PREDICTIVE HABITAT ANALYSIS AND MAPPING OF FOUR RARE VERNAL POOL SPECIES IN MERCED, SACRAMENTO AND PLACER COUNTIES

Great Valley, California, USA

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REPORT ACRONYMS

- **CNDDDB**: California Natural Diversity Database
- **CVPCP**: Central Valley Project Conservation Program
- **CVPIA**: Central Valley Project Improvement Act
- **DEM**: Digital Elevation Model
- **E.O. Number**: Element Occurrence Number (in CNDDDB)
- **ESRI**: Environmental Systems Research Institute
- **FGDC**: Federal Geographic Data Committee
- **GIS**: Geographic Information Systems
- **GPS**: Global Positioning Systems
- **HCP**: Habitat Conservation Plans
- **NAIP**: National Agricultural Imagery Program
- **PRISM**: Parameter-elevation Regressions on Independent Slopes Model
- **SSURGO Soils Data**: Soil Survey Geographic Database (Soils GIS Data)
- **STATSGO**: State Soil Geographic Database (Soils GIS Data)
- **USDA**: U.S. Department of Agriculture
- **USFWS**: U.S. Fish and Wildlife Service
- **USGS**: U.S. Geological Survey

GLOSSARY OF TERMS

**Alluvium.** Eroded rock material carried down and deposited along a stream course.

**Centroid.** Center point of an area

**Endemic.** Pertaining to a species that is only found in a specific region, location or habitat type.

**Endemism.** The state of being endemic.

**Escarpment.** A vertical rock outcrop.

**Extant.** Still in existence.

**Extirpated.** Pertaining to a species, population or habitat that has been locally eliminated.

**Mima Mound.** An individual mound within a unique topography consisting of closely-spaced large soils mounds with intervening depressions or swales.

**Tuff.** Rock type composed of consolidated volcanic ash.

**Pumice.** Rock type composed of light, porous acid volcanic rock.

**Soil Phase.** A term associated with soil series but not considered a classification category. A soil mapping unit that delineates such differences in soil as texture, thickness, percent slope, saltiness, or extent of erosion.

**Soil Series.** Soil unit differentiated on the basis of observable and mapping soil characteristics. Soils in the same series have approximately the same color, texture, structure, consistency, thickness, and pH.

**Terrace.** A raised, step-like landform with a level top and steep side slopes, produced from tectonic uplift or from peripheral erosion.
ABSTRACT

Holland and Hollander (2007) developed an original method that mapped the predicted pre-European distribution of 82 rare vernal pool taxa in California. Their method correlated available species occurrence records with associated habitat parameters related to soil, topography and climate. Their maps were insightful on a statewide basis, but were fairly inaccurate on a county scale due to the coarseness of some of the base data layers and the statewide scale of analysis. Our study attempted to refine Holland and Hollander’s method by limiting the focus to four species in three counties, using more extensive occurrence data, more refined soil and topographic data, including additional habitat parameters, and focusing on a county scale to produce more precise predicted habitat maps that could be used for county-scale conservation planning and species recovery. We also used our final maps to calculate the acreage of extant predicted habitat within remaining vernal pool habitat in our study areas in 2005 and 2010 and the loss of predicted habitat by species and county during that period. Our study species included three large branchiopod species (shrimp) (Branchinecta lynchi, Branchinecta mesovallensis, and Lepidurus packardi) and one plant species (Castilleja campestris ssp. succulenta). Our study areas included Merced, Sacramento and Placer counties.

Our method was successful in producing more refined and accurate predicted habitat maps for all the study species in all study counties. The accuracy of the mapping varied by species based on the abundance of available occurrence data, the specificity of known habitat affinities and other factors. C. campestris ssp. succulenta likely has the most accurate predictive mapping given its close association with certain landforms and soils and the availability of extensive, high-quality occurrence data. B. mesovallensis probably has the least certain predictive mapping given the sparser and more sporadic distribution of documented occurrences and less apparent habitat affinities. We ascribed the refinements in predictive habitat mapping primarily to the use of more abundant species occurrence records, more precise soil data, the inclusion of a novel habitat parameter, and a county-scale focus which restricted the range of each habitat parameter to the distribution of species occurrences within each county. Soil, slope, elevation and ‘low slope continuity’ were the most important parameters contributing to the accuracy of the predicted habitat maps. Climate parameters were less important, often introducing arbitrary and erroneous exclusions to the predicted habitat. As such they were generally not included in the final predicted habitat maps.

Given the presumed level of accuracy of the maps, we believe the calculation of extant and extirpated predicted habitat is also reasonably accurate. We calculated losses of predicted historic habitat ranging from 64% to 84% for the large branchiopod species within the study counties, and 54% for C. campestris ssp. succulenta in Merced County. The losses have been greater in Sacramento and Placer counties since the vernal pool habitats in these counties are more concentrated in areas prone to human disturbance. From 2005-2010, we calculated losses of extant predicted habitat ranging from 0.4% to 7.9% for the study species in the study counties. In contrast to the historic losses, the recent losses have been greater in Merced County where two large areas were deep-ripped and converted to intensive agriculture. The losses of predicted habitat within vernal pool core recovery areas followed similar trends, ranging from 0.4% to 6.1%.

Based on its presumed level of accuracy, the predicted habitat mapping produced by our study can be directly used for regional conservation planning and species recovery in our study areas. Also, predicted habitat mapping for these species could be readily produced for other counties using the base GIS layers, methods and assumptions used in this study. Extending the study methods to other species needs to be more carefully considered and should include consultation with experts that have knowledge of the target species and counties.
1.0 INTRODUCTION

Holland and Hollander (2007) produced an intriguing statewide analysis of ‘hogwallow biogeography’ that mapped the predicted pre-European distribution of 82 rare vernal pool taxa in California. Their method correlated available species occurrence records with associated soils units and then constrained the predicted distribution based on soil with additional topographic and climatic data to produce final predicted pre-European distributions. Their maps were insightful in terms of understanding potential range-wide distribution patterns and identifying vernal pool biodiversity hotspots in the state. The authors recognized some limitations to their study. These included the imperfect nature of the species occurrence records, the broad-brush nature of the soil data utilized, the use of 100-meter versus 30-meter pixel area for topographic data (the 30-meter data were not yet available statewide), and the coarse nature of available climate data. Due to these limitations, the predicted habitat for an individual species was often excessively large or otherwise imprecise, limiting the practical application of the mapping toward effective local or regional conservation planning and species recovery.

In this study, we attempt to refine Holland and Hollander’s original method by focusing on a local (county) scale, using more species occurrence records, higher resolution habitat data, and a novel habitat parameter to produce more accurate predictive habitat mapping. For the purposes of both studies, ‘vernal pool habitat’ as well as ‘predicted habitat’ include both vernal pools and the surrounding matrix of upland habitat within which vernal pools exist. The actual cover of vernal pools within this habitat can vary greatly from less than 1% to greater than 10% and rarely exceeds 15% (Witham et al. 2013).

We limited our study to four species (three large branchiopod species and one plant species) in three counties (Merced, Sacramento and Placer) within California’s Great Valley to test the refined method. We used the final predicted habitat maps to calculate the acreage of extant habitat for the study species within the study areas. We also evaluated our refined method as a tool for developing locally accurate predictive maps for the suite of rare vernal pool species throughout California. Ultimately, such a tool would be highly valuable for regional conservation planning and species recovery since much of the remaining vernal pool habitat in the state occurs on private lands with limited access. Also, remote analysis can be much less costly than conducting labor-intensive field surveys.

Our study included both plant and animal species since their distributions can be driven by different factors. Our four study species were Branchinecta lynchi (vernal pool fairy shrimp), Branchinecta mesovallensis (midvalley fairy shrimp), Lepidurus packardi (vernal pool tadpole shrimp), and Castilleja campestris ssp. succulenta (succulent owl’s-clover). We selected the large branchiopod (shrimp) species since they are relatively widespread in the Great Valley (as compared with other rare California vernal pool large branchiopod species) in areas of active land conversion and thus are commonly addressed in Biological Opinions and other environmental documents. They also offer different but overlapping distributions and habitat preferences allowing for interesting comparisons. C. campestris ssp. succulenta is a fairly common species within its restricted range (northeastern San Joaquin Valley) and thus is also commonly addressed in environmental documents. By addressing these species, our study provides information with simultaneous scientific, conservation and regulatory benefits.

We selected Merced, Sacramento and Placer counties for our study areas since each supports important vernal pool habitats that are under active threat from on-going land conversion. Thus, the information from our study can be immediately applied to aid in the conservation and recovery of the study species in these areas. The three large branchiopod species co-occur in Merced and Sacramento counties allowing for analysis across different geographies. C. campestris ssp. succulenta occurs only in Merced County within the study areas, but has widespread occurrences on a range of landforms and soils.
1.1 Overview of Vernal Pool Ecology, Distribution and Threats

Vernal pools are ephemeral seasonal rain pools that occur in limited areas around the world primarily where there is a combination of a Mediterranean climate and suitable soils with basin-mound topography and an underlying restrictive layer that supports the development of a perched water table during the rainy season. While these physical conditions are simple enough to describe, the combination is quite rare on a global level and the ensuing habitat conditions, alternating from cool and inundated in the winter-spring to hot and dry in the summer-fall, are very challenging to life. As a result, vernal pools support a unique suite of native plant and animal species, including many rare species, that have often evolved in situ and are specifically adapted to the dual aquatic-terrestrial habitat conditions. More detailed information on vernal pool geomorphology, ecology and distribution is available through a variety of previously published studies, reports and conference proceedings (Schlising and Alexander 2007, USFWS 2005, Vollmar 2002a, Witham et al. 1998).

California, due to its particular geologic history and current climate, supports arguably the most extensive, diverse and species-rich vernal pool habitats in the world. Vernal pools occur on various landforms across the state from sandstone mesas around San Diego in the south, to basin and terrace formations around the Great Valley and San Francisco Bay-Delta regions, to the volcanic plains of the Modoc Plateau in the north. Not unexpectedly, numerous rare species occur within these habitats, nearly all of which are endemic to local areas or regions and/or particular pool types.

Since most vernal pool habitats in California occur on relatively flat terrain in areas of human settlement, they have also been subjected to substantial impacts from land conversion. Holland (1998) estimated that more than 90% of the historic vernal pool habitat in the state has been lost since European arrival. The loss is apparently continuing unabated with an estimated 3.2% of remaining extant habitat mapped in Placer, Merced and Sacramento counties as of 2005 lost by 2010 (Witham et al. 2013). This loss of habitat has resulted in many of the rare and uncommon species becoming increasingly threatened (USFWS 2005).

1.2 Relationship of the Study to the Vernal Pool Ecosystems Recovery Plan

To address the threat to vernal pool habitats, the U.S. Fish and Wildlife Service (USFWS), in collaboration with other agencies, organizations and individuals, prepared a Recovery Plan for Vernal Pool Ecosystems of California and Southern Oregon (USFWS 2005). The plan includes 20 federally listed species and 13 additional species of concern. Among these are the four species included in our study. The plan takes an ecosystem-level approach to species recovery and conservation, including the protection and appropriate management of large blocks of intact habitat as well as small, critical preserves aimed at ensuring the long-term conservation and recovery of all plan species.

The ability to down-list or de-list individual species is contingent on the achievement of several ‘recovery criteria’ (USFWS 2005). The two that are most relevant to this study include: 1) the permanent conservation of sufficient occupied habitat to protect and maintain the full range of genetic and geographic variation in each species; and 2) the completion of research necessary to ensure appropriate and adequate habitat protection. The predictive habitat mapping developed through this study addresses both of these criteria by refining and documenting a method for identifying key conservation areas for the plan species, and then applying this method to identify key remaining habitat areas for four of the plan species within specific areas to aid in habitat conservation planning and recovery actions.
1.3 Foundations of Study Approach

Species distributions are a function of at least four classes of factors: 1) abiotic conditions, 2) biotic factors including competition, 3) regions that are accessible to dispersal, and 4) the ability of the species to adapt to new conditions (Soberon and Peterson 2005). The geographic and local distribution of a species is determined by the dynamic interaction of these factors in space and time. Determining the specific factors that control the distribution of a particular species can be extremely challenging. As an example from this study, *B. mesovallensis* can readily occupy a range of pool sizes and depths and can tolerate a range of pool temperature conditions. Yet, it has a very limited and sporadic distribution within two localized areas in the Great Valley. This may be due to competition with the more widespread *B. lynchii*, preference for more low-lying vernal pool habitats near the valley basin or some other unknown factor (Vollmar pers. obs.).

Predictive habitat modeling is a rapidly growing discipline that is being used to develop predictive maps of the distributions of species and habitats, often focusing on rare or sensitive resources of conservation interest. It has been marked by a steady increase in analytic capacity due to improvements in technology. Franklin et al. (1995) cites the origin of predictive modeling with the refining of ecological niche theory and gradient analysis. The ability to analyze digital geographic information and apply statistical methods has given ecologists the capacity to use the information about a species’ current distribution in a model that can predict other potential locations (Fertig and Reiners 2002). This process is driven by the ability to project environmental variables across a landscape and make predictions and calculations based on a range of parameters given by the habitat requirements of the study species.

We used **predictive habitat mapping** for this study, which may be regarded as a form of **predictive habitat modeling**. These two methods can be distinguished based primarily on data quality and analytical rigor. Predictive habitat modeling uses more rigorous, research-quality species occurrence data sets and research-level analyses to define and project the predicted extent of a species across a landscape. Predictive habitat mapping relies on less methodical data collection from readily available species occurrence data (such as California Natural Diversity Database (CNDDB) occurrence records), and more general analyses to develop the best available predictive habitat map with the available information. While more rigorous predictive habitat modeling may be preferred, the collection and analysis of appropriate occurrence and species ecological data is very resource intensive and often not economically possible or practical. Predictive habitat mapping offers an important and valuable alternative, especially when critical, time-sensitive conservation issues need to be addressed.

Most predictive modeling methods use either the mechanistic or correlative approach (Fertig and Reiners 2002, Soberon and Peterson 2005). The mechanistic approach measures the species’ response to physical parameters and then projects those parameters across the study area to produce the predictive map. The correlative approach uses known occurrence points to determine the physical and biological parameters that the species currently lives within and then projects these parameters across the study area to produce the predictive map (Soberon and Peterson 2005).

Our method is correlative and based on the assumption that there is a meaningful relationship between the known points of occurrence to the environmental parameters with which they coincide (Soberon and Peterson 2005). Our study builds on Holland and Hollander’s (2007) original study which was also correlative and was inspired by earlier correlative studies by Raxworthy et al. (2003) and Nix (1986). We also found guidance from Skov and Borchsenius (1997) as well as several papers included in the proceedings of a symposium on predicting species occurrences (Scott et al. 2002).
Using the correlative method as well as a non-randomized/presence only occurrence data set introduced limitations to our study analyses. Each occurrence data point includes both environmental and biological factors that cannot be separated. Therefore, it was generally difficult to ascribe distribution patterns to specific habitat factors. Also, the occurrence data were not collected using a randomized methodology, are not uniformly distributed, and do not include data points for species’ absence. Therefore, they could not be subjected to statistical analyses.

Despite these data limitations, critical insights can be gained from the use of correlative studies. Our study provides a useful tool for directing future surveys of vernal pool species towards the most appropriate locations. If successful, it will provide the most accurate understanding to date of the expected distribution of the four study species within the study counties and can form the basis for more effective conservation planning and species recovery.

1.4 Limitations of Study

The predictive habitat mapping produced by our study is intended to provide general guidance on the potential occurrence of the study species within the study areas. Actual occurrence in a specific location or pool can depend on a variety of factors such as local soil inclusions, the apparently random manner in which species tend to occupy individual pools in a complex, undetected past disturbances, etc. Also, the predicted mapping relies on occurrence records and habitat data layers that may include some errors. As such, actual occurrence or absence of the study species in a particular location would need to be verified by field sampling.

2.0 METHODS AND MATERIALS

We analyzed available, vetted species occurrence records using Geographic Information Systems (GIS) to predict habitat distribution for our focal species. This was based on the range of the occurrence locations within a cumulative set of habitat parameters related to soils, topography and climate. The output of predicted habitat was limited to the subset of areas that are spatially within the range of all the combined habitat parameters. We evaluated the contributions of the predictive parameters to the mapped output to determine which parameters were most important in predicting habitat for a given species. Based on this evaluation, we excluded those parameters that introduced obvious errors or artificial boundaries into the habitat mapping to produce the final output. For C. campestris ssp. succulenta, we were also able to identified primary (preferred) versus secondary (marginal) predicted habitat given the high quality of the occurrence data (Dittes and Guardino 2002) and its obvious strong affinities for certain landforms and soil types. This stratification was not suitable for the large branchiopod species since a lower proportion of the occurrence data were of research-quality and there were no clear affinities for certain soil types or other habitat factors.

2.1 Description of the Study Area

Our study area included all of Merced, Sacramento and Placer counties, California (Figures 1A and 1B). From a practical standpoint, only those areas of these counties that support vernal pool habitats and thus our study species were the focus of our analyses. These areas include the basin, basin rim and terrace formations associated with the Great Valley within the study counties. Areas within these counties that generally do not support vernal pool habitats include the lower foothills of the Sierra Nevada Mountains in eastern Sacramento and Placer counties, areas within the Sacramento-San Joaquin Delta in western Sacramento County, and areas of the interior Coast Ranges in western Merced County.
FIGURE 1-A
Distribution of Targeted Large Branchiopods
Vernal Pool Species Predictive Habitat Study
Central Valley, California

Legend
- Branchinecta mesovalensis
- Lepidurus packardi
- Branchinecta lynchii
- Extant Vernal Pool Habitat, 2005
- County Boundary
- Major Highway

Note: Species data include non-specific as well as specific data (CNDDB precision)

Data Sources: VNL,C. Wiltham, B. Holland, 2012
CNDDB, 01/2012 | B. Helm | Giseon & Skordal
Westenreid | USGS, Various | Gap, 1999 | DWR, 2001
GIS/Cartography by Jake Schweitzer, Jan. 2013
Map File: Vorticity-Spots_235_A-P_2013-0120.mxd

Elevation (NGVD Feet)
- >10,000
- 7,500 - 10,000
- 5,000 - 7,500
- 2,500 - 5,000
- 1,000 - 2,500
- 900 - 1,000
- 800 - 900
- 700 - 800
- 600 - 700
- 500 - 600
- 400 - 500
- 300 - 400
- 200 - 300
- 100 - 200
- 0 - 100
2.2 Study Species

The study species were selected based on several factors related to distribution, variation in geographic and microhabitat affinities, regulatory status, and threat, as described above. An overview of the distribution and ecology of each species is presented below to aid in interpreting the study results. Figures 1-A and 1-B show the ranges of these species within California.

*Branchinecta lynchi*, a federal threatened species, is the most widespread of the ‘rare’ California vernal pool large branchiopod species (*Figure 1-A*). It occurs in scattered areas throughout much of the Great Valley and sporadically in the central and southern Coast Ranges, Los Angeles Basin and up into southern Oregon. It has robust occurrences in all three study counties. It can occur in a wide range of pool sizes and depths, but typically occupies pools at least four inches in maximum potential ponding depth (Helm 1998, Helm and Vollmar 2002). It can tolerate a broad range of water quality conditions though it seems to prefer pools with relatively clear water and a medium level of algal growth (Vollmar pers. obs.). It thrives under cold water conditions, often dying off by late March when the ambient temperatures and pool waters begin to warm (Helm 1998). The species occurs in varied terrain including basin rim, low terrace and high terrace settings within the Great Valley. It also occurs on a broad range of soil types.

*Branchinecta mesovallensis*, a rare but not currently listed species, is endemic to the Great Valley where its range is restricted to two localized, disjunct population centers, one centered in Sacramento and Solano counties and the other in Merced County (*Figure 1-A*). It has not been documented in Placer County. It can occur in a wide range of pool sizes and depths but typically occupies shallow, ‘flashy’ pools as shallow as 2-3 inches (Helm 1998, Helm and Vollmar 2002). *B. lynchi* occurs throughout the range of *B. mesovallensis*, and they often co-occur on the same site. However, they rarely co-occur in the same pool (Helm and Vollmar 2002, Vollmar pers. obs.). *B. lynchi* may out-compete *B. mesovallensis* under some conditions, forcing the latter to breed in more shallow, flashy pools that are not suitable breeding sites for *B. lynchi* (Vollmar pers. obs.). Also, *B. mesovallensis* can tolerate warmer water than *B. lynchi* (Helm 1998, Helm and Vollmar 2002), allowing it to breed after *B. lynchi* has disappeared for the season. Competition with *B. lynchi* may explain, in part, the more limited distribution of *B. mesovallensis* within the Great Valley. However, if the species can tolerate shallower, flashier pools it seems that the species would occur widely on the high terraces along the eastern edge of the Valley where there is an abundance of such pools. Yet, this species appears restricted to only lower terrain areas. Apparently, there are other, as yet unknown factors controlling the distribution of this species.

*Lepidurus packardi*, a federal endangered species, is nearly endemic to the Great Valley with the exception of a few occurrences documented in southwest Alameda County near the southern end of the San Francisco Bay (*Figure 1-A*). Within the Great Valley, most occurrences are concentrated along the eastern side of the Valley, though population centers extend into western Merced County and Solano County. There are also some scattered occurrences along the west side of the Sacramento Valley. The species occurs in all three study counties, though there are only a few occurrences in Placer County all of which may be introduced within altered or created vernal pool habitats. In Merced County, there are a number of occurrences in the center of the county near the San Joaquin River floodplain. Many of these occurrences are in areas with managed wetlands on duck club lands and wildlife refuges. Since this area was prone to prolonged seasonal flooding prior to European arrival (Edminster 2002), it is likely that most of these occurrences represent recent colonization of man-made wetlands. This species typically inhabits medium to large pools that are at least 6-7 inches in maximum potential ponding depth (Helm 1998, Helm and Vollmar 2002). Some expert vernal pool shrimp biologists have observed that the species commonly occurs in areas with a medium to high density of large, hydrologically interconnected pools.
L. packardi can tolerate a broad range of water quality conditions including highly turbid or disturbed pools. It is occasionally found in seasonal stock ponds. Like B. mesovallensis, this species appears to be absent from the higher terrain of eastern Merced and Sacramento counties that is separated by steeper slopes from lower elevation areas. This distribution pattern makes more sense than B. mesovallensis since the low-lying areas have a higher occurrence and density of the larger vernal pools typically inhabited by the species. While larger pools occur sporadically on the high terrain, they rarely occur in large, interconnected networks.

_Castilleja campestris_ ssp. succulenta, a federal threatened and state endangered species, is restricted to the eastern San Joaquin Valley from southeast Stanislaus to northeast Fresno County (Figure 1-B). There is one disjunct occurrence in eastern San Joaquin County adjacent to the Sacramento County line that is of questionable validity. It is not known from the Sacramento Valley and is thus absent from both Sacramento and Placer County analyses in this study. The species typically occurs in medium to large pools with a maximum potential ponding depth of at least 5-6 inches (Dittes and Guardino 2002). It also appears to have strong soil affinities, preferring older, gravelly, acidic soils of the high terraces, especially Redding and Amador soils. The documented species occurrences are highly concentrated on these landforms and soils. While it is found on other soil series, these occurrences tend to be much sparser and widely scattered, especially on neutral pH soils (such as Madera, Marguerite, Montepelier, and Rocklin, soils) or clay soils.

2.3 Compilation of Occurrence Records

We compiled species occurrence records from two sources: CNDDDB (2012) and additional occurrence records obtained from private researchers and consultants (Table 1). The occurrence records from additional sources typically were more extensive and detailed than the available CNDDDB records, creating a more robust data set for analysis. Figures 2A-2C show the distribution and quality (specific versus non-specific points) of these occurrences within Merced, Sacramento and Placer counties, respectively.

The records contained in the CNDDDB are submitted mostly on a voluntary basis by individuals who have conducted field surveys either in a professional or amateur capacity. These records range from ‘non-specific’ records with a one-mile precision, to ‘specific’ point data with an 80-meter precision, to ‘specific’ polygon data encompassing a suitable habitat area within which the species occurs in one or more locations. All of the available CNDDDB records for the target species within our study counties were initially obtained for review and potential inclusion in the final data set.

During our initial review for this study, we found extensive areas within the study counties where surveys for the study species had been conducted but the detailed occurrence records were not available through the CNDDDB (often multiple data points are combined into a general site CNDDDB point). We were able to obtain detailed occurrence records from companies and individuals that had conducted these original surveys, all of whom gave authorization to use and publish these data as part of our study. All of these data were obtained from highly reputable sources and included Vollmar Natural Lands Consulting, Helm Biological Consulting, Gibson and Skordal, Carol Witham, and Westervelt Ecological Services. All of these data consisted of either point data or vernal pool polygon data collected using professional GPS units (submeter precision) or points marked on high-resolution aerial photograph maps clearly showing vernal pool signatures and the specific occupied pools.

Data from both sources (CNDDDB and original surveys) were evaluated by applying the process and exclusion criteria described below to ensure that all occurrence records used met basic levels of accuracy.
Table 1. Summary of species occurrence records used for vernal pool species predictive habitat mapping study.

<table>
<thead>
<tr>
<th>Species/County</th>
<th>CNDDB Occurrences used for Analysis</th>
<th>Additional Occurrences used for Analysis</th>
<th>Total No. of Occurrences used for Analysis</th>
</tr>
</thead>
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<td>n/a</td>
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</tr>
<tr>
<td>CACASU</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Merced</td>
<td>67</td>
<td>693</td>
<td>760</td>
</tr>
</tbody>
</table>

1. BRLY = Branchinecta lynchi; BRME = Branchinecta mesovalensis; LEPA = Lepidurus packardi; CACASU = Castilleja campestris ssp. succulenta.
2. CNDDB (2012) Occurrences – California Natural Diversity Database occurrences; the occurrences are publicly available occurrence records maintained by the California Department of Fish and Game.
3. Additional Occurrences – these occurrences were obtained directly from researchers and consultants that had conducted surveys for the study species within the study counties.
4. BRME does not occur in Placer County; there are three known occurrences of LEPA in Placer County, at least one of which is in a created vernal pool. Thus, the data are considered to be too sparse for meaningful analysis.

and consistency. All occurrence records were merged into a master dataset by employing the following steps in GIS. First, all data that consisted of an agglomeration of multiple points or polygons (‘multi-part’ polygons) were ‘exploded’ (separated) into solitary polygons (‘single-part’) and exported as a geodatabase layer. The area (acres) of each polygon was converted from the field area (m²) using the field calculator function and included in the associated attribute table. All polygons were then exported to a centroid point file. This point file was merged to the existing CNDDB point file with all additional occurrence point files into a cumulative geodatabase layer of all species occurrence records. All relevant attribute fields were maintained during the merge including fields describing attributes relevant to the four exclusion criteria listed below. This final point file was overlaid onto the most recent available National Agricultural Imagery Program (NAIP) imagery (2009) to review site conditions associated with the point.

Individual occurrences were excluded from the analysis subset if they met any of the following criteria:

- Not located in Sacramento, Merced or Placer counties;
- Classified as a ‘created’ or ‘constructed’ pool, including stock ponds;
- Occurrence description was so general in nature that it could not be reasonably verified to be in the vicinity of its assigned location; or
- Assigned occurrence location was mapped on a soil series or phase or in a topographic position that was not suitable for vernal pools and thus likely erroneous.

All CNDDB specific point occurrences within a 0.10-mile precision were automatically included in the dataset for analysis. The remaining, less accurate CNDDB occurrences were included for all parameters except soil and slope since they can vary substantially on a local scale. This approach was important because it allowed many non-precise occurrences to be included as part of the elevation analysis and also
to be depicted on maps as part of the species’ distribution. In nearly all cases, these non-precise
occurrences were in the vicinity of soils and slopes represented by other, more precise occurrences so the
loss of data with regards to these parameters was minimal. For a limited number of non-precise
occurrences, the associated soil could be reliably interpreted (such as where there was a large polygon of
a single soil). In such cases, the soil data were included data for the occurrence. In the case of duplicate
data, such as consultant data that was reported to CNDDB and therefore occurred twice in the dataset, the
CNDDB record was excluded since the consultant data were assumed to be the most reliable.

The data used in our study were collected over many years by numerous individuals using a wide array of
survey and occurrence representation methods, and, therefore are not generally suitable for rigorous
statistical analysis to determine the relative quality of predicted habitat for a given species. The only
exception for our study was soil associations of C. campestris ssp. succulenta. Roughly 90 percent of the
occurrence records for this species in eastern Merced County were collected during random stratified,
research-level surveys conducted in support of a proposed regional Habitat Conservation Plan (Dittes and
Guardino 2002, Schweitzer and Vollmar 2008). These surveys covered roughly 20,000 acres on 13 large
ranches distributed throughout the region. Thus, even when combined with additional CNDDB and
consultant occurrence records, we were able to use the cumulative dataset to evaluate trends in the affinity
of the species to specific landforms, soil series, types and phases.

2.4 Selection of Habitat Parameters

We used nine individual habitat parameters for our predicted habitat analysis: soil, elevation, slope, mean
annual precipitation, mean minimum January temperature, mean maximum July temperature, mean July
precipitation, mean relative summer humidity, and low slope continuity. We used all eight of the habitat
parameters used by Holland and Hollander (2007) (the first eight listed above). We also added a new
parameter developed for this study termed ‘low slope continuity’ (see description below). We considered
using additional parameters including mapped vernal pool habitat density, cover and/or diversity but
could not justify any differentiation of predicted habitat due to the potential bias inherent in the
occurrence data and the coarseness of the vernal pool habitat mapping data. While we found that a much
higher percentage of the occurrences of all four study species were documented on medium and high
density/cover habitats, the association could not be substantiated statistically. Also, while many more
occurrences were documented on these habitats, the low density/cover habitats still supported many
occurrences and were thus still considered good quality predicted habitat.

2.4.1 Soils

Numerous studies have correlated the distribution of vernal pools as well as vernal pool endemic species
with specific geologic surfaces and their associated soils (Dittes and Guardino 2002, Helm and Vollmar
2002b, Holland and Dains 1990). This association was a basic premise in both Holland and Hollander’s
(2007) study and our study.

We considered three different levels of available soil mapping for our predictive habitat mapping –
STATSGO, SSURGO soil series, and SSURGO soil phases. The STATSGO (State Soil Geographic)
data (USDA 1994) are the most generalized, mapping common landscape units often comprised of a set
of related soil series. This dataset was produced on a state-wide basis. Examples of STATSGO map
units include ‘Redding-Pentz-Corning’ and ‘Fresno-Dinuba-Lewis’. Holland and Hollander (2007) used
the STATSGO data since they were doing statewide analysis and the more precise SSURGO data were
not yet available on a statewide basis. We found that the STATSGO data often greatly exaggerated the
extent of predicted substrate when applied on a county scale. The SSURGO (Soil Survey Geographic)
data (USDA 2012) were developed by digitizing county soil surveys and are very detailed (particularly in the Great Valley and other agricultural regions), down to the soil phase. Examples of SSURGO map units (soil phases) are ‘Redding gravelly loam, 0-8% slope’ and ‘Lewis loam, moderately saline-alkali, 0-1% slopes’. We found that using SSURGO soil phase data sometimes results in under-mapping of predictive substrate, especially when there are a limited number of species occurrences. For example, while a species may have the capacity to occur on the full range of Redding soil phases (as appears to be the case for our four study species), limited surveys may have only documented the species on a subset of the different soil phases associated with the series. We were concerned that limiting the predictive substrate to only those specific soil phases on which the species has been documented might arbitrarily exclude other related soils types which are also likely suitable for the species. Also, slope is a component of soil map units. Since we used slope as a separate habitat parameter, it was not necessary to distinguish slope within the soil data layer. In consideration of these factors, we agglomerated individual SSURGO soil phases into common soil series such as ‘Redding’ or ‘Lewis’. We chose this approach to err on the side of inclusion versus exclusion of actual suitable habitat using the SSURGO data. This approach provided a broader, more inclusive predicted substrate without going as broad as the STATSGO data. Figure 3 presents a representative comparison of the extent of predicted habitat for *C. campestris* ssp. *succulenta* and *L. packardi* based on soils using the three different approaches discussed above. As shown, the STATSGO layer greatly exaggerates the extent of predicted habitat, especially for *C. campestris* ssp. *succulenta* while the SSURGO soil phase layer excludes many small polygons within otherwise predicted habitat.

For *C. campestris* ssp. *succulenta*, we conducted a more in-depth analysis of soil associations given the high quality of the occurrence records. For this species, we prepared a list of all soil phases with documented occurrences, calculated the percent acreage of these soil phases within mapped vernal pool habitat polygons, and then compared the percent acreage to the percent of occurrences on a given soil phase to identify any obvious soil affinities. These data were used to identify soils providing ‘primary’ (preferred) versus ‘secondary’ (marginal) predicted habitat for the species.

### 2.4.2 Elevation and Slope

We used 30-meter Digital Elevation Model (DEM) grids (USGS 1997) to analyze elevation and slope. We investigated using 10-meter DEM grids but found them to be too fine-grained which introduced erroneous slope ranges (excessively steep). Since the slope of an individual occurrence is calculated as the average of a 30-meter grid scale, there is a high potential that a small number of occurrences have erroneously high calculated slopes where there is a nearby bluff, creek bank or other steep feature not reflective of the overall landscape-level slope trend or the local site where the occupied vernal pool occurs. This potential exaggeration of slope could be addressed by eliminating slope ‘outliers’ though we did not do this for this parameter since we found it had only a very minor effect on the extent of predicted habitat when considered on a county scale.

### 2.4.3 Low Slope Continuity

‘Low slope continuity’ is a derived parameter that we developed for our study to represent an area that is contiguous with the basin of the Great Valley up to a selected slope maximum. Many expert vernal pool shrimp biologists (Vollmar pers. obs., Witham pers. obs., Schweitzer pers. obs., Helm pers. comm., Helm and Vollmar 2002) have noted the apparent association of *B. mesovallensis* and *L. packardi* with lower slope areas that are contiguous with the Great Valley basin. This association may be related to elevated ambient humidity in Great Valley basin (though the available coarse climate data do not show this), geologic history or other unknown factors. We developed this parameter to address this apparent
association. Low slope continuity was an important added parameter that excluded significant areas where *B. mesovallensis* and *L. packardi* are not known or expected to occur but otherwise would have been included as predicted habitat using the soil, slope and elevation parameters. This parameter excluded high terrain in the eastern portions of Sacramento and Merced counties that are separated or disjunct from the Great Valley Basin by moderate to steep slopes. This parameter includes the area in each county that is directly contiguous with the basin of the Great Valley up to a selected slope maximum. Areas that are not directly connected through a continuous slope below the maximum threshold were excluded. For example, while there are extensive, contiguous low gradient flat areas along the top of China Hat Ridge and in the northeast of Merced County, these areas are separated from the Great Valley basin by steeper terrain and were thus excluded.

The upper end of the slope range was unique for each species by county, and was set at the slope that included 95 percent of occurrences extending up from the valley basin. The 5 percent of occurrences on steeper slopes were eliminated to remove potential non-representative or erroneous outliers (as discussed in Section 2.3.2) that would distort the mapping. For example, we calculated that 95 percent of the *L. packardi* occurrences in Merced County used in our analysis occurred on slopes between 0.0 and 3.7 percent (see Table 2 in the Section 3.0 below). Thus the low slope continuity parameter for *L. packardi* in Merced County included all areas that were directly contiguous with the valley basin via slopes that were at or below a 3.7% slope.

### 2.4.4 Climate

We used the same dataset used by Holland and Hollander (2007) for our climate data since no more accurate climate data were available. This dataset was obtained from statewide 1.25 arc-minute Parameter-elevation Regressions on Independent Slopes Model (PRISM) climatic data, re-sampled to 100-meter grids.

### 2.5 Analysis of Predicted Habitat

We calculated the extent of predicted habitat for each species for each county using GIS by first calculating the habitat range of each parameter associated with the specific occurrence locations and then extrapolating to include all areas in the county within the range of that parameter. The individual habitat parameter range layers were then combined in GIS to produce the predicted habitat for each species within an individual county. The final output of predicted habitat was limited to the subset of areas that were spatially within the range of all combined habitat parameters. We also evaluated and tracked the extent of predicted habitat for each parameter individually to assess the relative contribution of each parameter towards the final predicted habitat mapping.

### 2.6 Calculation of Extant Predicted Habitat

The acreage of extant predicted habitat in 2005 and 2010 for each study species by county was determined by overlaying the respective 2005 and 2010 mapped vernal pool habitat polygons over the final predicted habitat layer and calculating the acreage of predicted habitat within the polygons. Thus, the extant predicted species habitat was a subset of the larger mapped extant vernal pool habitat polygons. This approach assumes that the extant predicted species habitat is limited to areas where vernal pools still exist since all of the study species are essentially vernal pool endemics. The loss of predicted habitat from 2005 to 2010 was calculated by simple subtraction.
The extant vernal pool habitat polygons used as the basis for analysis were mapped as a parallel effort to our study (Witham et al. 2013) and are the most precise that are currently available on a county-wide basis. The mapping was completed remotely using 2005 NAIP aerial imagery and other sources to identify the extent of remaining vernal pool habitat as of 2005. The 2005 mapped polygons were then reviewed in relation to 2010 NAIP aerial imagery in selected counties to determine the extent of remaining habitat in 2010 and identify areas where habitat had been lost. There was also some ‘created’ habitat added from 2005 to 2010 due to the creation of wetlands within mitigation banks. The remote mapping was ground-truthed via ‘windshield surveys’ throughout the study area to produce the final vernal pool habitat mapping.

3.0 RESULTS

3.1 Predicted Habitat Mapping

Figures 4-A and 4-B show the predicted habitat maps for *L. packardi* and *C. campestris* ssp. *succulenta*, respectively, as representative examples. Each figure also includes a map based on Holland and Hollander’s (2007) study for comparison. Appendix A presents the full set of maps for all species by county. These maps show the unique contributions of the climate parameters and low slope continuity to the predicted habitat maps since these parameters have important and unique effects as discussed below. Appendix C presents a set of small multiple maps for each species and county showing the distribution of predicted habitat by individual habitat parameter. These maps allow the reader to see the contribution of each parameter to the final predicted habitat map.

Among the study’s large branchiopod species, *B. lynchi* has the most extensive predicted habitat, *L. packardi* has an intermediate extent of predicted habitat, and *B. mesovallensis* has the least extensive predicted habitat. This correlates with the abundance and distribution of known occurrences of these species as well as their natural history characteristics which translates into the range values of the habitat parameters used to map the extent of predicted habitat (Table 2). The predicted habitat for *C. campestris* ssp. *succulenta* is restricted to eastern Merced County where it is correlated with specific landforms and soil types that occur in this region. The unique contributions of low slope continuity and climate parameters in excluding areas as predicted habitat maps are shown since they have important effects as discussed below. Appendix B presents a series of small multiple maps by species and county showing the individual contribution of each of the habitat parameter towards the final predictive habitat maps.

3.1.1 Branchinecta lynchi

*Branchinecta lynchi* occurs on a broad range of landscape settings and soils where vernal pools exist. This lack of terrain preference is reflected in the much greater number of documented occurrences (Table 2) and the more extensive predicted habitat for the species as compared to either *B. mesovallensis* or *L. packardi*. *B. lynchi* has slope and elevation range values that well exceed the other two species and also occupies a much greater number of soil series and phases (Tables 2 and 3). It also occurs extensively in all three study counties.

The predicted habitat for *B. lynchi* based on soil, slope and elevation generally includes all low-gradient slopes with geologic surfaces and associated soils that tend to support vernal pools (Figures A-1 through A-3 in Appendix A). Areas excluded as predicted habitat based on these parameters are simply areas that tend not to support vernal pools. These areas include moderate to steep slopes, bottomlands prone to prolonged or regular flooding (central Merced County along the San Joaquin River flood basin and deltaic southwest Sacramento County), major stream corridors and their associated floodplains and recent
FIGURE 4-A
Comparison of *Lepidurus packardi*
Predicted Habitat Results, 2007 vs. 2013

Merced County, Central Valley, California

* Holland and Hollander, 2007

Legend
- **Lepidurus packardi**
- Predicted Habitat, All Parameters
- Area Excluded from Predicted Habitat
  - Only by Climate Parameters
- Area Excluded from Predicted Habitat
  - Only by Low Slope Continuity
- Area Excluded from Predicted Habitat by Both Climate Parameters and Low Slope Continuity
- County Boundary
- Highway

*Data Sources: VNL, C. Willham, B. Holland, 2012 | B. Hatime
CNDDB, 01/2012 | Gibson & Skordal | TIGER 2010
GIS/Geography by Jake Schweidel, Jan 2013
Map File: Merced_LEPA_235_A-P_2013-0129.mxd*

Scale: 1:823,680

(1 inch = 13 miles at tabloid layout)
FIGURE 4-B
Comparison of *Castilleja campestris* ssp. *succulenta*
Predicted Habitat Results, 2007 vs. 2013
Merced County, Central Valley, California

**Notes:**
1. 2007 analysis conducted by Holland and Hollander.
4. No habitat limited by climate within county in 2007.
alluvial terraces where vernal pools do not tend to form (Merced River and lower Chowchilla River in Merced County and Sacramento, American and Cosumnes rivers in Sacramento County). Also, most of western Merced County (west of the San Joaquin River) is excluded due to a lack of suitable soils.

Areas excluded as predicted habitat by climate parameters only appear to be mostly arbitrary and erroneous. There are square shaped exclusions in central and southeast Merced County and a large block of excluded habitat along the northeast boundary which do not appear to correlate with any geographic realities. The only potentially meaningful exclusion based on climate may be the westernmost predicted habitat that is excluded by low mean annual precipitation. *B. lynchi* requires some minimum level of annual precipitation to fill the pools it inhabits. It is possible that western Merced County has insufficient rain due to the rain shadow effect of the adjacent Coast Ranges.

### 3.1.2 Branchinecta mesovallensis

*Branchinecta mesovallensis* has the most limited predictive habitat mapping of our three large branchiopod species ([Figures A-4 and A-5 in Appendix A](#)). This is consistent with the species’ occurrence and distribution patterns which are more restricted and sporadic than the other two species. The limited distribution is reflected in the slope and elevation range values and number of associated soil series and phases which are the most restricted compared with the other two large branchiopod species ([Table 2](#)). This species occurs in Merced and Sacramento counties, it does not occur in Placer County.

The predicted habitat based on soil, slope, elevation and low slope continuity is restricted to low-gradient slopes that tend to support vernal pools and that are directly contiguous with the Great Valley basin via a low-gradient slope. Areas excluded as predicted habitat based on these parameters include areas that tend not to support vernal pools as described for *B. lynchi* as well as high terrain areas in the eastern portions of Merced and Sacramento counties that are disjunct from the valley basin by moderate to steep slopes. Also, nearly all of western Merced County (west of the San Joaquin River) is excluded due to a lack of suitable soils. Interestingly, the high terrace terrain in northeast Merced County is not excluded by elevation since there are documented occurrences of the species at a similar elevation in the southeast of the county. Adding low slope continuity excludes the high terrace areas in eastern Merced County but has little unique effect in Sacramento County since the soil parameter already restricts the range in the east to a similar extent. As with *B. lynchi*, areas excluded by climate parameters only appear to be mostly arbitrary and erroneous.

The predictive mapping for *B. mesovallensis* is probably the least accurate or certain among the three large branchiopods given the species’ more limited and sporadic occurrences. There are only a few occurrences west of Highway 99 in Merced County with the one isolated occurrence near the center of the county recorded as ‘non-specific’ in the CNDDB ([Figure A-4 in Appendix A](#)). Some large areas are excluded based on a lack of ‘suitable’ soils but this may be an artifact of insufficient survey data. It also seems that this species could occur on suitable soils in northwest Sacramento County given the short distance to the nearest documented occurrences to the south. However, nearly all vernal pool habitat in this region has been eliminated.

### 3.1.3 Lepidurus packardi

*Lepidurus packardi* has an intermediate extent of predicted habitat mapping in Merced and Sacramento counties as compared to the other two species ([Figures A-6 and A-7 in Appendix A](#)). This is consistent with the known species occurrences, distribution patterns and occupied soil phases which are also intermediate between the other two species. The species is known from only three occurrences in Placer
County, at least one of which is in a created vernal pool. This limited occurrence data is considered too sparse for predictive habitat analysis.

As with *B. mesovallensis*, the predicted habitat based on soil, slope, elevation and low slope continuity is restricted to low-gradient slopes that are contiguous with the Great Valley basin via a low-gradient slope. The predicted habitat is somewhat more extensive than for *B. mesovallensis* since *L. packardi* occupies a broader set of soil series and phases (Tables 3 and 4). Areas excluded as predicted habitat based on these parameters include areas that tend not to support vernal pools as described for *B. lynchi* as well as high terrain areas in the eastern portions of Merced and Sacramento counties that are disjunct from the valley basin by moderate to steep slopes. Predicted habitat in western Merced County (west of the San Joaquin River) is the most extensive for this species due to the large number of occurrences on a range of soil series and phases around the Great Valley basin. The high terrace terrain in northeast Merced County is not excluded by elevation since there are documented occurrences of the species at a similar elevation in the southeast of the county. Adding low slope continuity excludes this area. It also excludes substantial areas in eastern Sacramento County, much more so than for *B. mesovallensis*. Areas excluded by climate parameters only appear to be mostly arbitrary and erroneous.

The predictive habitat mapping for *L. packardi* appears to be generally accurate given the moderate number of fairly well distributed occurrences in both Merced and Sacramento counties used as the basis for analysis. In Merced County, the area west of Highway 99 probably has the least certain mapping for the species for similar reasons as with *B. mesovallensis*. In Sacramento County, there is one documented occurrence in the northwest, bringing this area in as predicted habitat.

### 3.1.4 *Castilleja campestris* ssp. *succulenta*

The large majority (>90%) of the occurrence records for *C. campestris* ssp. *succulenta* in Merced County were collected in a random, stratified manner and can thus be analyzed to identify obvious soil affinities (Dittes and Guardino 2002). While Redding gravelly loam soils are the most common soil type in eastern Merced County, the proportion of *C. campestris* ssp. *succulenta* occurrences on this soil type are roughly double what would be expected if the species was evenly distributed across soil types. The species occurs at the expected level on Amador series soils and occurs much less than expected on the other soil series. Given this, we identified Redding and Amador series soils as the ‘primary’ or preferred substrate and all other soils as a ‘secondary’ or marginal substrate. The soil polygons were constrained by the other habitat parameters to develop the final predicted habitat map (Figure A-8 in Appendix A).

The restricted distribution of *C. campestris* ssp. *succulenta* is reflected in the more restricted slope and elevation range values and number of associated soil series and phases as compared with our other study species (Tables 2 and 3). Since the preferred soils tend to be those of the high terraces, the predicted primary habitat (on Redding and Amador series soils) is concentrated on the high terraces near the eastern edge of the county and along the top and around the base of ‘China Hat Ridge’ in the northeast of the county. Based on our analysis of the available occurrence records, we estimate that roughly 90% of all known occurrences (e.g. individual pools occupied by the species) in Merced County would occur within the primary predicted habitat. Secondary predicted habitat (on other soil series) is distributed along the lower terraces to the west and south and on soils other than Redding and Amador on the high terraces. Both the primary and secondary habitat is constrained to low gradient slopes where vernal pools tend to occur. Elevation is not included as a parameter since it would exclude a small area along the top of China Hat Ridge that has not been surveyed but almost certainly supports the species. Areas excluded as predicted habitat based on soil and slope include the Merced River floodplain, most of the low terrace...
terrain in eastern Merced County and all of western Merced County. As with the other species, areas excluded by climate parameters only appear to be mostly arbitrary and erroneous.

The predictive habitat mapping for *C. campestris ssp. succulenta* is probably the most accurate among our study species since it has strong, specific soil affinities, a fairly localized range and an abundance of high-quality occurrence records within Merced County.

Table 2. Range and mean values of habitat parameters associated with species occurrence records, vernal pool species predictive habitat study.

<table>
<thead>
<tr>
<th>Species/County</th>
<th>No. of Occurrences Used for Analysis</th>
<th>Total No. Soil Phases</th>
<th>Total No. Soil Series</th>
<th>Elevation (ft)</th>
<th>Slope (%)</th>
<th>Low Slope Continuity (% Slope)</th>
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<td>Range</td>
<td>Mean</td>
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1. BRLY = *Branchinecta lynchi*; BRME = *Branchinecta mesovalensis*; LEPA = *Lepidurus packardi*; CACASU = *Castilleja campestris ssp. succulenta*; BRME is not documented in Placer County and LEPA has only three occurrences so no analysis of these species was conducted for the county; CACASU does not occur in Sacramento or Placer counties.

2. There are no values for BRLY and CACASU since the low slope continuity parameter was not applied to these species.
Table 3. Number of species occurrence records by soil phase and series, based on the records used in the analysis, vernal pool species predictive habitat study.

| SOIL PHASE/SERIES (SSURGO 2012) | Number of Occurrence Records
table | BRLY | BRME | LEPA | CACASU |
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Vernal Pool Rare Species Predictive Habitat Mapping Study
USFWS Grant Agreement Number 80270-A-G509

25 Vollmar, Holland, Witham and Schweitzer

January 2013
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<td><strong>All Rocklin Soils</strong></td>
<td><strong>4</strong></td>
</tr>
<tr>
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<tr>
<td><strong>All Seville Soils</strong></td>
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<td><strong>All Snelling Soils</strong></td>
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<td>Waukena loam, strongly saline-alkali, 0 to 1 percent slopes</td>
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<td><strong>Whitey and Rocklin Soils</strong></td>
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<tr>
<td>Whitey and Rocklin soils, 3 to 8 percent slopes, eroded</td>
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<td>Whitey and Rocklin soils, 8 to 15 percent slopes, eroded</td>
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<tr>
<td>Wyman clay loam, 0 to 3 percent slopes</td>
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<td>Yokohl loam, 0 to 3 percent slopes</td>
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<td><strong>Yolo Loam Soils</strong></td>
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<tr>
<td>Yolo loam, 0 to 1 percent slopes</td>
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<tr>
<td>Yolo loam, deep over hardpan, 0 to 1 percent slopes</td>
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<td><strong>TOTAL MERCED COUNTY SOIL PHASES</strong></td>
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**SACRAMENTO COUNTY**

<table>
<thead>
<tr>
<th>SOIL PHASE/SERIES</th>
<th>Number of Occurrence Records²</th>
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<tbody>
<tr>
<td>Amador-Gillender complex, 2 to 15 percent slopes</td>
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</tr>
<tr>
<td>Argonaut-Auburn complex, 3 to 8 percent slopes</td>
<td>1</td>
</tr>
<tr>
<td>Corning complex, 0 to 8 percent slopes</td>
<td>158</td>
</tr>
<tr>
<td>Corning-Redding complex, 8 to 30 percent slopes</td>
<td>2</td>
</tr>
<tr>
<td>Creviscreek sandy loam, 0 to 3 percent slopes</td>
<td>7</td>
</tr>
<tr>
<td>SOIL PHASE/SERIES (SSURGO 2012&lt;sup&gt;1&lt;/sup&gt;)</td>
<td>Number of Occurrence Records&lt;sup&gt;2&lt;/sup&gt;</td>
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<tr>
<td>-------------------------------------------------------------------------------------------------------------</td>
<td>----------------------------------------</td>
</tr>
<tr>
<td></td>
<td>BLY</td>
</tr>
<tr>
<td>Dierssen clay loam, deep, drained, 0 to 2 percent slopes</td>
<td>1</td>
</tr>
<tr>
<td>Fiddyment fine sandy loam, 1 to 8 percent slopes</td>
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</tr>
<tr>
<td>Galt clay, 0 to 2 percent slopes</td>
<td>-</td>
</tr>
<tr>
<td>Hadselville-Pentz complex, 2 to 30 percent slopes</td>
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</tr>
<tr>
<td>Hedge loam, 0 to 2 percent slopes</td>
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<tr>
<td><strong>Hicksville Soils</strong></td>
<td></td>
</tr>
<tr>
<td>Hicksville gravelly loam, 0 to 2 percent slopes, occasionally flooded</td>
<td>2</td>
</tr>
<tr>
<td>Hicksville sandy clay loam, 0 to 2 percent slopes, occasionally flooded</td>
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</tr>
<tr>
<td><strong>All Hicksville Soils</strong></td>
<td>3</td>
</tr>
<tr>
<td>Lithic Xerorthents, 2 to 8 percent slopes</td>
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</tr>
<tr>
<td>Madera loam, 0 to 2 percent slopes</td>
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<td>Madera-Galt complex, 0 to 2 percent slopes</td>
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<tr>
<td>Natomas loam, 0 to 2 percent slopes</td>
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<tr>
<td><strong>Red Bluff Soils</strong></td>
<td></td>
</tr>
<tr>
<td>Red Bluff loam, 0 to 2 percent slopes</td>
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</tr>
<tr>
<td>Red Bluff loam, 2 to 5 percent slopes</td>
<td>1</td>
</tr>
<tr>
<td><strong>All Red Bluff Soils</strong></td>
<td>4</td>
</tr>
<tr>
<td>Red Bluff-Redding complex, 0 to 5 percent slopes</td>
<td>13</td>
</tr>
<tr>
<td>Red Bluff-Xerarents complex, 0 to 2 percent slopes</td>
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<td>Redding gravelly loam, 0 to 8 percent slopes</td>
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<tr>
<td><strong>San Joaquin Soils</strong></td>
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</tr>
<tr>
<td>San Joaquin fine sandy loam, 0 to 3 percent slopes</td>
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</tr>
<tr>
<td>San Joaquin fine sandy loam, 3 to 8 percent slopes</td>
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<tr>
<td>San Joaquin silt loam, 0 to 3 percent slopes</td>
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</tr>
<tr>
<td>San Joaquin silt loam, 3 to 8 percent slopes</td>
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</tr>
<tr>
<td>San Joaquin silt loam, leveled, 0 to 1 percent slopes</td>
<td>1</td>
</tr>
<tr>
<td><strong>All San Joaquin Soils</strong></td>
<td>23</td>
</tr>
<tr>
<td>San Joaquin-Galt complex, 0 to 3 percent slopes</td>
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</tr>
<tr>
<td>San Joaquin-Xerarents complex, leveled, 0 to 1 percent slopes</td>
<td>1</td>
</tr>
<tr>
<td>Tehama loam, 0 to 2 percent slopes</td>
<td>-</td>
</tr>
<tr>
<td>Tinnin loamy sand, 0 to 2 percent slopes</td>
<td>1</td>
</tr>
<tr>
<td>Vleck gravelly loam, 2 to 15 percent slopes</td>
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</tr>
<tr>
<td>Xerarents-Redding complex, 0 to 2 percent slopes</td>
<td>1</td>
</tr>
<tr>
<td>Xerorthents, dredge tailings, 2 to 50 percent slopes</td>
<td>2</td>
</tr>
<tr>
<td>Unassigned</td>
<td>30</td>
</tr>
<tr>
<td><strong>TOTAL SACRAMENTO COUNTY SOIL PHASES</strong></td>
<td>29</td>
</tr>
</tbody>
</table>

**PLACER COUNTY**

|                                                                                                              |       |       |       |       |
| Alamo-Fiddyment complex, 0 to 5 percent slopes                                                             | 3     | N/A   | N/A   | N/A    |
| Cometa sandy loam, 1 to 5 percent slopes                                                                   | 2     | N/A   | N/A   | N/A    |
| Cometa-Fiddyment complex, 1 to 5 percent slopes                                                            | 7     | N/A   | N/A   | N/A    |
| Cometa-Ramona sandy loams, 1 to 5 percent slopes                                                           | 15    | N/A   | N/A   | N/A    |
| Exchequer-Rock outcrop complex, 2 to 30 percent slopes                                                     | 1     | N/A   | N/A   | N/A    |
| Fiddyment-Kaseberg loams, 2 to 9 percent slopes                                                            | 10    | N/A   | N/A   | N/A    |
| Inks-Exchequer complex, 2 to 25 percent slopes                                                             | 1     | N/A   | N/A   | N/A    |
| Kilaga loam                                                                                                | 1     | N/A   | N/A   | N/A    |
### Table 1

<table>
<thead>
<tr>
<th>SOIL PHASE/SERIES (SSURGO 2012)</th>
<th>Number of Occurrence Records²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BRLY</td>
</tr>
<tr>
<td>San Joaquin sandy loam, 1 to 5 percent slopes</td>
<td>20</td>
</tr>
<tr>
<td>San Joaquin-Cometa sandy loam, 1 to 5 percent slopes</td>
<td>13</td>
</tr>
<tr>
<td>Redding and Corning gravelly loam, 2 to 9 percent slopes</td>
<td>1</td>
</tr>
<tr>
<td><strong>Xerofluvents Soils</strong></td>
<td></td>
</tr>
<tr>
<td>Xerofluvents, frequently flooded</td>
<td>1</td>
</tr>
<tr>
<td>Xerofluvents, hardpan substratum</td>
<td>2</td>
</tr>
<tr>
<td><strong>All Xerofluvent Soils</strong></td>
<td></td>
</tr>
<tr>
<td>Unassigned</td>
<td>3</td>
</tr>
<tr>
<td><strong>TOTAL PLACER COUNTY SOIL PHASES</strong></td>
<td>13</td>
</tr>
</tbody>
</table>

1. Soil phases and soil series from SSURGO soil data layer (USDA 2012).
2. Occurrences from California Natural Diversity Data Base records and other additional occurrences gathered during surveys by researchers and consultants; BRLY = Branchinecta lynchii; BRME = Branchinecta mesovallensis; LEPA = Lepidurus packardi; CACASU = Castilleja campestris ssp. succulenta.

### 3.2 Analysis of Extant and Extirpated Predicted Habitat

**Figures 5-A and 5-B** show the extant predicted habitat maps for *L. packardi* and *C. campestris* ssp. *succulenta*, respectively, as representative examples. **Appendix B** presents the full set of extant predicted habitat maps for all species by county. These maps also show the areas where predicted habitat was lost from 2005 to 2010 and areas where predicted habitat was gained due to habitat creation.

All of our study species have experienced a significant loss of historic predicted habitat in all study counties as of 2010 based on an analysis of the historic and extant predicted mapping produced by our study (Table 4). These losses ranged from 64% to 84% for the three large branchiopod species. The percent losses have been higher in Sacramento and Placer County where vernal pool habitats tend to be more concentrated in areas of human disturbance. Merced County habitats have been somewhat protected by the extensive occurrence of significant acreages on more remote ‘high terrace’ landscapes that are more difficult to convert for agriculture or otherwise develop. Overall, *C. campestris* ssp. *succulenta* has experienced the lowest percent loss (54%) since the much of the predicted habitat is concentrated on these high terrace areas. Though not calculated, it is assumed that most of the loss has been of ‘secondary’ habitat on lower terrace areas.

All of our study species also experienced a significant loss of remaining (extant) habitat from 2005 to 2010 based on our calculations (Table 4). These losses ranged from 0.4% to 7.9% for the three large branchiopod species. In this case, the percent losses have been higher in Merced County due to the deep-ripping and conversion of two large areas in the southeast of the county. *C. campestris* ssp. *succulenta* experienced a 5.6% loss, nearly all of which is due to the conversion of the two large areas. All extirpated habitat was classified as ‘secondary’ predicted habitat.

There was also some gain in predicted habitat from 2005-2010 for the three large branchiopod species in Sacramento and Placer counties (Table 4). This was due to the construction of wetlands in mitigation banks (Witham et al. 2013). These gains ranged from 236-712 acres.

The loss of predicted habitat within core vernal pool recovery areas followed similar trends (Table 4). The losses ranged from 0.2% to 6.1% with the highest losses in Merced County due to the conversion of the two large properties.
FIGURE 5-B

Castilleja campestris ssp. succulenta
Status of Predicted Habitat in Merced County
Vernal Pool Species Predictive Habitat Study

Legend
- Castilleja campestris ssp. succulenta
  - Predicted Habitat
    - Extant in 2010 (54,971 ac.)
    - Extant in 2005 (3,250 ac.)
  - Water Body
  - Urban Area
  - County Boundary
  - Highway

Data Sources:
- VNLC, C. Witham, B. Holland, 2012
- B. Helm
- CHDO, 01/2012
- ジッカ & ショット, 1997
- CHDO
- CHDO, 2013

Map File: M:\CA\Extant_205\AP\2013-0110.mxd
Table 4. Calculated acreage of historic, 2005 and 2010 extant predicted habitat stratified by species and county, vernal pool species predicted habitat study. Calculations also include acreage of natural habitat lost from 2005-2010 as well as acreage gained from 2005-2010 due to creation of wetlands within mitigation banks in Sacramento and Placer counties. Data compiled by Vollmar Natural Lands Consulting, Berkeley, CA.

<table>
<thead>
<tr>
<th>Species/County</th>
<th>Total Historic Predicted Habitat (acres)</th>
<th>2005 Predicted Extant Habitat (acres)</th>
<th>2010 Predicted Extant Habitat (acres)</th>
<th>Historic-2010 % Loss of Predicted Habitat</th>
<th>2005-2010 Loss of Predicted Extant Habitat (acres)</th>
<th>2005-2010 Loss of Predicted Extant Habitat (%)</th>
<th>2005 Predicted Habitat within Vernal Pool Core Recovery Areas (acres)</th>
<th>2005-2010 Loss of Predicted Habitat within Vernal Pool Core Recovery Areas (acres/%)</th>
<th>2005-2010 Created Habitat (acres)</th>
</tr>
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<tbody>
<tr>
<td>BRLY</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Merced</td>
<td>407,364</td>
<td>110,737</td>
<td>105,515</td>
<td>74%</td>
<td>5,222</td>
<td>4.7%</td>
<td>87,462</td>
<td>3,740 (4.3%)</td>
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<tr>
<td>Sacramento</td>
<td>268,437</td>
<td>55,724</td>
<td>53,914</td>
<td>80%</td>
<td>1,810</td>
<td>3.2%</td>
<td>38,731</td>
<td>1,128 (2.9%)</td>
<td>712</td>
</tr>
<tr>
<td>Placer</td>
<td>115,433</td>
<td>28,581</td>
<td>27,937</td>
<td>76%</td>
<td>644</td>
<td>2.3%</td>
<td>20,803</td>
<td>378 (1.8%)</td>
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<tr>
<td>BRME</td>
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<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Merced</td>
<td>183,202</td>
<td>60,887</td>
<td>56,057</td>
<td>69%</td>
<td>4,830</td>
<td>7.9%</td>
<td>55,519</td>
<td>3,390 (6.1%)</td>
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<tr>
<td>Sacramento</td>
<td>87,964</td>
<td>14,433</td>
<td>14,254</td>
<td>84%</td>
<td>179</td>
<td>1.2%</td>
<td>8,921</td>
<td>52 (0.6%)</td>
<td>236</td>
</tr>
<tr>
<td>Placer³</td>
<td>-</td>
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<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Merced</td>
<td>235,117</td>
<td>88,564</td>
<td>83,733</td>
<td>64%</td>
<td>4,831</td>
<td>5.5%</td>
<td>59,911</td>
<td>3,365 (5.6%)</td>
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<tr>
<td>Sacramento</td>
<td>199,769</td>
<td>41,702</td>
<td>41,537</td>
<td>79%</td>
<td>165</td>
<td>0.4%</td>
<td>28,046</td>
<td>52 (0.2%)</td>
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<tr>
<td>Placer³</td>
<td>-</td>
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<td>Merced</td>
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<td>58,221</td>
<td>54,971</td>
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<td>3,250</td>
<td>5.6%</td>
<td>57,354</td>
<td>3,198 (5.6%)</td>
<td>-</td>
</tr>
</tbody>
</table>

1. BRLY = Branchinecta lynchi; BRME = Branchinecta mesovalensis; LEPA = Lepidurus packardi; CACASU = Castilleja campestris ssp. succulenta.
2. Represents the acreage of predicted habitat under natural, historic conditions prior to European arrival and subsequent land conversions.
3. BRME does not occur in Placer County.
4. LEPA has only three known occurrences in Placer County, at least one of which is introduced. No analysis conducted given the sparse number of occurrence records.
4.0 DISCUSSION

4.1 Evaluation of Refined Predicted Habitat Mapping

A comparison of the predicted habitat maps from our study with those from Holland and Hollander’s original study (Appendix A) clearly demonstrate that our more refined approach resulted in much more refined predicted habitat mapping. The main factors that appear to be driving the refinements are as follows:

1) County-scale Focus - The original study used range-wide occurrence records for a given species which tended to over-exaggerate the range of habitat parameters in a local area. For our study, we analyzed each species on a county scale using only the occurrence records from the county, which appeared to tailor the final predictive habitat maps much more accurately to the local area. This meant that all the habitat parameters, especially soil, elevation and low slope continuity had ranges specific to the local area.

2) Occurrence Data - The original study used only CNDDB occurrence records while we obtained abundant additional occurrence records. Though we did no formal analysis of the effects, these additional occurrence records likely improved the capacity to develop more accurate predictive habitat maps on a local scale, especially when they included new records that expanded the local range of the species related to occupied soil phases, slope and elevation. It would be a worthwhile future exercise to compare the extent of predicted habitat mapping using only CNDDB data versus the combined data used for our study. If the improvement is not significant, future predictive mapping efforts could use only available CNDDB data which would save significant time and cost required for preparing the baseline dataset.

3) Soil Data - The STATSGO data used by the original study are fairly coarse, often leading to significant over-mapping of predicted soils on a local scale (Figure 3). The more detailed and precise SSURGO soil data that we used greatly refined and tailored the predicted soil layer in a manner that appeared to more accurately reflect the distribution of suitable soils for our species.

4) Low Slope Continuity – This parameter was developed for the current study to address the apparent association of two of the study species (B. mesovallensis and L. packardi) with low-gradient terrain contiguous with the Great Valley basin. This parameter proved to be very effective in refining predicted habitat for these species along the eastern edge of the range. Also, this was the only parameter that excluded the high terrace habitats in northeastern Merced County and eastern Sacramento County (where the species are not known or expected to occur) if the climate parameters were not used.

Beyond a simple comparison with Holland and Hollander maps, we believe that our final predicted habitat maps are fairly to quite accurate for the study species and counties. This assessment is based on our knowledge of the geography of the study areas, ecology and known distribution of the study species, and extent and results of surveys that have been conducted for these species. The accuracy of predicted habitat mapping likely varied among the species based on differences in autecology and other factors as discussed above. C. campestris ssp. succulenta probably has the most accurate predicted habitat mapping among our study species since it has strong, specific soil affinities, a fairly localized range and an abundance of high-quality occurrence records within Merced County. B. mesovallensis probably has the least accurate mapping since it has the most limited and sporadic occurrences and less apparent habitat affinities.
We found that soil, slope and elevation, as well as low slope continuity for *B. mesovallensis* and *L. packardi*, were the parameters that most accurately defined the predicted habitat mapping for each species. In contrast, the climate parameters did not appear to function well for defining predicted habitat on a county scale and in fact often appeared to introduce arbitrary and erroneous exclusions or additions. Our final predicted habitat maps (Appendix B) were produced using only these parameters except for *B. mesovallensis* in Sacramento County. This county represents the species’ northeastern edge of range where climate parameters may have an important local effect.

Numerous studies have correlated the distribution of vernal pools as well as vernal pool endemic species with specific geologic surfaces and their associated soils (Dittes and Guardino 2002, Helm and Vollmar 2002b, Metz 2001, Holland and Dains 1990). This soil-species association was a basic premise in Holland and Hollander’s (2007) study and continued to be a premise for our study.

Slope is an obvious controlling factor in the distribution of vernal pools since they are concentrated on relatively flat slopes where pool basins can form and hold water. Our study species, being essentially vernal pool endemics, are also strongly associated with relatively flat slopes.

Elevation functioned well on a county scale for defining predicted habitat since all of the study counties have a general east to west gradient with the highest areas along the base of the Sierra Nevada foothills in the east and the lowest areas toward the basin of the Great Valley in the west. The one confounding feature was ‘China Hat Ridge’ in northeastern Merced County which extends out roughly ten miles west-southwest from the eastern county boundary. The top of this ridge has an elevation roughly equal to the highest areas along the eastern county boundary, disrupting the typical east-west gradient. As a result, there were limited areas along highest portion of the ridge excluded as predicted habitat by elevation which support vernal pools and almost certainly support two of the study species (*B. lynchi* and *C. campestris* ssp. *succulenta*). This anomaly points to the need to carefully assess the topography and geography of a study area before applying elevation as a parameter for predicted habitat.

Low slope continuity was an important added parameter that excluded significant areas where *B. mesovallensis* and *L. packardi* are not known or expected to occur but otherwise would have been included as predicted habitat using the soil, slope and elevation parameters. The value of this parameter points to the importance of carefully considering the ecology of the individual species being treated and developing novel habitat parameters as appropriate to refine the predicted habitat mapping.

### 4.2 Accuracy of Calculated Extant Predicted Habitat

Given the apparent accuracy of the final predicted habitat maps for all the study species, we believe that the calculated acreages of both historic and extant predicted habitat for each species and county are also reasonably accurate. The quality of these data was enhanced by the quality of the vernal pool habitat mapping produced as a parallel effort to this study (Witham et al. 2013). Also, they allowed accurate calculation of the acreage of predicted habitat that was lost (or gained due to vernal pool creation) from 2005 to 2010. Since the accuracy of predictive mapping of *B. mesovallensis* is likely the least certain, the accuracy of its calculated extant habitat is also the least certain. As an example, Figure B-3 in Appendix B shows a large of block of ‘predicted’ habitat that was eliminated between 2005 and 2010 in southeast Merced County. Given the lack of documented occurrences in the vicinity, it is fair to say that it is uncertain if this area was actually occupied by the species. Calculations of extant habitat for *C. campestris* ssp. *succulenta* are probably the most certain and accurate given the species’ strong soil and slope affinities, both of which can be accurately mapped.
4.3 Application of Predictive Habitat Mapping Method to Other Rare Vernal Pool Species

While this study approach proved to be fairly accurate at predicting habitat for the species we selected, it is less clear whether it would function equally well for the full suite of rare vernal pool species in California. Our four study species all have a relatively large number of documented occurrences and fairly clear landscape affinities that make them amenable to reasonably accurate predictive mapping. However, many other vernal pool species have limited occurrence data available and less apparent soil or landscape affinities. One example is *Branchinecta longiantenna* (longhorn fairy shrimp) which is only known from a few widely dispersed locations with very different microhabitat characteristics including sandstone rock pools near Livermore (eastern Contra Costa County), alkaline grassland pools within basin rim formations in central Merced County, and alkali pools within alkali sink scrub habitat on the Carrizo Plain. Another example is *Legenere limosa* (legenere) which is known from only 52 widely scattered extant occurrences on a variety of landforms and soils distributed across the central and northern Great Valley and the Central Coast Ranges (USFWS 2005). Nonetheless, in looking over the list of species included in the Vernal Pool Ecosystem Recovery Plan (USFWS 2005), we think that reasonably accurate predictive mapping could be developed for a majority of these species due to their known affinities for specific soils, distinct pool types, and other remotely discernible characteristics. It also seems that the method presented and refined in our study, building on previous efforts by Holland and Hollander (2007), is by far the best currently available approach to undertake such predictive mapping. As such, we recommend that it be applied to additional rare species to improve the capacity for effective conservation planning and species recovery. Also, applying our method to additional species inhabiting different microhabitats than those of our study species would likely lead to more refinements and improvements of the approach.

5.0 SUMMARY AND CONCLUSIONS

We believe our study was successful in refining a method for developing predicted habitat mapping that is sufficiently precise and can be used for conservation planning and recovery for rare vernal pool species on a county scale. To our knowledge, this is the first time such a level of accuracy has been achieved on this scale and as such we believe this study represents a major step forward in the use of remote analysis for the conservation and recovery of rare vernal pool species. We also believe our study was able to produce reasonably accurate calculations of the acreage of both historic and remaining extant predicted habitat for our study species based on the quality of the predictive habitat mapping along with vernal pool habitat mapping developed as a parallel component to our study (Witham et al. 2013). The specific methods that we used to develop the predictive habitat maps are described in detail in the Methods section of this report. The specific steps involved are also summarized in sequential order in Appendix D for those interested in applying our method to other rare vernal pool species.

Based on its presumed level of accuracy, the predicted habitat mapping produced for our study species can be directly used for regional conservation planning and species recovery in the study areas. The final mapping layers can be incorporated into datasets used by government agencies, non-profit land conservation groups and others to identify and protect key remaining habitat areas. USFWS can also use these data to assess the historic and current status of the species in the study areas as a basis for assessing recovery status and actions that are needed to assure the long-term survival of each species. The extant predicted habitat polygons mapped in Placer and Sacramento counties, and west of Highway 99 in Merced County demonstrate the limited extent of remaining habitat in these areas as priorities for conservation.
The methods used in our study can be readily extended to develop predicted habitat maps for our study species in other counties. The main effort required would be to obtain and vet species occurrence records using the methods outlined in this study. After that, the actual analysis is a relatively straightforward process that can be conducted by a reasonably proficient GIS analyst. Extending the study methods to other species needs to be more carefully considered and should include consultation with experts that have knowledge of the target species and counties. Each species has its own unique ecology and distribution patterns that should be considered when identifying and applying habitat parameters towards developing final predicted habitat maps. USFWS should consider funding additional work to produce predictive mapping for other rare vernal pool species. The recommended approach would be to select additional species within the counties included in this study since data on the habitat parameters are already compiled. The selected species should have ecological and occurrence characteristics that are different from the species included in this study to test the limitations of the predictive mapping methods under different circumstances.

6.0 SUMMARY OF STUDY EXPENDITURES

A final financial report using Form SF-425 has been prepared and submitted along with the final report for this project.

7.0 RAW DATA AND ANALYTIC TOOLS

Along with this written report to USFWS, we provided all of the GIS data processed, as depicted on the report map figures. These data include the following GeoDatabase feature files:

1. Species occurrence point data, separated by species as well as by county. These data represent a combination of CNDDDB data and data provided by several environmental consultants. The data have been evaluated and coded according to relative accuracy based on CNDDDB coding as well careful inspection of each point with respect to aerial photography, slope, and other reference information. These data are depicted on all of the maps throughout the report.

2. Raw “predictive habitat” polygon data based on species occurrences habitat parameter ranges for each county. For example, elevation values throughout Merced County that fall within the minimum and maximum values of documented *B. lynchi* occurrences. All of the various habitat parameters (elevation, slope, climate, soils) for each species in each county are combined into a single GeoDatabase. Since the raw data for many of these datasets were in ESRI GRID format (e.g., DEMs and climate data), the attribute values are typical binary GRID values (i.e., 1 for cells within the species range, and 0 for no-data cells). These datasets are depicted in Appendix C using definition queries to show single parameters.

3. Predicted habitat polygon data, produced by clipping and classifying the polygon data described in “2” above. The data were clipped and classified according to vernal pool habitat status (extant versus extirpated vernal pool landscape in 2005 and 2010). The data were clipped using the polygons described below in “4.” The results of the clipping and classification are in Figures B-1 through B-7.

4. Extant vernal pool habitat polygon data, coded according to relative vernal pool cover, level of disturbance, and other descriptive information. The polygons were digitized from 2005 and 2010 USDA NAIP 1-meter pixel resolution aerial photography. Vernal pool habitat was digitized in all
counties in the Central Valley for 2005, but only for the three targeted counties for 2010. The 2005 data are depicted on Figure 1-A and Figure 1-B. The 2010 data were used to produce clip and classify the predicted habitat data described above in “3.” All polygons were clipped at county boundaries using statewide county data distributed by the Gap Analysis Project (1998) (included with final clipped predicted habitat data). The results of the clipping and classification are in Figures B-1 through B-7.

5. Predicted habitat polygon data for each species that has been extirpated within Vernal Pool Core Recovery Areas between 2005 and 2010. The polygons were produced by clipping the publically distributed 2005 Vernal Pool Core Recovery Area dataset with the features representing predicted habitat areas extirpated between 2005 and 2010. These data are not depicted on map figures, but the statistics are provided in Table 4.

All data conform to the following planer projection system: Teal Albers, Datum: NAD83, Units: Meters.

All data were processed using ESRI ArcGIS versions 10.1 and 9.3, with the Spatial Analyst extension grid used for processing raster data.

Complete FGDC-compliant metadata are included for all data produced primarily by VNLC or by Dr. Robert Holland and Carol Witham. The metadata files also reference maps which depict each dataset. Metadata for all other constituent data (e.g., CNDDB, USGS DEMs, USDA Soils, PRISM climate, Vernal Pool Core Recovery Areas, and Gap Analysis Project) are available on the Internet at the respective organization websites. The metadata are provided in XML format and were edited using ArcCatalog (ArcMap) version 9.3.

8.0 PROBLEMS ENCOUNTERED DURING THE STUDY

In our original study design, we proposed a process for developing the predictive habitat maps that involved producing initial mapping using available species occurrence records, conducting ground-truthing to determine actual presence or absence of species in predicted habitat areas with no previously documented occurrences, and then preparing the final predicted habitat maps based on the results of the ground-truthing. However, once we began our study, we found that many areas that we targeted for ground-truthing had in fact already been surveyed but the results had not yet been submitted or incorporated into the CNDDB. We thus changed our study design and gathered these occurrence data in lieu of conducting extensive ground-truthing. We did conduct some field surveys for our study species in areas with predicted habitat that were outside the apparent range of known occurrences. Additional occurrences documented during these surveys were incorporated into the set of species occurrence records used for our analyses. We did not encounter any other significant problems or issues during the course of our study.
9.0 REFERENCES

California Natural Diversity Database (CNDDB). 2012. Rare species occurrence records from Merced, Sacramento and Placer counties, California. California Department of Fish and Game, Sacramento, CA.


Helm, B. Personal Communication. President and Senior Ecologist, Helm Biological Consulting and recognized California vernal pool shrimp expert, Sheridan, CA. 2012.


Appendix A

Predicted Habitat Maps,
2007 and 2013 Study Comparison
FIGURE A-1
Comparison of Branchinecta lynchii
Predicted Habitat Results, 2007 vs. 2013
Merced County, Central Valley, California

Legend
- Branchinecta lynchii
- Predicted Habitat, All Parameters
- Area Excluded from Predicted Habitat by Climate Parameters
- County Boundary
- Highway

* Holland and Hollander, 2007

Data Sources:
- VNL C. Wilham, B. Holland, 2012
- B. Helm, C. Wilham, B. Holland, 2012
- CNDDB, 01/2012
- Gibson & Skordal TIGER 2010
- Wetlands USGS, Various, Gap 1998
- DWR, 2001
- GIS/Geography by J. L. Schwitzer, Jan 2013
- Map File: Merced-BRLY_235_A-P_2013-0129.mxd

1:823,680
(1 inch = 13 miles at tabloid layout)
FIGURE A-2
Comparison of *Branchinecta lynchii*
Predicted Habitat Results, 2007 vs. 2013
Sacramento County, Central Valley, California

**Legend**
- Branchinecta lynchii
- Predicted Habitat, All Parameters
- Area Excluded from Predicted Habitat by Climate Parameters
- County Boundary
- Highway

* Holland and Hollander, 2007

Data Sources:
- VMCL, C. Wilham, B. Holland, 2012
- B. Helm CNCCB, 01/2012
- Gibson & Skordal TIGER 2010
- G&SC Artboard by Jake Schweitzer Jan 2013
Map File: Sac-IRL_v_235_A-P_2013-0126.mxd
FIGURE A-4
Comparison of *Branchinecta mesovallensis*
Predicted Habitat Results, 2007 vs. 2013
Merced County, Central Valley, California

* Holland and Hollander, 2007
FIGURE A-5
Comparison of Branchinecta mesovallensis Predicted Habitat Results, 2007 vs. 2013
Sacramento County, Central Valley, California

Legend
- Branchinecta mesovallensis
- Green: Predicted Habitat, All Parameters
- Yellow: Area Excluded from Predicted Habitat Only by Climate Parameters
- Orange: Area Excluded from Predicted Habitat Only by Low Slope Continuity
- Red: Area Excluded from Predicted Habitat by Both Climate Parameters and Low Slope Continuity
- Blue: County Boundary
- Gray: Highway

* Holland and Hollander, 2007

Data Sources:
- VNL, C. William C. Holland, 2012 | B. Helmin
- CNCCB, 11/2012 | Gibson & Skordal | TIGER 2010
- GIS Data by Jake Schiessler, Jan 2013

Map File: Sac-BRME_23R_A-P_2013-0129.mxd

Scale: 1:23,680

(1 inch = 13 miles at tabloid layout)
FIGURE A-7
Comparison of Lepidurus packardi
Predicted Habitat Results, 2007 vs. 2013
Sacramento County, Central Valley, California

Legend
- Lepidurus packardi
- Green: Predicted Habitat, All Parameters
- Yellow: Area Excluded from Predicted Habitat Only by Climate Parameters
- Orange: Area Excluded from Predicted Habitat Only by Low Slope Continuity
- Red: Area Excluded from Predicted Habitat by Both Climate Parameters and Low Slope Continuity
- County Boundary
- Highway
- Extent of Primary Maps

* Holland and Hollander, 2007

Data Sources:
- NLCD, 2011
- B. Hahn CNDD, 01/2012
- Gibson & Skordal | TIGER 2010
- GSCI cartography by Jake Schneider, Jan 2013
- Map files: Sac-LHDA_735_A-P_2013-0129.mxd

1:823,680
(1 inch = 13 miles at tabloid layout)
FIGURE A-8
Comparison of *Castilleja campestris* ssp. *succulenta*
Predicted Habitat Results, 2007 vs. 2013

Merced County, Central Valley, California

Notes:
1. 2007 analysis conducted by Holland and Hollander.
4. No habitat limited by climate within county in 2007.
Appendix B

2005 and 2010 Extant Predicted Habitat Maps (2013 Study)
**FIGURE B-1**

*Branchinecta lynchii*

Status of Predicted Habitat in Merced County

Vernal Pool Species Predictive Habitat Study

1:633,600

(1 inch = 10 miles at tabloid layout)
FIGURE B-3

Branchinecta mesovallensis
Status of Predicted Habitat in Merced County

Vernal Pool Species Predictive Habitat Study

Data Sources: VNL, C. Wham, B. Holland, 2012 | B. Heim
CDOTB, 01/2012 | Gibson & Sokoloff | TIGER 2010
Wetlands/LCPC, Vernal Pool, 1984 | SWP, 2001
GIS/ Cartography by Jake Schwarzer, Jan. 2013
Map File: Mer-BRME-Extant_2354_A+P_2013-0130.mxd
FIGURE B-5
Lepidurus packardi
Status of Predicted Habitat in Merced County
Vernal Pool Species Predictive Habitat Study

Legend
- Lepidurus packardi
  Predicted Habitat
  Extant in 2010 (83,733 ac.)
- Predicted Habitat, Extant in 2005
  Extrapolated as of 2010 (4,831 ac.)
- Predicted Habitat, Extrapolated as of 2005 and 2010 (146,553 ac.)
- Water Body
- Urban Area
- County Boundary

Data Sources: VNL, C. Wilham, B. Holland, 2013 | B. Helm
CNIDOT, 01/2012 | Gibson & Skordal | TIGER 2010
Wavelenit, USGS, Various (Map, 1984) | NR, 2001
GIS/Cartography by Jake Schweitzer, Jan. 2013
Map File: Mer-LEPA-Extant_235_A-P_2013-0730.mxd

Scale: 1:633,600
(1 inch = 10 miles at tabloid layout)

Legend of Elevation (NGVD Feet):
- >10,000
- 7,500 - 10,000
- 5,000 - 7,500
- 2,500 - 5,000
- 1,000 - 2,500
- 900 - 1,000
- 800 - 900
- 700 - 800
- 600 - 700
- 500 - 600
- 400 - 500
- 300 - 400
- 200 - 300
- 100 - 200
- 0 - 100
FIGURE B-6
Lepidurus packardi
Status of Predicted Habitat in Sacramento County
Vernal Pool Species Predictive Habitat Study

Legend
- Lepidurus packardi
- Predicted Habitat Extant in 2010 (41,537 ac.) (not including created habitat)
- Predicted Habitat Extant in 2005
- Extirpated as of 2010 (165 ac.)
- Predicted Habitat, Created Between 2005 and 2010 (303 ac.)
- Predicted Habitat, Extirpated as of 2005 and 2010 (158,067 ac.)
- Water Body
- Urban Area
- County Boundary

Note: No occurrences within Placer County
FIGURE B-7
Castilleja campestris ssp. succulenta
Status of Predicted Habitat in Merced County
Vernal Pool Species Predictive Habitat Study

Legend
- Castilleja campestris ssp. succulenta
- Predicted Habitat
  Extant in 2010 (54,971 ac.)
  Extant in 2005
  Extirpated as of 2010 (3,250 ac.)
- Predicted Habitat, Extirpated as of 2005 and 2010 (60,770 ac.)
- Water Body
- Urban Area
- County Boundary
- Highway

Data Sources: VNL/C. Witham, B. Holland, 2012 | B. Helm
CNDDB, 012/2012 | Gibson & Skordal (TIGER, 2010)
GIS Cartography by Jane Schreiber Jan 2013
Map File: M:GACA/Extant_235_A/L_20130130.mxd
Appendix C

Small Multiple Maps of the Predicted Habitat of Individual Parameters, stratified by County and Species (2013 Study)
Figure A-1-1: Merced County Branchinecta lynchii
Predicted Habitat Based on Mean Annual Precipitation

Figure A-1-2: Merced County Branchinecta lynchii
Predicted Habitat Based on Mean January Minimum Daily Temperature

Figure A-1-3: Merced County Branchinecta lynchii
Predicted Habitat Based on Mean July Maximum Daily Temperature

Figure A-1-4: Merced County Branchinecta lynchii
Predicted Habitat Based on Mean July Precipitation

Figure A-1-5: Merced County Branchinecta lynchii
Predicted Habitat Based on Relative Summer Humidity

Figure A-1-6: Merced County Branchinecta lynchii
Predicted Habitat Based on All Climate Variables
Figure A-1-7: Merced County Branchinecta lynchii Predicted Habitat Based on Elevation

Figure A-1-8: Merced County Branchinecta lynchii Predicted Habitat Based on Soils

Figure A-1-9: Merced County Branchinecta lynchii Predicted Habitat Based on Slope

Figure A-1-10: Merced County Branchinecta lynchii Predicted Habitat Based on All Variables

Figure A-1-11: Merced County Branchinecta lynchii Mapped Soil Series Coverage Comparison

*Note: STATSGO mapped soils underlie nearly all SSURGO mapped soils. SSURGO mapped soil series underlie all SSURGO mapped soil types. Dark brown polygons show areas where STATSGO soil data extend beyond SSURGO data. Medium brown polygons show areas where SSURGO soil series data extend beyond SSURGO soil type data.
Figure A-2-1: Merced County Branchinecta mesovallensis Predicted Habitat Based on Mean Annual Precipitation

Figure A-2-2: Merced County Branchinecta mesovallensis Predicted Habitat Based on Mean January Minimum Daily Temperature

Figure A-2-3: Merced County Branchinecta mesovallensis Predicted Habitat Based on Mean July Maximum Daily Temperature

Figure A-2-4: Merced County Branchinecta mesovallensis Predicted Habitat Based on Mean July Precipitation

Figure A-2-5: Merced County Branchinecta mesovallensis Predicted Habitat Based on Relative Summer Humidity

Figure A-2-6: Merced County Branchinecta mesovallensis Predicted Habitat Based on All Climate Variables
Figure A-3-1: Merced County *Lepidurus packardi* Predicted Habitat Based on Mean Annual Precipitation

Figure A-3-2: Merced County *Lepidurus packardi* Predicted Habitat Based on Mean January Minimum Daily Temperature

Figure A-3-3: Merced County *Lepidurus packardi* Predicted Habitat Based on Mean July Maximum Daily Temperature

Figure A-3-4: Merced County *Lepidurus packardi* Predicted Habitat Based on Mean July Precipitation

Figure A-3-5: Merced County *Lepidurus packardi* Predicted Habitat Based on Relative Summer Humidity

Figure A-3-6: Merced County *Lepidurus packardi* Predicted Habitat Based on All Climate Variables
Figure A-4-1: Merced County *Castilleja campestris* ssp. *succulenta* Predicted Habitat Based on Mean Annual Precipitation

Figure A-4-2: Merced County *Castilleja campestris* ssp. *succulenta* Predicted Habitat Based on Mean January Minimum Daily Temperature

Figure A-4-3: Merced County *Castilleja campestris* ssp. *succulenta* Predicted Habitat Based on Mean July Maximum Daily Temperature

Figure A-4-4: Merced County *Castilleja campestris* ssp. *succulenta* Predicted Habitat Based on Mean July Precipitation

Figure A-4-5: Merced County *Castilleja campestris* ssp. *succulenta* Predicted Habitat Based on Relative Humidity

Figure A-4-6: Merced County *Castilleja campestris* ssp. *succulenta* Predicted Habitat Based on All Climate Variables
**Figure A-4-7:** Merced County *Castilleja campestris* ssp. *suculenta* Predicted Habitat Based on Elevation

**Figure A-4-8:** Merced County *Castilleja campestris* ssp. *suculenta* Predicted Habitat Based on Soils

**Figure A-4-9:** Merced County *Castilleja campestris* ssp. *suculenta* Predicted Habitat Based on Slope

**Figure A-4-10:** Merced County *Castilleja campestris* ssp. *suculenta* Predicted Habitat Based on All Variables

**Figure A-4-11:** Merced County *Castilleja campestris* ssp. *suculenta* Mapped Soil Series Coverage Comparison

*Note: STATSGO mapped soils underlie nearly all SSURGO mapped soils. SSURGO mapped soil series underlie all SSURGO mapped soil types. Dark brown polygons show areas where STATSGO soil data extend beyond SSURGO data. Medium brown polygons show areas where SSURGO soil series data extend beyond SSURGO soil type data.*
Figure B-1-1: Sacramento County Branchinecta lynchi
Predicted Habitat Based on Mean Annual Precipitation

Figure B-1-2: Sacramento County Branchinecta lynchi
Predicted Habitat Based on Mean January Minimum Daily Temperature

Figure B-1-3: Sacramento County Branchinecta lynchi
Predicted Habitat Based on Mean July Maximum Daily Temperature

Figure B-1-4: Sacramento County Branchinecta lynchi
Predicted Habitat Based on Mean July Precipitation

Figure B-1-5: Sacramento County Branchinecta lynchi
Predicted Habitat Based on Relative Summer Humidity

Figure B-1-6: Sacramento County Branchinecta lynchi
Predicted Habitat Based on All Climate Variables
Figure B-1-7: Sacramento County *Branchinecta lynchi* Predicted Habitat Based on Elevation

Figure B-1-8: Sacramento County *Branchinecta lynchi* Predicted Habitat Based on Soils

Figure B-1-9: Sacramento County *Branchinecta lynchi* Predicted Habitat Based on Slope

Figure B-1-10: Sacramento County *Branchinecta lynchi* Predicted Habitat Based on All Variables

Figure B-1-11: Sacramento County *Branchinecta lynchi* Mapped Soil Series Coverage Comparison

*Note: STATSGO mapped soils underlie nearly all SSURGO mapped soils. SSURGO mapped soil series underlie all SSURGO mapped soil types. Dark brown polygons show areas where STATSGO soil data extend beyond SSURGO data. Medium brown polygons show areas where SSURGO soil series data extend beyond SSURGO soil type data.*
Figure B-2-1: Sacramento County Branchinecta mesovalensis Predicted Habitat Based on Mean Annual Precipitation

Figure B-2-2: Sacramento County Branchinecta mesovalensis Predicted Habitat Based on Mean January Minimum Daily Temperature

Figure B-2-3: Sacramento County Branchinecta mesovalensis Predicted Habitat Based on Mean July Maximum Daily Temperature

Figure B-2-4: Sacramento County Branchinecta mesovalensis Predicted Habitat Based on Mean July Precipitation

Figure B-2-5: Sacramento County Branchinecta mesovalensis Predicted Habitat Based on Relative Summer Humidity

Figure B-2-6: Sacramento County Branchinecta mesovalensis Predicted Habitat Based on All Climate Variables
Figure B-3-1: Sacramento County *Lepidurus packardi* Predicted Habitat Based on Mean Annual Precipitation

Figure B-3-2: Sacramento County *Lepidurus packardi* Predicted Habitat Based on Mean January Minimum Daily Temperature

Figure B-3-3: Sacramento County *Lepidurus packardi* Predicted Habitat Based on Mean July Maximum Daily Temperature

Figure B-3-4: Sacramento County *Lepidurus packardi* Predicted Habitat Based on Mean July Precipitation

Figure B-3-5: Sacramento County *Lepidurus packardi* Predicted Habitat Based on Relative Summer Humidity

Figure B-3-6: Sacramento County *Lepidurus packardi* Predicted Habitat Based on All Climate Variables
Figure C-1-1: Placer County Branchinecta lynchi
Predicted Habitat Based on Mean Annual Precipitation

Figure C-1-2: Placer County Branchinecta lynchi
Predicted Habitat Based on Mean January Minimum Daily Temperature

Figure C-1-3: Placer County Branchinecta lynchi
Predicted Habitat Based on Mean July Maximum Daily Temperature

Figure C-1-4: Placer County Branchinecta lynchi
Predicted Habitat Based on Mean July Precipitation

Figure C-1-5: Placer County Branchinecta lynchi
Predicted Habitat Based on Relative Summer Humidity

Figure C-1-6: Placer County Branchinecta lynchi
Predicted Habitat Based on All Climate Variables
Figure C-1-7: Placer County *Branchinecta lynchii*
Predicted Habitat Based on Elevation

Figure C-1-8: Placer County *Branchinecta lynchii*
Predicted Habitat Based on Soils

Figure C-1-9: Placer County *Branchinecta lynchii*
Predicted Habitat Based on Slope

Figure C-1-10: Placer County *Branchinecta lynchii*
Predicted Habitat Based on All Variables

Figure C-1-11: Placer County *Branchinecta lynchii*
Mapped Soil Series Coverage Comparison

*Note: STATSGO mapped soils underly nearly all SSURGO mapped soils. SSURGO mapped soil series underly all SSURGO mapped soil types. Dark brown polygons show areas where STATSGO soil data extend beyond SSURGO data. Medium brown polygons show areas where SSURGO soil series data extend beyond SSURGO soil type data.*
Appendix D

Basic Steps and Instructions for Developing Predictive Habitat Maps for Rare Vernal Pools Species
Basic Steps and Instructions for Developing Predictive Habitat Maps for Rare Vernal Pools Species

January 2013

This document summarizes the basic steps involved in producing predictive habitat maps for rare vernal species using the methods developed in the study entitled ‘Predictive Habitat Mapping and Analysis of Four Rare Vernal Pool Species in Merced, Sacramento and Placer Counties, Great Valley, California, USA’. The study was authored by John Vollmar, Robert Holland, Carol Witham and Jake Schweitzer. Details related to each of these steps are described in the Methods section of the study as well as in the metadata documentation and should be referred to as needed.

Step 1: Identify Study Species and Study Area. The method for developing predictive habitat maps outlined in this study can theoretically be applied to any rare vernal pool species in any county in California. In reality, the method will work better for some species over others based on the number of reliable species occurrences within the study area, the level of habitat affinities exhibited by the species, and other factors. The species of potential interest should be carefully evaluated prior to undertaking an in-depth predictive habitat mapping effort to determine if it is amenable to such mapping such that the final products will be sufficiently accurate to be useful for the intended application. The proposed study area should also be carefully evaluated to ensure it is amenable to predictive species mapping, and that critical spatial data are available. The county level (roughly 500K-1,000K acres) appears to be a good scale for applying the predictive habitat mapping methods. Extremely large study areas (such as the entire Sacramento Valley) lose the ability to tailor the predicted mapping to the local geography based on a more limited extent of species occurrence records. Small areas (less than 100K acres) may be amenable to the predictive mapping method but at smaller scales it may be more effective to include mapping of individual pools and field survey components of the mapping method.

Step 2: Review Available Geomorphic and Ecological Information on the Study Species and Area. Each rare vernal pool species and each vernal pool region has unique characteristics that should be studied and understood as key components to identifying the habitat parameters to be used for the predicted habitat mapping. It is highly recommended that experts on the selected species and study area be included as part of the effort.

Step 3: Identify Habitat Parameters to be used for the Predicted Habitat Analysis. Most mapping efforts will use the base habitat parameters identified in this report – soil, slope, elevation, and climate. Other potential habitat parameters, including novel parameters, should be investigated and used if found to be effective. The ‘low slope continuity’ parameter developed for this study is such an example. While the climate parameters were generally found to be less useful than the other parameters in our study, more refined and useful climate data will likely become available in the future.

Step 4: Obtain and Vet Species Occurrence Data. Species occurrence data can be most readily obtained from the California Natural Diversity Database (CNDDB) maintained by the California Department of Fish and Wildlife. It is optimal to obtain the original source data that was submitted rather than the derived CNDDB ‘element occurrence’ points which sometimes lump a set of individual, precisely located occurrence points into a single, generalized ‘element occurrence’. Also, some CNDDB records consist of polygons encompassing a vernal pool habitat area that may support a number of individual occupied pools. These data will also need to be processed following the methods described in the report. Additional occurrence data from other sources should be obtained as time and funding allows. Most vernal pool areas in California have been surveyed, yet species occurrence data may not have been submitted or incorporated into the CNDDB. We found these additional data were fairly easy to obtain for
our study. It should be quite easy to find out who conducted surveys within a particular study area and where surveys were specifically conducted. Once all available occurrence records have been obtained, they need to be carefully reviewed and vetted following the methods described in this report.

**Step 5: Develop Habitat Parameter Data Layers.** Each habitat parameter to be used in the predictive habitat mapping will need to be prepared in unique ways for the analysis. This is done using GIS technology. This may involve re-sampling grid data as needed, merging or splitting soil polygon data (see methods in this study), determining appropriate pixel or data resolution, etc. We found this to be an experimental process that involved implementing and evaluating different approaches to see which best worked for the species and study area of interest.

**Step 6: Analyze Occurrence Data in relation to Habitat Parameters and Produce Draft Predicted Habitat Map.** Using GIS technology, the draft predicted habitat map is produced by first calculating the range of each habitat parameter associated with the species occurrence locations and then extrapolating to include all areas in the study area within the range of that parameter. The individual habitat parameter range layers are then combined in GIS to produce the draft predicted habitat for the study species. The final output of predicted habitat is limited to the subset of areas that are spatially within the range of all combined habitat parameters.

**Step 7: Evaluate Effects of Individual Habitat Parameters and Modify or Exclude as Appropriate.** The predicted habitat produced by the different habitat parameters should be evaluated individually to determine which parameters are most important and accurate in contributing to the accuracy of the predicted habitat mapping. Certain parameters may be found to be highly inaccurate or erroneous, introducing false exclusions or inclusions of predicted habitat (such as the climate parameters for our study). These parameters should be modified or eliminated as appropriate to improve the accuracy of the predictive mapping. Experts with specific knowledge of the study species and area should be involved in this process since it can be highly subjective and prone to erroneous decision-making by individuals within more limited knowledge.

**Step 8: Produce Final Predicted Habitat Map.** The process for producing the draft map is repeated using only the final selected habitat parameters to produce the final predicted habitat map for the study species.