus (using weak bray assay), Mg = magnesium, na = sodium, zn = zinc.

** RANOVA performed with log(X+1) transformed data to meet assumption of normality/reduce skew. Data not transformed for Bartlett's test.

**Appendix C-9**. Principle Components Analysis for Dehesa Nolina (*Nolina interrata*).

| Principle Component | Variable[1] | In Average | Near Average | Far Average | RANOVA F | RANOVA P | In v Near Post-hoc P | In v Far Post-hoc P | In v Near Post-hoc P | Bartlett's Test $x^2$ | Bartlett's Test P |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Texture & pH | B** | 0.40 | 0.31 | 0.26 | **5.94** | **0.01** | 0.01 | 0.01 | 0.38 | 3.25 | 0.20 |
| Texture & pH | Ca | 1540.20 | 1397.40 | 1186.90 | **3.77** | **0.05** | 0.05 | 0.06 | 0.81 | 3.32 | 0.19 |
| Texture & pH | CEC | 13.59 | 14.07 | 11.26 | 2.21 | 0.14 | 0.75 | 0.08 | 0.12 | 3.62 | 0.16 |
| Texture & pH | Clay | 23.50 | 27.90 | 22.10 | 1.66 | 0.22 | - | - | - | 0.77 | 0.68 |
| Texture & pH | Fe | 10.20 | 9.00 | 11.20 | 0.13 | 0.88 | - | - | - | 3.19 | 0.20 |
| Texture & pH | K% | 3.27 | 2.86 | 3.94 | 1.51 | 0.25 | - | - | - | 1.82 | 0.40 |
| Texture & pH | Mg | 517.20 | 639.70 | 395.90 | 3.10 | 0.07 | 0.27 | 0.09 | 0.07 | 5.80 | 0.06 |
| Texture & pH | Mn | 8.20 | 10.20 | 11.50 | **5.18** | **0.02** | 0.11 | 0.01 | 0.22 | 1.44 | 0.49 |
| Texture & pH | Na** | 34.60 | 44.60 | 41.30 | 2.34 | 0.13 | 0.04 | 0.65 | 0.16 | **6.39** | **0.04** |
| Texture & pH | pH | 6.45 | 6.30 | 6.10 | **7.89** | **0.00** | 0.08 | 0.00 | 0.08 | 0.10 | 0.95 |
| Texture & pH | Sand | 52.30 | 49.70 | 53.40 | 1.55 | 0.24 | - | - | - | 0.18 | 0.92 |
| Ca & Mg Balance | Ca:Mg ratio** | 1.88 | 1.77 | 2.41 | 0.54 | 0.59 | - | - | - | **5.94** | **0.05** |
| Ca & Mg Balance | Ca% | 56.30 | 50.23 | 53.83 | 1.35 | 0.28 | - | - | - | 0.50 | 0.78 |
| Ca & Mg Balance | Mg% | 30.97 | 34.84 | 26.95 | 0.86 | 0.44 | - | - | - | 5.26 | 0.07 |
| Ca & Mg | Na% | 1.16 | 1.39 | 1.45 | 0.83 | 0.45 | - | - | - | 0.63 | 0.73 |

**Appendix C-9**. Principle Components Analysis for Dehesa Nolina (*Nolina interrata*).

| Principle Component | Variable[1] | In Average | Near Average | Far Average | RANOVA F | RANOVA P | In v Near Post-hoc P | In v Far Post-hoc P | In v Near Post-hoc P | Bartlett's Test $x^2$ | Bartlett's Test P |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Balance | | | | | | | | | | | |
| Fertility | Cu | 0.63 | 1.11 | 0.72 | **3.46** | **0.05** | 0.02 | 0.53 | 0.15 | 1.20 | 0.55 |
| Fertility | K | 171.40 | 140.10 | 158.10 | 1.10 | 0.36 | - | - | - | 1.25 | 0.54 |
| Fertility | $NO_3$** | 3.40 | 2.90 | 3.50 | 1.19 | 0.33 | - | - | - | 0.38 | 0.83 |
| Fertility | OM** | 3.74 | 2.80 | 2.76 | 2.65 | 0.10 | 0.04 | 0.16 | 0.94 | **10.66** | **0.01** |
| Fertility | Silt | 24.60 | 22.80 | 24.90 | 0.40 | 0.68 | - | - | - | 0.30 | 0.86 |
| Fertility | $SO_4$** | 3.40 | 3.30 | 4.00 | 1.63 | 0.23 | - | - | - | 3.58 | 0.17 |
| Fertility | Soluble salt** | 0.20 | 0.17 | 0.17 | 0.32 | 0.73 | - | - | - | 2.66 | 0.27 |
| Fertility* | P_olsen** | 3.50 | 4.38 | 4.60 | 1.29 | 0.31 | - | - | - | 4.84 | 0.09 |
| Fertility* | P_WB** | 3.60 | 3.10 | 5.50 | 0.74 | 0.49 | - | - | - | 1.37 | 0.50 |
| Fertility | Zn** | 1.39 | 1.01 | 1.41 | 1.60 | 0.23 | - | - | - | 4.55 | 0.10 |
| Color* | Red (Dry)** | 0.47 | 0.49 | 0.55 | 1.90 | 0.18 | - | - | - | 5.94 | 0.05 |
| Color* | Green (Dry)** | 0.34 | 0.35 | 0.37 | 0.38 | 0.69 | - | - | - | 5.30 | 0.07 |
| Color* | Blue (Dry)** | 0.22 | 0.23 | 0.23 | 0.21 | 0.81 | - | - | - | 2.15 | 0.34 |

**Appendix C-9**. Principle Components Analysis for Dehesa Nolina (*Nolina interrata*).

| Principle Component | Variable[1] | In Average | Near Average | Far Average | RANOVA F | RANOVA P | In v Near Post-hoc P | In v Far Post-hoc P | In v Near Post-hoc P | Bartlett's Test $x^2$ | Bartlett's Test P |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Color* | Red (Wet)** | 0.33 | 0.35 | 0.35 | 1.00 | 0.39 | - | - | - | 0.39 | 0.82 |
| Color* | Green (Wet)** | 0.25 | 0.24 | 0.24 | 0.38 | 0.69 | - | - | - | 1.69 | 0.43 |
| Color* | Blue (Wet)** | 0.18 | 0.18 | 0.17 | 0.06 | 0.95 | - | - | - | **3.33** | **0.05** |

[1] B = boron, Ca = calcium, Mg = magnesium, CEC = cation exchange capacity, Cu = copper, Fe = iron, K = potassium, Mn = manganese, Na = sodium, $NO_3$ = nitrate, OM = organic matter, SO4 = sulfate, SOLSALT = soluble salts, Zn = zinc.

* Excluded from Final PCA due to missing cases.

** RANOVA performed with log(X+1) transformed data to meet assumption of normality/reduce skew. Data not transformed for Bartlett's test.

**Appendix C-10**. Logistic Regression Analysis for Dehesa Nolina (*Nolina interrata*).[1,2]

| Dependent | Model[3] | aic | bic | df | $X^2$ | P | Rho | df diff | $X^2$diff | Diff P |
|---|---|---|---|---|---|---|---|---|---|---|
| **NOIN** | ***Ca ppm*** | ***27.473*** | ***29.465*** | ***1*** | ***4.25*** | ***0.039*** | ***0.153*** | - | - | - |
| NOIN | OM** | 28.48 | 30.48 | 1 | 3.24 | 0.072 | 0.117 | - | - | - |
| NOIN | pH | 29.089 | 31.081 | 1 | 2.637 | 0.104 | 0.095 | - | - | - |
| NOIN | B** | 30.254 | 32.245 | 1 | 1.472 | 0.225 | 0.053 | - | - | - |
| NOIN | Mn | 30.436 | 32.428 | 1 | 1.29 | 0.256 | 0.047 | - | - | - |
| NOIN | Cu | 31.44 | 33.44 | 1 | 0.281 | 0.596 | 0.01 | - | - | - |
| NOIN | Na** | 31.55 | 33.54 | 1 | 0.178 | 0.673 | 0.006 | | | |
| NOIN | Ca ppm+pH | 29.413 | 32.401 | 2 | 4.313 | 0.116 | 0.156 | 1 | 0.063 | 0.801815649 |
| NOIN | Ca ppm+OM** | 29.19 | 32.28 | 2 | 4.43 | 0.109 | 0.16 | 1 | 0.18 | 0.671373241 |
| NOIN | Ca ppm+B** | 20.27 | 32.014 | 2 | 4.699 | 0.095 | 0.169 | 1 | 0.449 | 0.502810221 |
| NOIN | Ca+Mn | 28.67 | 31.65 | 2 | 5.06 | 0.08 | 0.182 | 1 | 0.81 | 0.368120251 |
| NOIN | Ca+Cu | 29.47 | 32.46 | 2 | 4.25 | 0.119 | 0.153 | 1 | 0 | 1 |
| NOIN | Ca+Na** | 28.97 | 31.96 | 2 | 4.76 | 0.093 | 0.172 | 1 | 0.51 | 0.475138856 |

[1] Logistic regression run with *in* points as present and *far* points as absent.

[2] Italics indicate an intermediate step, bold indicates the preferred model.

[3] Ca = calcium, OM = organic matter, Mn = manganese, Cu = copper, Na = sodium, B = boron.

** RANOVA performed with log(X+1) transformed data to meet assumption of normality/reduce skew. Data not transformed for Bartlett's test.

**Appendix C-11**. Principle Components Analysis for Parry's Tetracoccus (*Tetracoccus dioicus*).

| Principle Component | Variable[1] | In Average | Near Average | Far Average | RANOVA F | RANOVA P | In v Near Post-hoc P | In v Far Post-hoc P | In v Near Post-hoc P | Bartlett's Test $x^2$ | Bartlett's Test P |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Texture & pH | B | 0.39 | 0.33 | 0.34 | 1.65 | 0.22 | - | - | - | 0.56 | 0.76 |
| Texture & pH | Ca | 1699.60 | 1459.60 | 1434.00 | 1.97 | 0.17 | - | - | - | 0.98 | 0.61 |
| Texture & pH | CEC | 14.68 | 14.06 | 12.90 | 1.36 | 0.28 | - | - | - | 2.00 | 0.37 |
| Texture & pH | Clay | 22.70 | 24.60 | 21.60 | 0.49 | 0.62 | - | - | - | 0.47 | 0.79 |
| Texture & pH | Fe | 11.50 | 11.60 | 11.10 | **4.03** | **0.04** | 0.01 | 0.13 | 0.51 | 3.09 | 0.21 |
| Texture & pH | K%** | 2.96 | 3.26 | 4.06 | 1.24 | 0.31 | - | - | - | 3.23 | 0.20 |
| Texture & pH | Mg** | 520.70 | 576.60 | 457.60 | 1.18 | 0.33 | - | - | - | 3.12 | 0.21 |
| Texture & pH | Mn** | 10.10 | 11.70 | 13.20 | 0.51 | 0.61 | - | - | - | 2.04 | 0.36 |
| Texture & pH | Na** | 39.00 | 35.40 | 41.30 | 0.52 | 0.60 | - | - | - | 3.80 | 0.15 |
| Texture & pH | pH | 6.38 | 6.32 | 6.27 | 0.52 | 0.61 | - | - | - | 0.26 | 0.88 |
| Texture & pH | Sand | 51.80 | 50.70 | 52.00 | 0.09 | 0.91 | - | - | - | 1.40 | 0.50 |
| Ca & Mg Balance | Ca:Mg ratio** | 2.19 | 1.86 | 2.27 | 0.80 | 0.47 | - | - | - | 0.02 | 0.99 |
| Ca & Mg Balance | Ca% | 57.53 | 53.16 | 55.75 | 0.75 | 0.49 | - | - | - | 2.74 | 0.25 |
| Ca & Mg Balance | Mg%** | 28.94 | 32.10 | 27.67 | 0.91 | 0.42 | - | - | - | 3.12 | 0.21 |
| Ca & Mg | Na% | 1.16 | 1.10 | 1.33 | 0.76 | 0.48 | - | - | - | 5.19 | 0.08 |

**Appendix C-11**. Principle Components Analysis for Parry's Tetracoccus (*Tetracoccus dioicus*).

| Principle Component | Variable[1] | In Average | Near Average | Far Average | RANOVA F | RANOVA P | In v Near Post-hoc P | In v Far Post-hoc P | In v Near Post-hoc P | Bartlett's Test $x^2$ | Bartlett's Test P |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Balance | | | | | | | | | | | |
| Fertility | Cu** | 0.55 | 0.89 | 0.82 | 0.20 | 0.21 | - | - | - | **8.68** | **0.01** |
| Fertility | K** | 170.80 | 178.30 | 186.00 | 0.25 | 0.78 | - | - | - | 0.79 | 0.68 |
| Fertility | $NO_3$** | 4.60 | 5.10 | 3.78 | 0.99 | 0.39 | - | - | - | **7.71** | **0.02** |
| Fertility | OM** | 4.14 | 3.44 | 3.21 | 2.05 | 0.16 | - | - | - | 1.61 | 0.45 |
| Fertility | Silt | 25.80 | 24.90 | 26.60 | 0.32 | 0.73 | - | - | - | 2.68 | 0.26 |
| Fertility | $SO_4$** | 3.70 | 3.60 | 3.33 | 0.21 | 0.81 | - | - | - | 0.57 | 0.75 |
| Fertility | Soluble salt** | 0.23 | 0.20 | 0.18 | **3.60** | **0.05** | 0.05 | 0.05 | 0.97 | **5.18** | **0.08** |
| Fertility | Zn | 1.63 | 1.49 | 1.52 | **8.15** | **0.00** | 0.01 | 0.01 | 0.39 | 1.51 | 0.47 |
| Fertility* | P_olsen** | 4.43 | 4.57 | 5.38 | 0.48 | 0.63 | - | - | - | 0.70 | 0.71 |
| Fertility* | P_WB** | 5.40 | 4.00 | 7.80 | 1.51 | 0.25 | - | - | - | 0.83 | 0.66 |
| Color* | Red (Dry)** | 0.49 | 0.52 | 0.52 | 0.32 | 0.73 | - | - | - | 2.76 | 0.25 |
| Color* | Green (Dry)** | 0.34 | 0.37 | 0.37 | 0.91 | 0.43 | - | - | - | 2.76 | 0.25 |
| Color* | Blue (Dry)** | 0.21 | 0.25 | 0.25 | 1.27 | 0.31 | - | - | - | 0.99 | 0.61 |

**Appendix C-11**. Principle Components Analysis for Parry's Tetracoccus (*Tetracoccus dioicus*).

| Principle Component | Variable[1] | In Average | Near Average | Far Average | RANOVA F | RANOVA P | In v Near Post-hoc P | In v Far Post-hoc P | In v Near Post-hoc P | Bartlett's Test $x^2$ | Bartlett's Test P |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Color* | Red (Wet)** | 0.34 | 0.32 | 0.33 | 0.06 | 0.94 | - | - | - | 0.18 | 0.91 |
| Color* | Green (Wet)** | 0.24 | 0.23 | 0.24 | 0.14 | 0.87 | - | - | - | 0.04 | 0.98 |
| Color* | Blue (Wet)** | 0.18 | 0.16 | 0.17 | 0.44 | 0.65 | - | - | - | 0.99 | 0.61 |

[1] B = boron, Ca = calcium, Mg = magnesium, CEC = cation exchange capacity, Cu = copper, Fe = iron, K = potassium, Mn = manganese, Na = sodium, $NO_3$ = nitrate, OM = organic matter, SO4 = sulfate, SOLSALT = soluble salts, Zn = zinc.

* Excluded from Final PCA due to missing cases.

** RANOVA performed with log(X+1) transformed data to meet assumption of normality/reduce skew. Data not transformed for Bartlett's test.

**Appendix C-12**. Logistic Regression Analysis for Parry's Tetracoccus (*Tetracoccus dioicus*).[1,2]

| Dependent | Model[3] | aic | bic | df | $X^2$ | P | Rho | df diff | $X^2$diff | Diff P |
|---|---|---|---|---|---|---|---|---|---|---|
| TEDI | *solsalt ** * | *26.24* | *28.13* | *1* | *4.046* | *0.044* | *0.154* | - | - | - |
| TEDI | Cu** | 28.181 | 30.172 | 1 | 3.545 | 0.06 | 0.128 | - | - | - |
| TEDI | Zn | 30.226 | 32.115 | 1 | 0.061 | 0.805 | 0.002 | - | - | - |
| TEDI | Fe | 31.7 | 33.691 | 1 | 0.026 | 0.872 | 0.001 | - | - | - |
| TEDI | *solsalt ** +Cu** * | *21.49* | *24.323* | *2* | *10.8* | *0.005* | *0.411* | *1* | *6.754* | *0.0093538* |
| TEDI | solsalt ** +Zn | 22.106 | 24.78 | 2 | 8.625 | 0.013 | 0.349 | 1 | 4.579 | 0.0323661 |
| TEDI | solsalt **+Fe | 28.09 | 30.92 | 2 | 4.2 | 0.122 | 0.16 | 1 | 0.154 | 0.6947418 |
| TEDI | ***solsalt+ Cu**+ Zn*** | ***17.004*** | ***20.566*** | ***3*** | ***15.73*** | ***0.001*** | ***0.636*** | ***1*** | ***4.93*** | ***0.0263943*** |
| TEDI | solsalt+ Cu**+ Fe | 21.05 | 24.83 | 3 | 13.234 | 0.004 | 0.503 | 1 | 2.434 | 0.1187296 |
| TEDI | solsalt+Cu**+Zn+Fe | 18.38 | 22.83 | 4 | 16.353 | 0.003 | 0.661 | 1 | 0.623 | 0.4299346 |

1 Logistic regression run with *in* points as present and *far* points as absent.

2 Italics indicate an intermediate step, bold indicates the preferred model.

3 solsalt = soluble salts, cu = copper, Zn = zinc, FE = iron.

** RANOVA performed with log(X+1) transformed data to meet assumption of normality/reduce skew. Data not transformed for Bartlett's test.