Temporal Vegetation Dynamics in Central and Northern California Vernal Pools

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JENNIFER JOANNE BUCK
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Approved:

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Michael G. Barbour, PhD.

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Marcel Rejmanek, PhD.

____
Robert F. Holland, PhD.

Committee in Charge

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Abstract

It is well established that vernal pool ecosystems are complex and variable along many spatial scales. A recent fine-scale classification of vernal pool vegetation makes the question of temporal stability fundamental to the recognition of floristically-based vernal pool associations. To address this question, an existing long-term dataset was used to examine the range of annual and seasonal variation in vernal pool plant species. Data were analyzed from ten vernal pool sites adjacent to a 300-km stretch of a PGE/PGT gas pipeline corridor extending through central and northern California. A total of 156 pools were visited twice each growing season between the months of March and June for five consecutive years (1994-1998). Results show that vernal pool plant species are not static; the vegetation seems to have cyclic dynamics that may be stable over time at a "loose equilibrium". Diagnostic species for the class *Downingio bicornutae-Lasthenietea fremontii* and three orders within it show high values of temporal persistence. As the classification of vernal pool plant associations is refined, temporal persistence should be incorporated in determining the most useful diagnostic species to each association.

Keywords: wetlands, class *Downingio bicornutae-Lasthenietea fremontii*, persistence, diagnostic species.

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Introduction

It is well established that species within plant communities fluctuate in time and space due to both biotic interactions and abiotic factors (Rahel 1990, Sawyer and Keeler-Wolf 1995, Anand and Kadmon 2000, Collins 2000). Variability within floristic assemblages is particularly evident in ephemeral habitats (Husband and Barrett 1996), including California's vernal pools (Holland and Jain 1981b, Zedler 1981, Ebert and Balko 1987, Holland and Dains 1990, Jokerst 1990b, Bliss and Zedler 1998).

Vernal pools are defined as ephemeral wetlands that fill with precipitation in the winter months, dry down in the spring, and are completely desiccated throughout the summer (Keeley and Zedler 1996). The vegetation of California vernal pools is dominated by native annual forbs, many of which are endemic to the state (Keeler-Wolf *et al*. 1998), and some of which are considered rare, threatened or endangered by federal and state agencies and non-government organizations. Presently, vernal pools are thought to be among the most threatened wetland ecosystems in the state (Stone 1989); estimates of habitat loss range from 66% to 90% (Holland 1978, California Department of Parks and Recreation 1988).

A recent fine-scale classification of vernal pool vegetation (Barbour *et al*. 2003) makes the question of temporal stability fundamental for the recognition and acceptance of floristically-based vernal pool associations. This new classification attempts to describe the internal heterogeneity of vernal pool vegetation by defining autonomous associations within individual pools. Previous classifications of vernal pools within California have focused primarily on abiotic characteristics, such as physiographic and edaphic factors, rather than on plant taxa (Holland 1976, 1986, Sawyer and Keeler-Wolf 1995, Keeler-Wolf *et al.* 1998). This is largely due to the complexity and variation inherent in the ecological system of vernal pools.

Vernal pool vegetation is variable at many spatial scales. State-wide, research has shown that the floristic composition within vernal pools varies considerably due to abiotic factors such as soil type, chemistry, landform, and geomorphic surface (Holland and Dains 1990, Ferren *et al.* 1996, Smith and Verrill 1996). Other elements that influence existing vegetation at this large scale include source biota and climate which changes along latitude (Holland and Jain 1977, Holland and Dains 1990).

At a more local scale, the vegetation of a vernal pool is variable within a vernal pool complex - defined as a group of "naturally occurring pools in close proximity" by Keeler-Wolf *et al.* (1998). A complex of vernal pools shares relatively similar abiotic conditions, yet differences in each pool's topography such as basin area, shape, and depth significantly affect the pools plant community composition (Holland and Jain 1981a, Rosario and Lathrop 1984, Jokerst 1990a, Keeley and Zedler 1996). Site history and land management practices have a large influence on the floristic composition of vernal pools at the local scale (Holland and Dains 1990, Barbour *et al.* unpublished data).

At an even finer spatial scale, the locations of different plant species vary within the microhabitats of individual vernal pools (Platenkamp 1996). Plant species are distributed along an inundation gradient and are highly influenced by precipitation, specifically by the timing and length of inundation (Schlising and Sanders 1982, Bliss and Zedler 1998, Bauder 2000). Platenkamp (1996) found that deep pools contain more depth ranges than shallower pools, resulting in higher species richness.

Of particular interest in this paper is the question of temporal variation within the vegetation of vernal pools. Previous research has made note of variation between years (Holland and Jain 1981a, Keeley and Zedler 1996, Bauder 2000), however, no long-term datasets have quantitatively assessed temporal patterns in species composition. I present the results of analyses using an existing long-term dataset to examine temporal dynamics of vernal pool plant species in central and northern California.

My aim is to analyze the magnitude of change in the floristic composition of vernal pools between years and/or within a growing season. I will investigate the range of variation and the extent to which climatic factors explain temporal dynamics. Finally, I will discuss the impact of temporal variation on the detection of listed plant taxa and also of diagnostic species that are important in the recognition and naming of floristically-based associations within vernal pools.

Methods

Study Sites

All field data were provided by Carol Witham through PGE, and were collected from ten study sites adjacent to a 300-km stretch of the PGT/PGE gas pipeline corridor through northern and central California (Figure 1), see also Taylor *et al.* 1992, King *et al.* 1996, Simovich 1998. This analysis examines 156 vernal pools that were surveyed twice each growing season between the months of March and June for five consecutive years (1994-1998). The ten study sites are distributed within three distinct vernal pool regions as defined by Keeler-Wolf *et al.* (1998) (Table 1).

The northern-most site, Fall River, is contained within the Modoc Plateau Vernal Pool Region and consists of small, shallow vernal pools at an elevation greater than 1000 m. The pools on this site can be further classified as northern basalt flow vernal pools, based on a previous classification by (Holland 1986). The soils of this site are derived from Pleistocene and Pliocene basaltic lavas that extend over much of the Modoc Plateau (Keeler-Wolf *et al.* 1998).

The seven sites between Red Bluff and Wilson Creek are located in the Northwestern Sacramento Valley Vernal Pool Region and are classified as hardpan vernal pools. The dominant soils at these sites are Redding and Corning gravelly loams, on old alluvial terraces that exhibit a distinctive mima-mound topography (Simovich 1998).

The two southern-most sites, Allendale and Jepson Prairie, occur in the Solano-Colusa Vernal Pool Region. The Allendale vernal pools are underlain by a hardpan, while the Jepson Prairie vernal pools are underlain by a claypan substrate and typically alkaline soils (Keeler-Wolf *et al.* 1998). Vernal pools at Jepson Prairie may reach several hectares in size (e.g. Olcott Lake covers 17 ha).

Field Surveys

PG&E contracted with Carol Witham to conduct vernal pool surveys using a team of six botanists between the years of 1994 and 1998. During each survey, species composition and absolute cover were visually estimated for all species within the vernal pool boundary. This boundary, also termed the high water mark (Platenkamp 1996), is defined as the zone where the vegetation composition shifts in dominance from hydophytic to upland plant species. The zone of this transition within a vernal pool tends to occur over an area of less than 1 m in width (Holland and Jain 1981a). Nomenclature of all recorded plant species follows the Jepson Manual (Hickman 1993). Other variables measured within each pool include absolute percent cover of bare soil, water, cobble, algal matting, bryophytes, litter, thatch, and cow pie.

Data Analysis

Characteristics of vernal pool species were compiled in order to analyze the distribution of guilds within the data set. These include: *life form* – annual, perennial, forb, and graminoid; *vernal pool specialist* – indicator, associate, and generalists following the California Department of Fish and Game classification (Keeler-Wolf *et al.* 1998); *native to California* (Hickman 1993); *listing status* (California Native Plant Society 2001); and *diagnostic species* as defined by Barbour *et al*. (2003) in a preliminary classification of vernal pool plant associations for this region.

Daily precipitation and temperature for each study site were downloaded from weather station data available at the University of California Integrated Pest Management

Program website (Statewide IPM Program 2004). Monthly averages of temperature and precipitation were calculated for use as a site-level variable. In order to test the significance of the timing of rain on population dynamics, precipitation totals were partitioned into seasonal components: *fall* (September to November), *winter* (December to February), and *spring* (March – May). Precipitation during summer is infrequent due to California's mediterranean climate and has a negligible influence on vernal pool plant species growth.

Statistical analyses were performed at the grain of whole pool (sample unit) and at two spatial scales; site and vernal pool region. I analyzed 156 vernal pools with a matrix of 1235 whole pool samples and 310 plant taxa. Of the 156 pools, eighty were sampled consistently over the ten sample periods (twice each year from 1994-1998) (Table 2). These eighty pools are distributed over seven sites and fall into one vernal pool region, the Northwestern Sacramento Valley. This matrix of pools includes 800 samples and 187 taxa and was used in temporal variation analyses requiring a balanced design.

To calculate significant changes in richness between vernal pool regions, sites, years, and seasons, I used repeated measures analysis of variance which takes into account co-variation within repeatedly sampled pools (Sokal and Rohlf 1995). Linear regression was used to examine the relationship between climatic variables such as annual/seasonal precipitation and temperature on vernal pool richness.

Patterns of abundance and temporal variation were analyzed for diagnostic species, as defined by Barbour *et al*. (2003) in a preliminary classification of vernal pool plant associations, and for all CNPS listed plant taxa. Temporal persistence (P) was calculated using the formula:

$$P = \frac{100\left(\sum \frac{a}{b}\right)}{n},$$

where a = the count of occurrences of a species in one pool over time, b = the number of sample periods for that pool and n = the number of pools in which a particular species is present at least once. The average temporal persistence of each species was taken over all pools in which a species was present, and is reported as a percent. The higher the value of P, the more stable a species is temporally; P represents the average probability of finding a species in a pool in consecutive surveys over time.

A time lag analysis introduced by (Collins et al. 2000), was used to measure the pattern and degree of variability within an individual vernal pool association. This approach is basically an extension of autocorrelation analysis; it examines differences in species composition between samples at increasing time lags. Specifically, the analysis compares a Euclidean distance matrix along the square root transformation of the time intervals. A regression is then calculated to summarize trends in the temporal data (Collins *et al.* 2000).

A detrended correspondence analysis (DCA) ordination for all completely surveyed pools within a site was analyzed using a vector overlay. The connection of sequential vernal pool surveys allows the general pattern of species composition change within a pool to be tracked over time (McCune and Grace 2002). Ordinations were run independently for three randomly selected sites; Redding, Hall-Stony Creek, and Truckee Creek.

A Mantel test was used to detect relationships between distance matrices, using 1000 runs of randomized data for a Monte Carlo test of significance. This method contributes more information than a species richness analysis, as it calculates a Sørensen distance matrix for species composition and then compares this matrix to environmental variables (McCune and Grace 2002). Tests were run comparing the similarities of species composition for all 156 pools to eight different variables, including: distance apart (along the pipeline at the site-level), vernal pool habitat, year, season (early or late survey), annual precipitation (mm), and the three seasonal components of precipitation (absolute mm for fall, winter, and spring). Data were analyzed using the software package PC-ORD for Windows, Version 4.27 (McCune and Mefford 1999).

Results

The total number of plant taxa found across all sites was 310, from 45 plant families (see species list in Appendix). Of these species, 33% are characterized as vernal pool specialists (vernal pool indicators or vernal pool associates) as listed in the California Vernal Pool Assessment Report (Keeler-Wolf *et al.* 1998) (Figure 2). The remaining species were treated as generalists, 26% of which are not native to California.

While vernal pools support a large diversity of species, most of these species are locally restricted and sparse in abundance (Figure 3). The four most widespread and abundant plant taxa across all sampled pools were *Lasthenia fremontii, Eryngium vaseyi, Navarretia leucocephala ssp. leucocephala,* and *Deschampsia danthonioides.* Many other species had a widespread distribution but were not as abundant across all pools. Of the 310 taxa found throughout the survey, 31% (95 species) were detected every sampling period. This figure simply summarizes overall occurrence, and does not reveal whether that species was found in the same pool over different samples.

Vernal Pool Regions

The three vernal pool regions are floristically distinct. Of the 310 plant taxa found throughout the survey, only 14% (44 species) are shared among all three sites. The Modoc Plateau had the highest number of unique species with 47% (55 out of a total of 117). Within the seven Northwestern Sacramento Valley sites, 33% (69 out of 209) of detected species were unique, while the Solano-Colusa region had 25% (41 out of 164) of its flora restricted to its pools.

The distribution of non-native species in vernal pools varies among regions. While the Modoc Plateau had fewer total species than the other two regions, more of its species are native to California than in the other regions (Figure 4). The mean number of species per pool was significantly lower within the Solano-Colusa region, in comparison to the other two regions ($p < 0.0001$). A DCA ordination was used to summarize patterns among samples in vernal pool habitats based on designations by Holland (1986). Discrete clusters which correspond to the three habitat types become apparent when all sample units are plotted along the ordination axes (Figure 5). An overlay of environmental variables shows that Axis 1 reflects distinct floristic changes along an elevation gradient.

Species Richness

Table 3 lists the average species richness per pool, for all sites and years. The average vernal pool survey had 36.2 plant species (s.d. = 8.8, $N = 310$), ranging from 12 to 71 taxa. The species composition between individual vernal pools is highly variable, thus a greater number of plant species are found at the site level than in any individual pool. The same is true when scaling up to a vernal pool region; more species are found within a region than within any one site. This was not shown for the Modoc Plateau Region as only one site was surveyed. A calculation of mean richness among different spatial scales reveals that an individual pool, site, or region contains, on average, 12%, 39%, and 53%, respectively, of the total species richness in the study (Table 4).

Climate

The mean pool richness differed significantly between the early and late season surveys ($p = 0.0015$) and between years ($p < 0.001$). Both 1995 and 1998 had a significantly higher richness than 1994, 1996, and 1997 (Figure 6). Precipitation levels differed in amount and timing over the five-year study (Figure 7). The total rainfall in the two wettest years (1995 and 1998) was more than twice the amount in the driest year (1994). There was a significantly positive correlation between mean pool richness and average annual precipitation, ($r = 0.117$, $p < 0.0001$, $N = 1235$; Figure 8). After partitioning precipitation into seasonal components, only levels of winter and spring precipitation were significantly correlated to mean pool richness (Figure 9). There was a significantly negative correlation between mean pool richness and average yearly temperature ($r = 0.06$, $p < 0.0001$, $N = 800$; Figure 10) although it should be noted that this factor has a causal relationship with precipitation.

Abundance

The total percent cover of the four most abundant and widespread vernal pool species fluctuated over the course of the study (Figure 11). In order to take a closer look at the temporal dynamics of species abundance, one pool was selected at random from the 80 completely surveyed pools. Over ten sample periods (twice each year for five years), the total vegetative cover of pool COY-9B ranged between 40% and 90% (Figure 12). The changes in total vegetative cover are reflected in fluctuations within the community composition of the pool (Figure 13).

A DCA ordination of the plant community within pool COY-9B illustrates a stochastic change in the vegetation over time (Figure 14A). This ordination diagram was orthogonally rotated to align the environmental variable of "year" with Axis 2. A regression of the time-lag analysis reveals a negative slope for species composition changes within this pool (Figure 14B). According to Collins *et al.* (2000), a negative slope indicates that the species composition may be converging to a type characteristic of one of the earlier sample periods. This result may occur when temporal vegetation change has cyclical dynamics. Another inspection of Figure 13 shows a striking similarity of the pool's species composition and abundance between the wettest years of 1995 and 1998.

Diagnostic Species

Diagnostic species for the vegetation class *Downingio bicornutae-Lasthenietea fremontii* and three orders within it (Table 5A), show high temporal persistence (Table 6A), most likely because they are among the most common species found in vernal pools. Species diagnostic to preliminary plant associations (Table 5B), vary in persistence between 78% and 20% (Table 6B). A graph of abundance over time illustrates the dynamics of diagnostic species for the association *Psilocarpho tenelli-Limnanthetum douglasii (ass. nov. prov.)*, an edge association of vernal pool vegetation corresponding to "community 10" in Barbour *et al.* (2003) (Figure 15). The total abundance of common edge species such as *Achyrachaena mollis* increased dramatically in the driest year (1994). Total cover of the invasive weed *Taeniatherum caput-medusae* plummeted to near zero in vernal pool surveys during the highest rainfall years of 1995 and 1998.

Rare Plants

Eleven plant taxa listed as species of concern by the California Native Plant Society were detected at 8 of the 10 study sites (California Native Plant Society 2001). Listed taxa include *Astragalus tener* var. *tener, Downingia pusilla, Hesperevax caulescens, Juncus leiospermus* var. *leiospermus, Legenere limosa, Navarretia leucocephala* ssp. *bakeri, N. cotulifolia, N. heterandra, Paronychia ahartii, Pogogyne floribunda,* and *Psilocarphus brevissimus* var. *multiflorus* (California Native Plant Society 2001). Table 7 reports calculations of temporal persistence for each listed species and summarizes the range of dates for species detected over the five-year study.

Jepson Prairie had the highest number of listed species among all sites, with 7 out of the 11 species occurring in its pools. *Downingia pusilla* was the only listed species present consistently over the five year survey period. A graph of species abundance over time illustrates a predictable and dramatic decrease in absolute cover between the early and late season surveys (Figure 16). This pattern matches the autecology of *D. pusilla,* which is an early-blooming species. The pattern of late season cover values suggests a positive (but statistically insignificant) correlation between precipitation and cover.

As often is the case with rare plant species, patterns of abundance are difficult to characterize. *Astragalus tener* var. *tener* occurred only once over the five year study, with an extremely low cover of 0.1%. *Hesperevax caulescens* occurred in eight pools and was most commonly detected in early season surveys. *Juncus leiospermus* var. *leiospermus* was found in one pool consecutively over five surveys (both seasons of the first two years), then was not detected again. *Legenere limosa* blinked in and out of four pools among two sites. *Navarretia bakeri* was detected in six pools during the early season surveys of 1996 with only two other occurrences in late 1997. *Navarretia cotulifolia, Paronychia ahartii,* and *Pogogyne floribunda* each occurred 3 times in one to two pools over the study period. *Navarretia heterandra* was usually found in late season surveys, often in different pools over time. *Psilocarphus brevissimus* var. *multiflorus* was found in many pools within Jepson Prairie and Allendale, often occurring in the same pool over consecutive surveys.

Species composition

DCA ordinations with vector overlays that track individual pools over time show a stochastic response of vegetation with no set direction of change (Figure 17). In each of three ordinations, Axis 1 corresponds to floristic changes across years. Only the Red Bluff site was strongly influenced by the season variable (Axis 2). Table 8 summarizes the relationship of environmental variables to the species composition of all pools. The strength of the relationship between two distance matrices is described using the standardized Mantel statistic (*r*) (Sokal and Rohlf 1995). The strongest correlations were seen in "habitat" and "distance apart"; thus, the farther apart pools are from each other geographically, the more different their floristic composition.

Both the year and season variables had small *r* statistics that, while significant, lead us to conclude that the dissimilarity between years/seasons is positively, but only weakly related to dissimilarity in the species composition of all pools. Surprisingly, annual precipitation (including the partitioned fall component) does not significantly affect the dissimilarity of species composition in pools across the survey. Winter and spring precipitation both had a small and weak positive relationship with dissimilarity in species composition.

Discussion and Summary

The investigation of 156 vernal pools across central and northern California shows that a vernal pool, on average, has 36 plant species. The mean pool richness is significantly higher in this study than accounts in other vernal pool publications, which report 15 – 25 species (Holland and Jain 1977, 1981b, Zedler 1987, Stone 1989, Keeley and Zedler 1996). This may be due to a variety of reasons: (1) Many vernal pool species are extremely small and difficult to distinguish, however, this study was conducted thoroughly in order to identify all species; (2) vernal pool species grow and flower at different times throughout the year, thus, surveying each pool both in the early and late season allowed for a more complete census; and (3) differences in the definition of the boundary of a vernal pool's vegetation may omit the pool edge where species richness tends to be high. The mean pool richness for data used in the preliminary classification of vernal pool associations (Barbour *et al.* 2003) was 34 species per pool (N = 181 pools, range 10 – 60 species), closely matching the results of this study.

The average vernal pool site encompassed only 39% of the total species richness found throughout pools of central and northern California; this emphasizes that the protection of multiple sites across the state are needed in order to capture the full floristic variation within vernal pools. Abundance analyses from this five-year study also emphasize the importance of the completion of rare plant surveys that are timed appropriately with the life cycle of a given species (e.g. surveys for *D. pusilla* must be completed early in the season in order to accurately detect its presence and peak abundance). Another implication of this data set is that surveys must be conducted over different years in order to detect certain rare taxa (e.g. *Astragalus tener* var. *tener* was found in only one out of the five years).

This study is consistent with previous research in detecting a positive correlation between precipitation and species richness within vernal pools. This pattern was seen across all pools, sites, and regions. A partitioning of the seasonal components of precipitation revealed that levels of winter and spring rainfall had the most influence on species richness. Temperature had a significantly negative correlation with pool richness although it undoubtedly co-varies with precipitation. Years with higher average temperatures tended to have less diversity than cooler years, possibly due to higher evapotranspiration rates within the pool.

While precipitation had a positive effect on the species richness of a pool, a Mantel test showed that precipitation was not significantly correlated with differences in the total floristic composition. A Mantel test over season and year showed that there is a much smaller amount of correlation between floristic dissimilarities in temporal variation than there is in spatial variation. In other words, the plant compositions of pools that are far apart geographically are much more different from each other than the plant compositions within a particular pool over time. This is important in addressing the question of temporal stability within vernal pool plant associations.

Although the dynamics of species abundances are complex, there appears to be a synchronous response between years in which all species exhibit either a high or low abundance. Seasonally, some species such as *Eryngium vaseyi*, have a predictably higher abundance in late-season surveys, while others tend to decrease in cover, such as *Lasthenia fremontii*. The change in abundance between seasonal surveys is most likely controlled by the germination and growth rates of individual species. For example, *E. vaseyi* is a slow-growing, deep-rooted perennial species that reaches full size and flowers well into the summer months, while *L. fremontii* quickly flowers and sets seed as the pools dry in early spring.

When looking closely at temporal dynamics within one pool (COY-9B), the relative abundances of common species fluctuated over time. This fluctuation indicates an interaction between abiotic factors such as precipitation and biotic factors such as competition. In years with high precipitation (1995 and 1998), the relative abundances of species occurring in pool COY-9B were quite similar. The vegetation within this pool seems to undergo cyclical dynamics. A time-lag analysis supported this hypothesis, by indicating that the species composition of the pool converges to a type that is characteristic of one of the earlier sample periods. While vernal pool species are not static over time, there does not seem to be a directional change in floristic composition and abundance. Collins (2000) states that if a plant community does not undergo a definite directional change, yet contains a significant amount of temporal variation, the community may be stable at a "loose equilibrium" over time.

The existence of a persistent seedbank adds complexity to the question of the stability of ephemeral plant associations. Bliss and Zedler (1998) point out that seed dormancy allows annual plant species to cope with temporal change; this in turn has a stabilizing effect on the vernal pool plant community. In the analysis of one edge association, *Psilocarpho tenelli-Limnanthetum douglasii (ass. nov. prov.)*, abundances of diagnostic plant species rose and fell. This fluctuation in abundances may signify the spatial expansion and contraction of the edge zone, although this could not be tested using this data set.

This data set sampled whole vernal pools as one unit, rather than focusing on within-pool associations. Thus, a direct test of the stability of plant associations within vernal pools was not possible. It was possible, however, to analyze the presence or absence over time of diagnostic species which define known associations in this region. The analysis of temporal persistence for diagnostic species contributes more information to the question of association stability than an analysis of abundance. The temporal persistence values for the class *Downingio bicornutae-Lasthenietea fremontii* and three orders within it indicate a high temporal stability. Species diagnostic at the association level range in persistence from a low of 20% to a high of 78% and only half of the diagnostic species had a persistence of greater than 50%. The vernal pool association classification recently published by Barbour *et al*. (2003) is preliminary, with only one-third of the data analyzed. As the classification of associations is refined, temporal persistence values should be incorporated in determining the most useful diagnostic species to each association.

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Tables

Table 1. Location and elevation information for ten vernal pool sites (arranged north to south) surveyed twice a year over a five-year period (1994 – 1998).

Site Name	County	Vernal Pool Region	Elevation (m)
Fall River Mills	Shasta	Modoc Plateau	1015
Red Bluff	Tehama	Northwestern Sacramento Valley	88
Coyote Creek	Tehama	Northwestern Sacramento Valley	82
Truckee Creek	Tehama	Northwestern Sacramento Valley	95
Thomes Creek	Tehama	Northwestern Sacramento Valley	99
Corning	Tehama	Northwestern Sacramento Valley	106
Hall-Stony Creek	Tehama	Northwestern Sacramento Valley	103
Wilson Creek	Glenn	Northwestern Sacramento Valley	77
Allendale	Solano	Solano-Colusa	34
Jepson Prairie	Solano	Solano-Colusa	8

Table 2. Number of vernal pools surveyed per site, including calculations of the completeness of data collected over ten sample periods.

Site Name	Total count of pools	Number of surveys	Number of missing surveys	Count of pools with all 10 surveys
Fall River Mills	13	73	57	0
Red Bluff	9	89	1	8
Coyote Creek	4	30	10	1
Truckee Creek	14	132	8	12
Thomes Creek	26	228	32	18
Corning	29	271	19	24
Hall-Stony Creek	29	238	52	15
Wilson Creek	3	29	1	2
Allendale	11	39	71	0
Jepson Prairie	18	106	74	0
Total	156	1235	325	80

Table 3. The mean number of species per pool, calculated within ten sites over five years.

Site Name	1994	1995	1996	1997	1998	Mean Richness/Site
Fall River Mills	27	39	41	36	--	35
Red Bluff	34	41	34	35	42	37
Coyote Creek	40	52	46	40	43	45
Truckee Creek	37	44	36	33	42	38
Thomes Creek	37	43	38	36	45	40
Corning	34	37	37	36	44	38
Hall-Stony Creek	27	36	30	28	27	31
Wilson Creek	32	32	40	31	37	34
Allendale	34	40	32	27	--	30
Jepson Prairie	31	37	34	31	--	33
Mean Richness/Year	33	39	36	33	41	**36**

Table 4. Mean richness and the percent of total species richness at different spatial scales for vernal pool vegetation.

Spatial Scale	Mean Richness	Standard Deviation	N	Percent of Total Species Richness
Individual Vernal Pool	36.2	8.8	1235	12%
Site Level	120.3	24.0	10	39%
Vernal Pool Region	163.3	46.0	3	53%

Table 5. Summary of floristic differentiation among vernal pool association types from (Barbour et al. 2003). Numbers within the body of the table represent constancy (percent of plots with the species present). Boxes indicate species that are diagnostic to a particular association type. (A) Class *Downingio bicornutae-Lasthenietea fremontii* and three orders within it. (B) Sixteen preliminary associations under the class.

A.

Vegetation type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Eryngium vaseyi	100	89	92	100	80	79	75	79	60	91	64	37	62	83	29	68
Plagiob stipitatus	100	56	82	64	72	74	66	36	100	13	73	48	43	25	.	43
Lasthenia fremontii	100	67	64	36	51	83	70	81	.	87	55	59	68	8	83	81
Psilocarphus brevissimus	80	72	75	43	54	69	80	52	.	70	18	19	60	.	100	88
Crassula aquatica	40	72	57	29	72	83	73	76	40	100	18	33	46	.	58	43
Deschampsia danthonioi	20	22	29	71	49	78	60	64	.	78	46	74	73	33	25	51
Callitriche marginata	80	72	21	7	35	47	43	41	.	61	18	11	62	25	13	5
Navarretia leucocephala	.	.	79	43	33	36	36	7	.	.	64	63	.	8	.	77
Juncus bufonius	.	.	21	.	33	64	47	21	60	74	36	44	19	42	.	14
Pogogyne ziziphoroides	.	11	14	.	23	52	43	38	80	87	46	96	.	.	17	1
Eleocha acicula	20	.	25	14	51	53	27	5	.	.	.	.	54	8	8	18
Alopecurus saccatus	.	72	32	71	47	12	33	41	.	44	18	4	24	8	4	10
Pilularia americana	.	28	18	14	28	66	39	26	.	26	.	.	11	.	29	5
Isoetes orcuttii	20	28	14	.	30	50	33	21	.	65	9	11	22	.	.	.
Veronic peregri	.	17	.	.	5	.	22	17	80	22	27	11	.	.	63	30
Lasthenia glaberrima	100	100	100	100	100	5	8	21	.	13	.	4	16	.	33	1
Eleocharis palustris	40	50	79	100	81	38	8	33	.	22	.	.	5	17	54	36
Limnanth douglas s. ro	40	33	4	.	.	.	15	41	20	87	64	30	78	58	.	.
Trifolium depauperatum	.	.	7	.	14	2	17	17	60	57	100	30	14	8	.	.
Hemizonia fitchii	.	17	.	.	12	48	19	7	60	17	64	41	3	50	29	1
Lepidium nitidum	.	.	.	.	.	3	5	10	80	22	18	70	46	17	.	.
Plagiobothrys greenei	.	.	.	.	2	10	12	10	100	78	9	26	.	.	.	.
Blennosper nanum v. na	.	6	.	.	.	3	5	14	.	57	.	59	51	42	.	.
Cicendia quadrangulari	.	.	.	.	14	17	25	24	.	74	.	41	.	.	.	1
Hypochaeris glabra	.	6	7	.	14	12	39	52	100	100	18	82	35	33	.	.
Erodium botrys	.	28	7	.	28	17	40	64	60	96	18	44	11	25	.	.
Vulpia bromoides	.	6	4	.	16	3	19	43	20	83	18	11	35	.	8	1
Bromus hordeaceus	.	6	7	.	7	17	34	19	100	26	36	78	41	.	29	5
Plantago elongata	.	6	.	.	.	.	5	21	.	9	9	48	5	.	79	60
Downingia insignis	.	.	.	.	.	.	.	.	.	.	.	.	.	.	67	56
Cressa truxillensis	.	.	.	.	.	.	.	.	.	.	.	.	.	.	38	77
Myosurus minumus	.	17	.	.	.	.	2	7	.	13	.	4	3	.	42	53
Polypogon monspeliensi	.	.	.	.	21	7	2	.	.	.	.	.	.	.	100	56
Crypsis schoenoides	.	.	.	.	.	.	0.9	.	.	.	.	.	.	.	79	55
Cotula coronopifolia	.	17	.	.	7	.	2	10	.	.	.	.	.	.	79	21

Table 5. continued

B.

Community type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Pogogyne douglasii	100	.	.	.	.	.	.	.	.	.	.	.	27	.	.	.
Castill campest s. suc	20	.	.	.	.	.	5	.	.	.	.	.	16	.	.	.
Pleuropogon californic	.	72	.	.	.	.	.	45	.	26	.	.	.	.	.	.
Isoetes howellii	.	.	.	79	7	24	1	.	.	.	.	.	3	8	.	.
Castilleja campestris	.	6	4	.	12	76	5	12	.	4	.	.	.	.	.	.
Navarre myersii s. mye	.	.	.	.	.	59	6	.	.	.	.	.	.	.	.	.
Hesperevax caulescens	.	.	.	.	.	.	.	.	100	.	27	.	.	.	.	.
Holocarpha virgata	.	.	4	.	9	5	8	2	100	22	.	.	8	.	.	.
Hedypnois cretica	.	.	.	.	.	.	0.4	.	100	.	.	.	.	.	.	.
Mimulus tricolor	.	.	14	7	7	14	10	.	80	.	9	7	.	.	.	.
Medicago polymorpha	.	.	.	.	.	.	2	2	80	.	.	15	.	.	13	1
Trifolium gracilentum	.	.	.	.	.	.	.	.	60	.	.	4	.	.	.	.
Microseris elegans	.	.	.	.	.	.	.	.	60	.	.	.	.	.	.	.
Cerastium glomeratum	.	.	.	.	2	2	3	10	60	4	.	4	8	8	.	.
Psilocarphus oregonus	.	.	.	.	.	.	3	24	80	74	18	4	.	.	.	2
Achyrachaena mollis	.	6	4	.	5	5	6	17	.	74	100	82	.	.	.	6
Triphys erianth s. eri	.	.	.	.	.	.	6	24	.	70	82	93	16	.	.	.
Lasthenia californica	.	.	.	.	.	2	3	10	.	74	27	70	19	8	.	.
Layia fremontii	.	.	.	.	.	14	6	.	.	.	82	59	14	.	.	.
Microseris acuminata	.	.	.	.	.	.	0.4	.	40	.	64	74	5	.	.	.
Taeniatheru caput-medu	.	.	.	.	.	.	1	17	.	9	46	48	.	.	.	.
Phalaris lemmonii	.	6	.	7	2	.	0.9	17	.	83	.	4	.	.	.	.
Psiloca tenellu v. glo	.	.	4	.	5	3	11	2	.	70	.	4	8	.	4	.
Trifolium willdenowii	.	.	.	.	.	.	2	2	.	9	91	26	3	.	.	.
Lupinus bicolor	.	.	.	.	2	.	1	10	20	13	64	4	5	.	.	.
Navarretia tagetina	.	.	.	.	.	.	5	.	.	.	9	85	8	.	.	.
Plagiobothrys austinia	.	.	.	.	2	.	5	.	.	.	.	82	14	.	.	.
Vulpia microstachys	.	6	.	.	2	.	2	2	.	.	.	74	30	8	.	.
Chlorogalum angustifol	.	.	.	.	.	.	2	.	.	.	18	67	3	8	.	.
Plantago erecta	.	.	.	.	.	.	1	.	.	.	18	63	8	8	.	.
Navarretia pubescens	.	.	.	.	.	.	.	.	.	.	18	48	.	.	.	.
Montia fontana	40	.	4	.	7	2	2	.	.	.	9	4	70	92	.	.
Trifolium variegatum	.	.	14	.	23	2	20	7	80	.	9	.	73	92	.	.
Sidalcea calycosa	20	.	.	.	2	.	0.9	.	.	.	.	.	24	58	.	.
Mimulus guttatus	.	.	.	.	.	.	.	.	.	.	.	.	.	83	.	7
Plagiobothr glyptocarp	.	.	.	.	.	.	.	.	.	.	.	.	8	75	.	.
Grindelia camporum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	80
Epilobium densiflorum	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	67
Frankenia salina	.	.	.	.	.	.	.	.	.	4	.	.	.	.	17	38

Table 6. Temporal persistence calculated for diagnostic species under (A) vegetation class *Downingio bicornutae-Lasthenietea fremontii* and three orders within it, and (B) 16 associations based on a preliminary classification by Barbour *et al.* (2003). An * indicates a species that is not native to California.

A.

Species Name	**Group**	**Temporal Persistence (%)**
Eryngium vaseyi	Class	99
Lasthenia fremontii	Class	95
Deschampsia danthonioides	Class	94
Pogogyne zizyphoroides	Class	92
Navarretia leucocephala ssp. leucocephala	Class	91
Psilocarphus brevissimus var. brevissimus	Class	90
Juncus bufonius var. occidentalis	Class	79
Crassula aquatica	Class	76
Plagiobothrys stipitatus var. micranthus	Class	75
Alopecurus saccatus	Class	70
Veronica peregrina ssp. xalapensis	Class	54
Callitriche marginata	Class	50
Isoetes orcuttii	Class	45
Pilularia americana	Class	42
Eleocharis acicularis var. acicularis	Class	41
Eleocharis macrostachya	Order 1	77
Lasthenia glaberrima	Order 1	60
Trifolium depauperatum	Order 2	86
Erodium botrys*	Order 2	85
Hypochaeris glabra*	Order 2	81
Limnanthes douglasii ssp. rosea	Order 2	76
Plagiobothrys greenei	Order 2	74
Hemizonia fitchii	Order 2	73
Blennosperma nanum var. nanum	Order 2	71
Lepidium nitidum var. nitidum	Order 2	65
Bromus hordeaceus*	Order 2	63
Cicendia quadrangularis	Order 2	60
Vulpia bromoides*	Order 2	51
Downingia insignis	Order 3	100
Cressa truxillensis	Order 3	58
Plantago elongata	Order 3	49
Cotula coronopifolia*	Order 3	48
Myosurus minimus	Order 3	32
Polypogon monspeliensis*	Order 3	30
Crypsis schoenoides*	Order 3	15

Table 6. continued

B.

Species Name	Preliminary Group	Temporal Persistence (%)
Pleuropogon californicus	Association 2, 8	78
Isoetes howellii	Association 4	31
Castilleja campestris	Association 6	69
Mimulus tricolor	Association 9	73
Hesperevax caulescens	Association 9	53
Psilocarphus oregonus	Association 9, 10	51
Holocarpha virgata ssp. virgata	Association 9	44
Trifolium gracilentum var. gracilentum	Association 9	43
Cerastium glomeratum*	Association 9	39
Trifolium variegatum	Association 9, 13, 14	29
Medicago polymorpha*	Association 9	25
Achyrachaena mollis	Association 10, 11, 12	76
Triphysaria eriantha ssp. eriantha	Association 10, 11, 12	74
Layia fremontii	Association 10, 11, 12	72
Phalaris lemmonii	Association 10	70
Microseris acuminata	Association 10, 11, 12	61
Psilocarphus tenellus var. globiferus	Association 10	46
Taeniatherum caput-medusae*	Association 10, 11, 12	46
Lasthenia californica	Association 10, 11, 12	41
Lupinus bicolor	Association 11	43
Trifolium willdenovii	Association 11	38
Navarretia tagetina	Association 12	68
Chlorogalum angustifolium	Association 12	64
Plantago erecta	Association 12	59
Plagiobothrys austinae	Association 12	43
Vulpia microstachys	Association 12	40
Navarretia pubescens	Association 12	20
Montia fontana	Association 13, 14	36
Mimulus guttatus	Association 14	33
Frankenia salina	Association 16	75

Table 7. Listed vernal pool taxa recognized by the (California Native Plant Society 2001) and detected in vernal pools over the five year survey period.

Species Name	**Listed Status**	**Earliest Date Detected**	**Latest Date Detected**	**Temporal Persistence (%)**
Astragalus tener var. tener	CNPS - 1B	March 24	--	14
Downingia pusilla	CNPS - 2	March 27	May 27	61
Hesperevax caulescens	CNPS - 4	March 25	May 8	53
Juncus leiospermus var. leiospermus	CNPS - 1B	April 7	May 31	63
Legenere limosa	CNPS - 1B	March 27	May 26	29
Navarretia cotulifolia	CNPS - 4	April 7	May 1	43
Navarretia heterandra	CNPS - 4	April 10	May 12	14
Navarretia leucocephala ssp. bakeri	CNPS - 1B	April 7	May 20	37
Paronychia ahartii	CNPS - 1B	April 2	April 22	25
Pogogyne floribunda	CNPS - 1B	April 30	June 11	43
Psilocarphus brevissimus var. multiflorus	CNPS - 4	March 24	May 1	61

Table 8. Mantel test results comparing the species composition matrix of 156 vernal pools sampled over five years against eight different environmental variables.

Tested Variable	standardized Mantel statistic *r*	*p*-value
Habitat	0.518	0.001
Distance	0.409	0.001
Year	0.113	0.001
Season	0.025	0.001
Annual Precipitation	0.014	0.074 NS
Fall Precipitation	-0.027	0.050 NS
Winter Precipitation	0.108	0.001
Spring Precipitation	0.121	0.001

Figures

Figure 1. Map of central and northern California showing locations of the ten study sites along a PGT-PG&E pipeline.

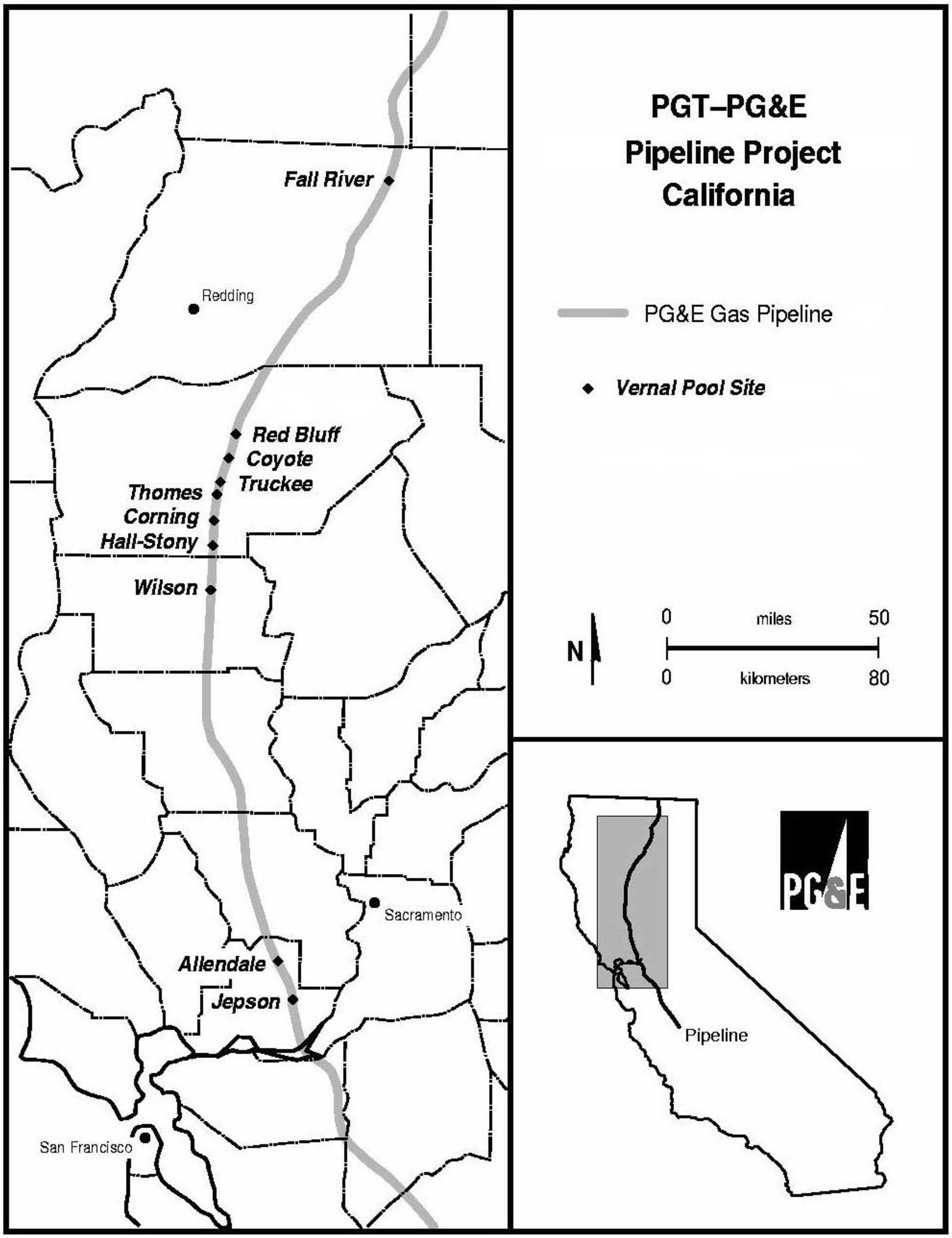


Figure 2. Guilds of vernal pool taxa. Vernal pool specialists are shown in stippled wedges: VPI denotes a vernal pool indicator species, VPA a vernal pool associate. All other detected species are treated as generalists, and split into native and non-native species.

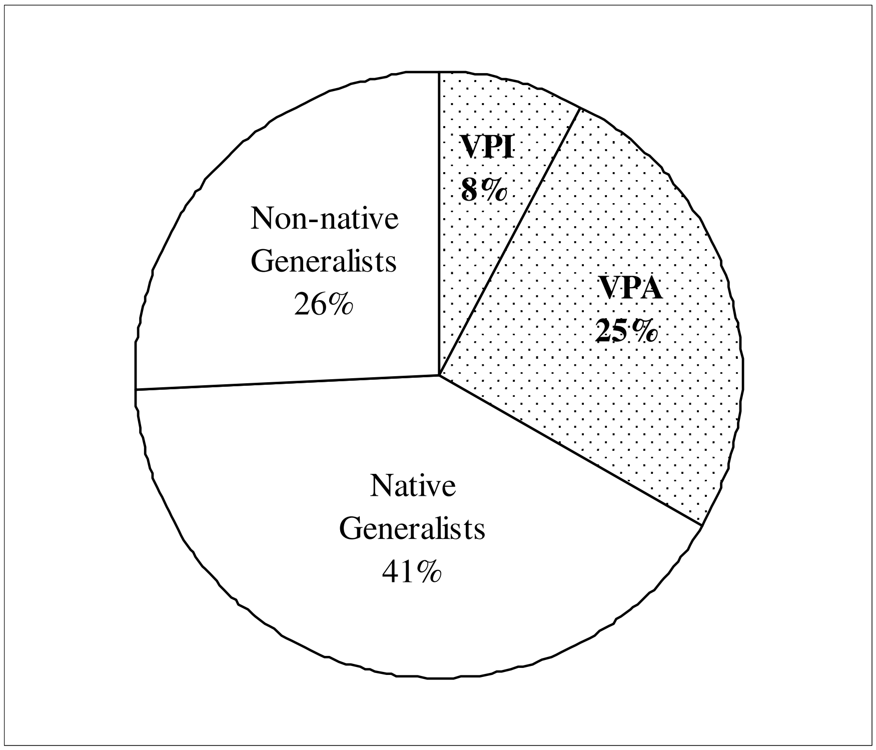


Figure 3. The frequency and average percent cover of 187 vernal pool plants species calculated across 80 vernal pools. Widespread species are labeled using the first three letters of genus and species (see plant species list in Appendix for full name).

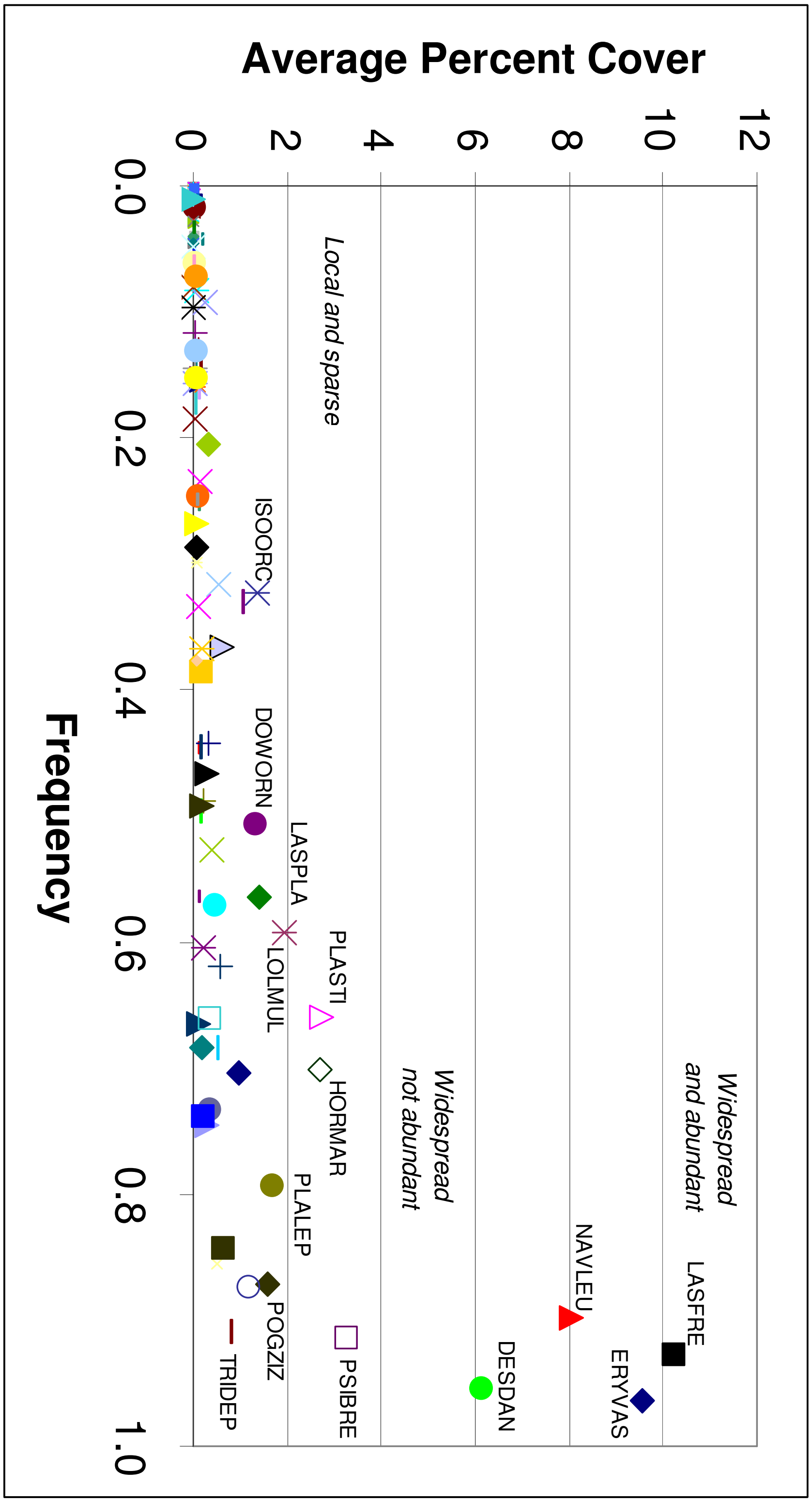


Figure 4. The distribution of native (left bars) versus non-native (right bars) vernal pool taxa by region.

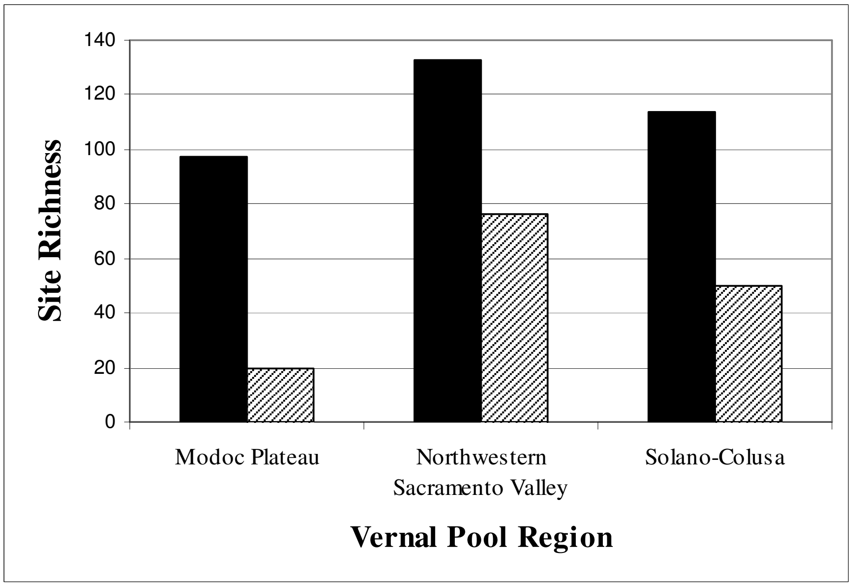


Figure 5. DCA ordination of 156 vernal pools surveyed over five years; analysis uses only taxa defined as vernal pool specialists in the California Vernal Pool Assessment Report (Keeler-Wolf *et al.* 1998).

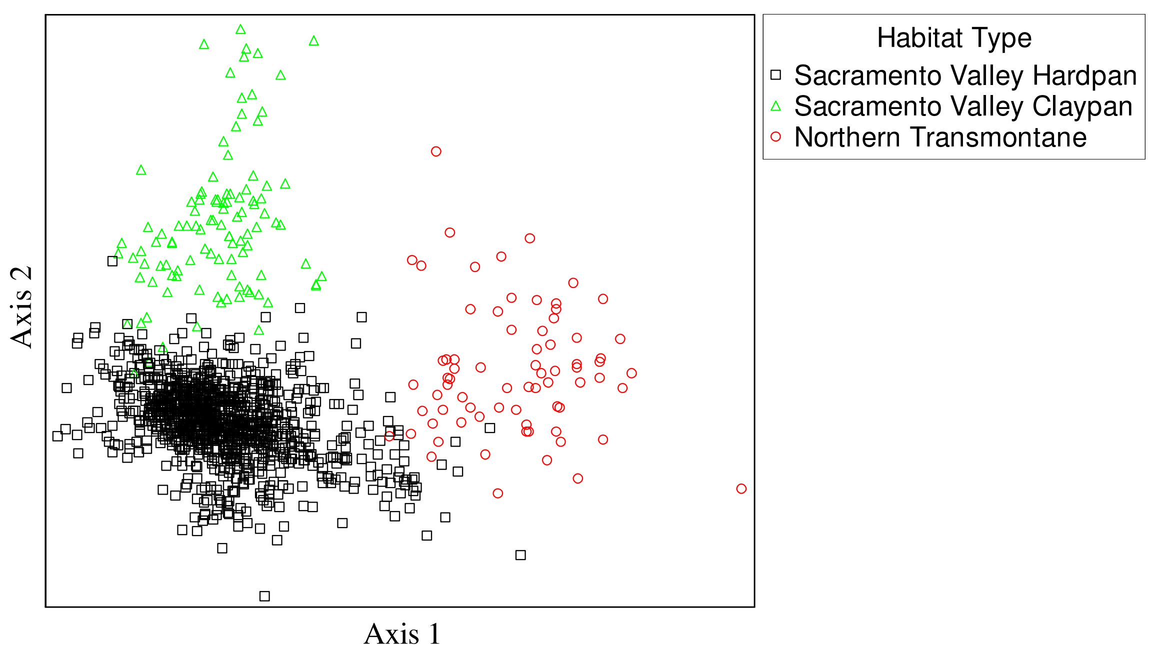


Figure 6. Mean richness per pool over five years. N = 80 vernal pools. Mean diamonds above the grand mean line are significantly different from means below the line. Survey year 1 corresponds to 1994; year 5 to 1998.

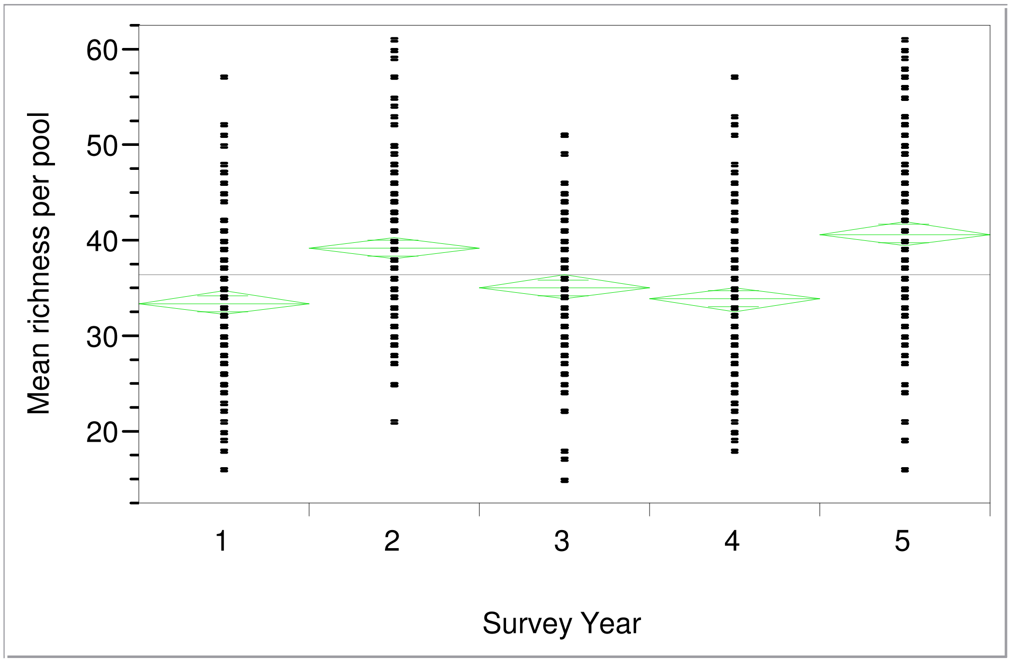


Figure 7. Average precipitation in millimeters across ten vernal pool sites for each survey year. Total rainfall is partitioned into seasonal components for fall (September – November, bottom portion of each bar), winter (December – February, mid portion), and spring (March – May, top portion).

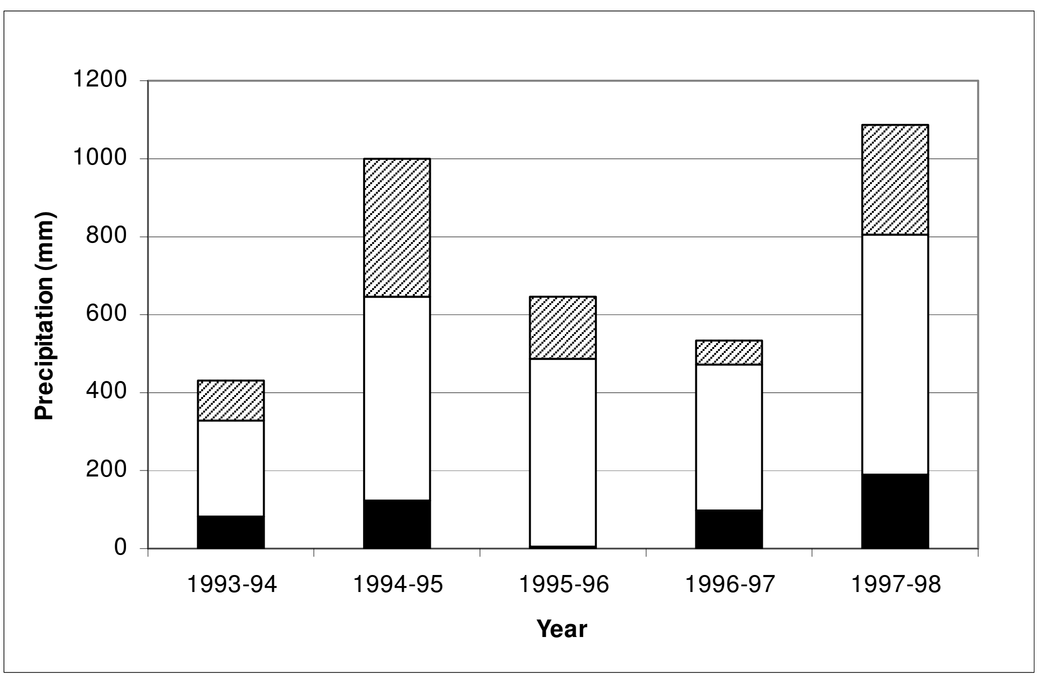


Figure 8. Linear regression of mean pool richness by total precipitation (mm). Linear fit line has the formula y = 0.009x + 29.5, $r^2 = 0.12$, $p < 0.0001$. $N = 1235$ surveys.

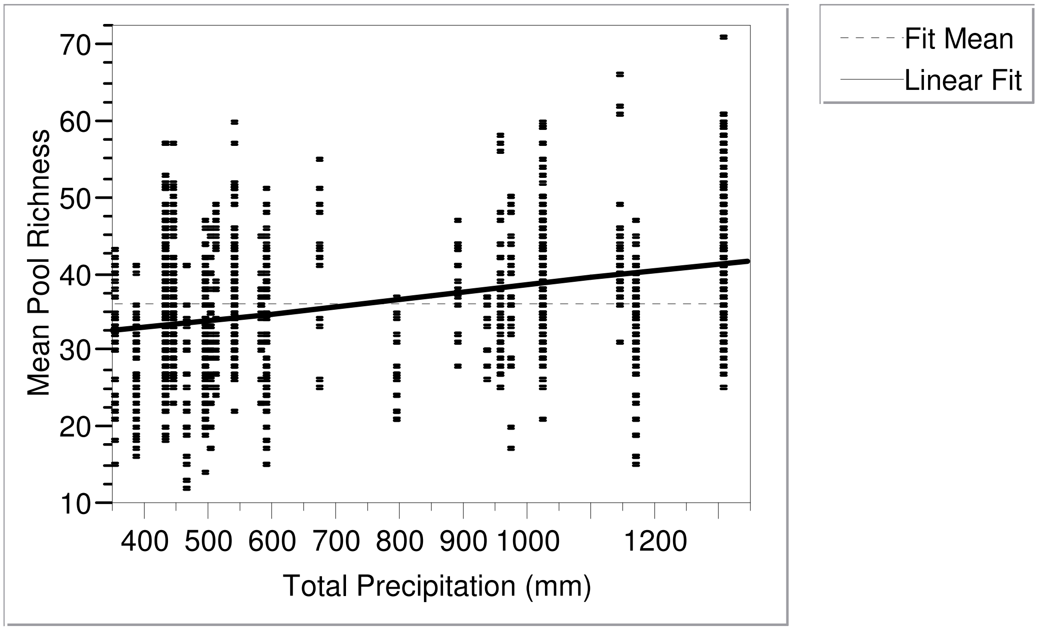


Figure 9. Leverage plot of residuals using repeated measures model, effect of partitioned seasonal precipitation on mean pool richness. N = 1235 pool surveys.

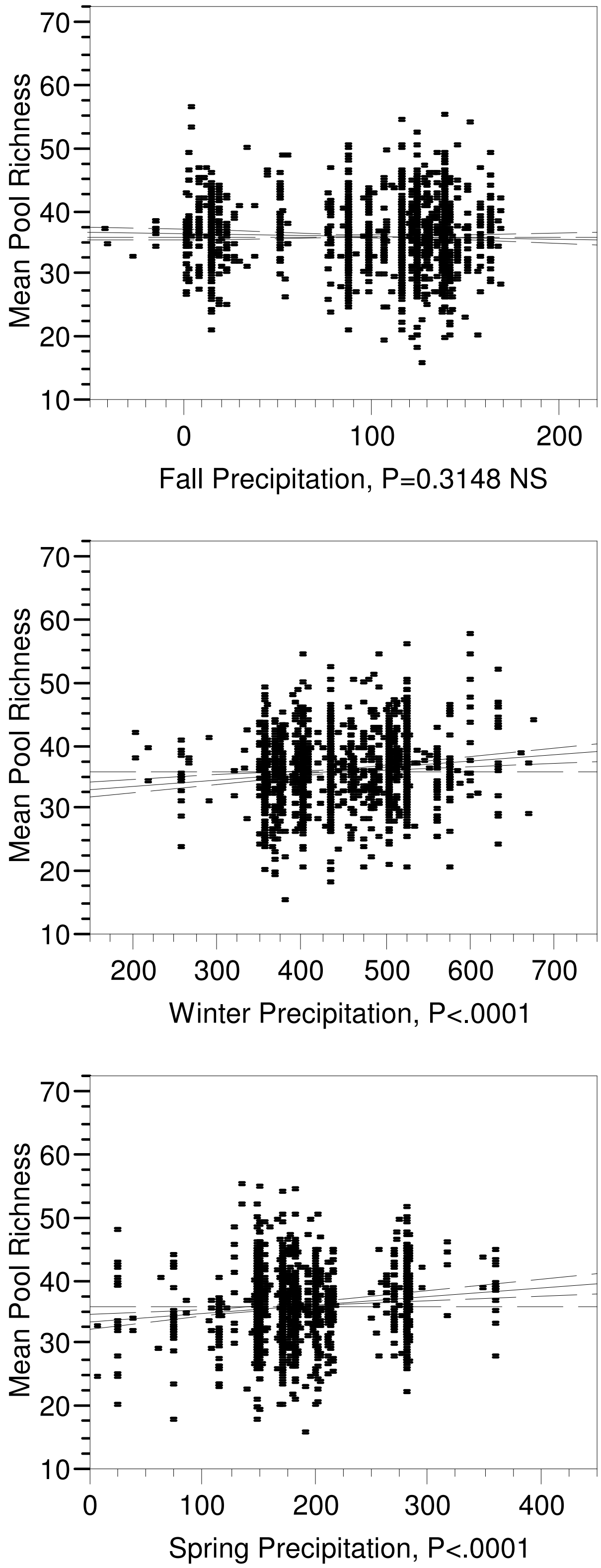


Figure 10. Linear regression of mean pool richness by average yearly temperature (C°). N = 800 pool surveys. Linear fit line has the formula $y = -2.14x + 66.2$, $r^2 = 0.06$, $p < 0.0001$

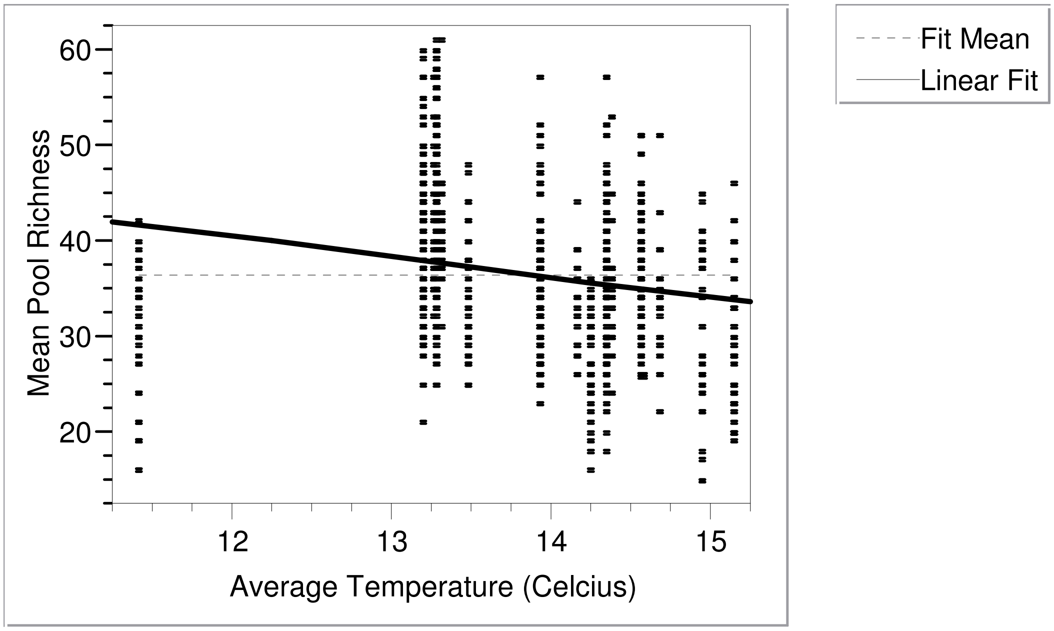


Figure 11. Metapopulation dynamics of the four most widespread and abundant vernal pool species over a five-year survey period. N = 80 pools. Species codes refer to the first three letters of genus and species (see plant species list in Appendix for full names).

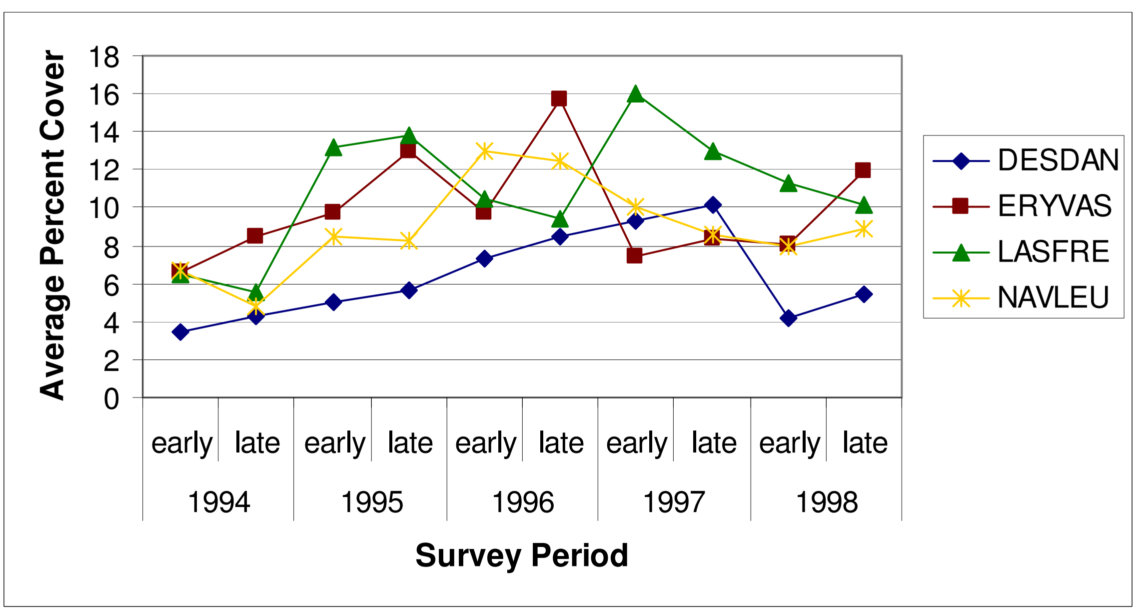


Figure 12. Temporal variation of vegetative cover within one vernal pool (COY-9B, located on the Coyote Creek site), sampled twice each year for 5 years (1994-1998).

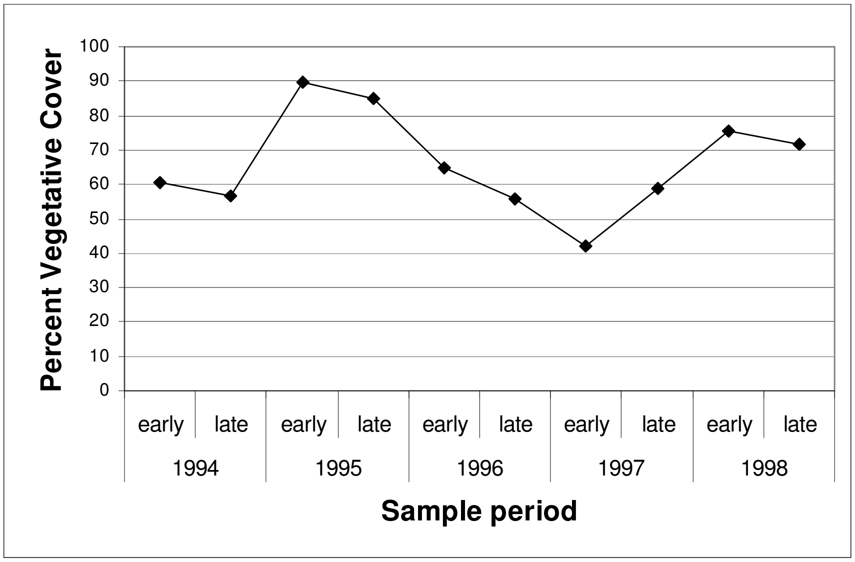


Figure 13. Plant community composition within one vernal pool (COY-9B, located on Coyote Creek site) sampled twice each year for 5 years (1994-1998). The relative abundance of the four most common species are shown individually, all other species are lumped. Species codes refer to the first three letters of genus and species (see plant species list in Appendix for full names).

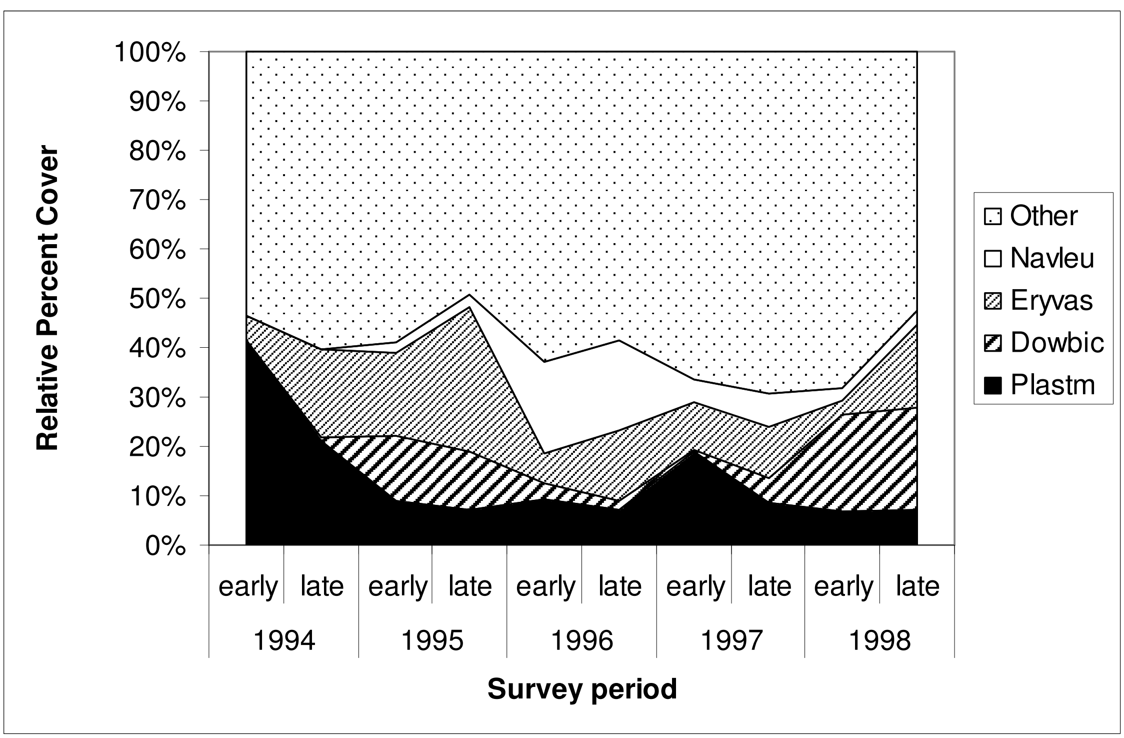
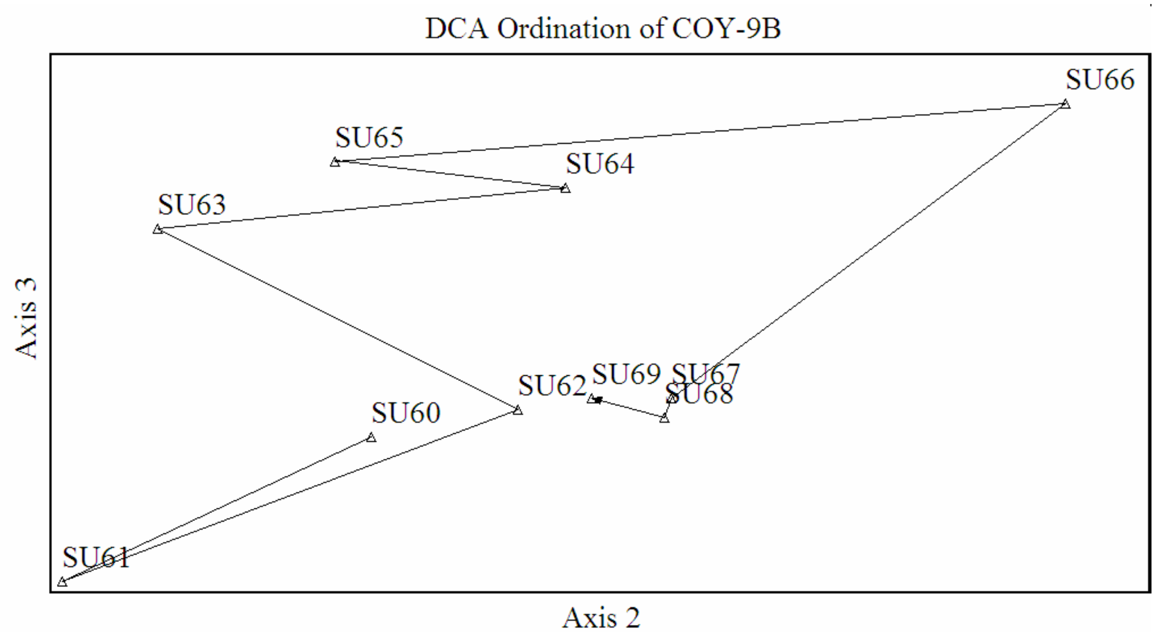


Figure 14. (A) DCA ordination with a vector overlay, SU60 corresponds to the first survey (early season, 1994) and SU69 to the last survey (late season, 1998) and (B) time lag analysis of community dynamics in vernal pool vegetation. Linear fit line has the formula $y = -3.88x + 26.77$, $r^2 = 0.1629$, $p < 0.0060$.

A.



B.

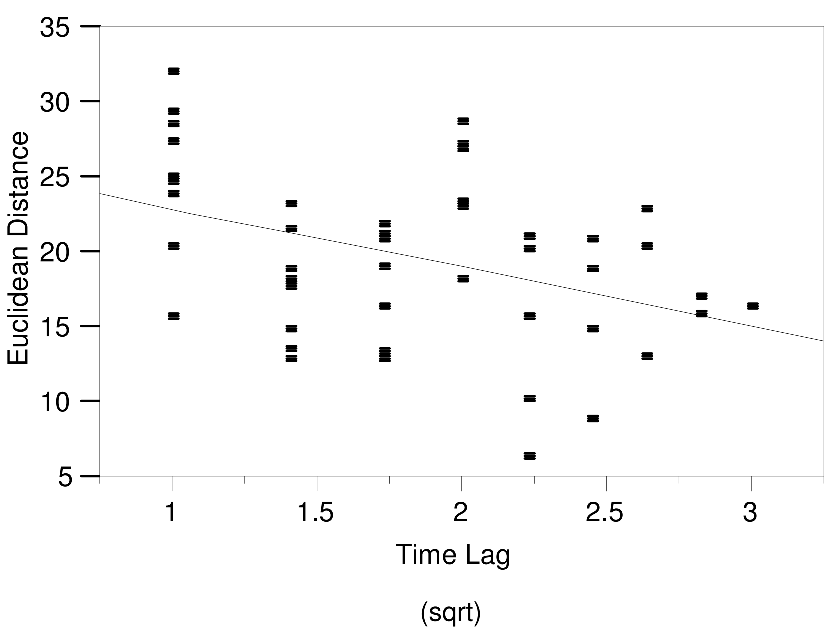


Figure 15. Metapopulation dynamics of the diagnostic species for association *Psilocarpho tenelli-Limnanthetum douglasii (ass. nov. prov)* as defined by Barbour *et al.* (2003) surveyed over 5 years. N = 80 pools.

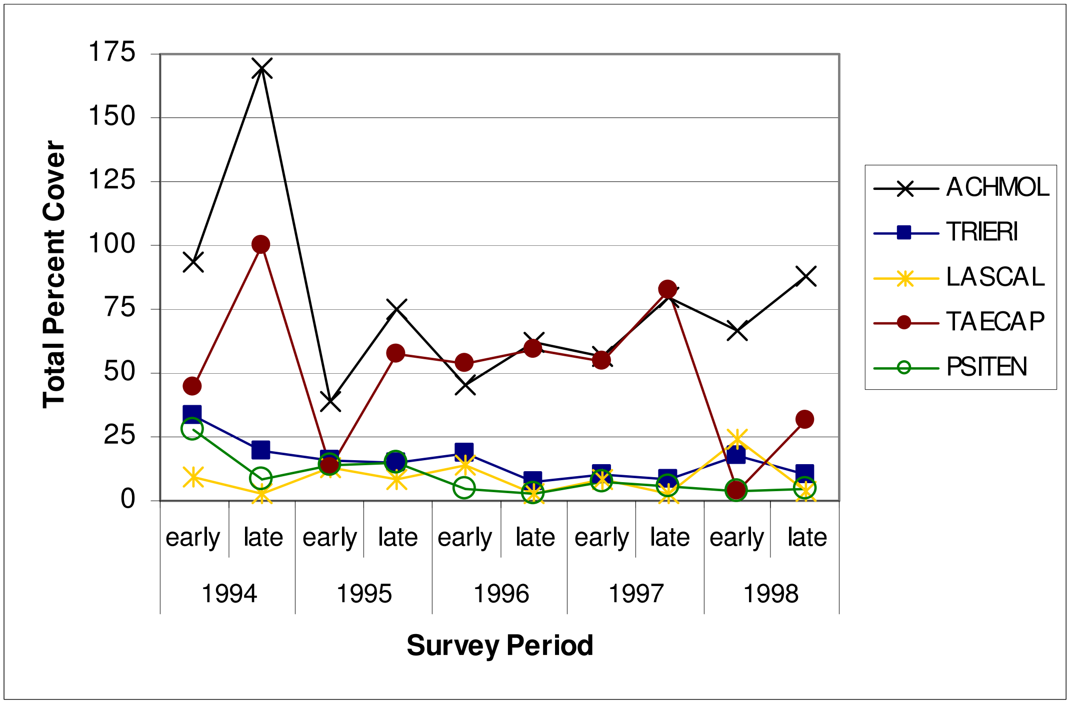


Figure 16. Metapopulation dynamics of listed taxon, *Downingia pusilla*, between the years of 1994 and 1998. Lines depict abundance during early and late season surveys. N = 80.

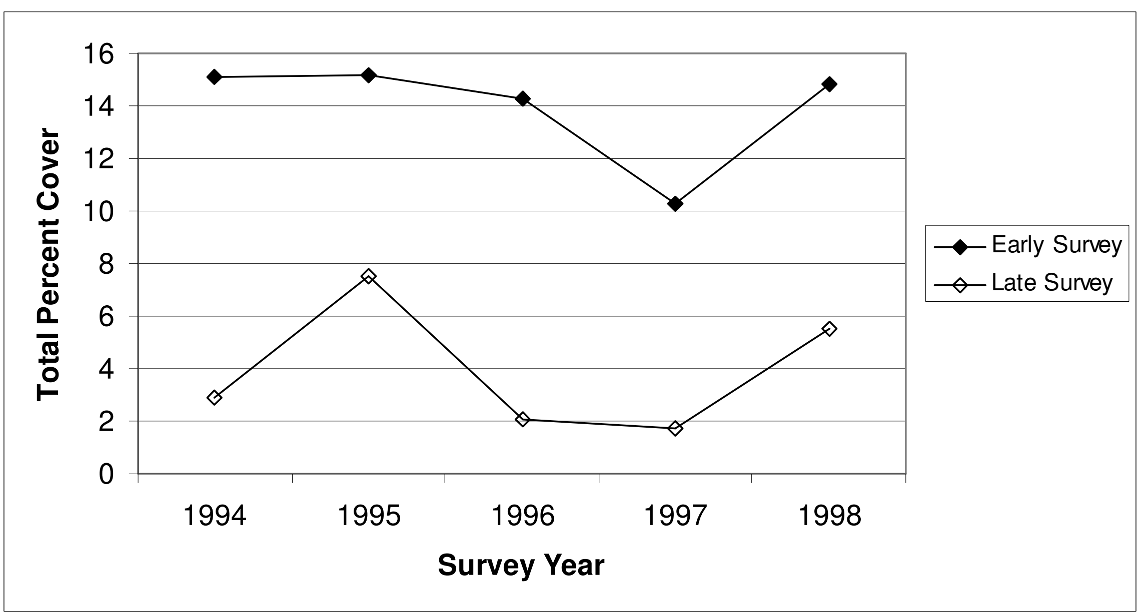


Figure 17. A DCA ordination with vector overlays that track individual vernal pools over time. Vectors connect 10 survey periods conducted twice each season for five years (1994-1998). Three sites are shown, A. Hall-Stony Creek, B. Red Bluff, and C. Truckee Creek.

A.

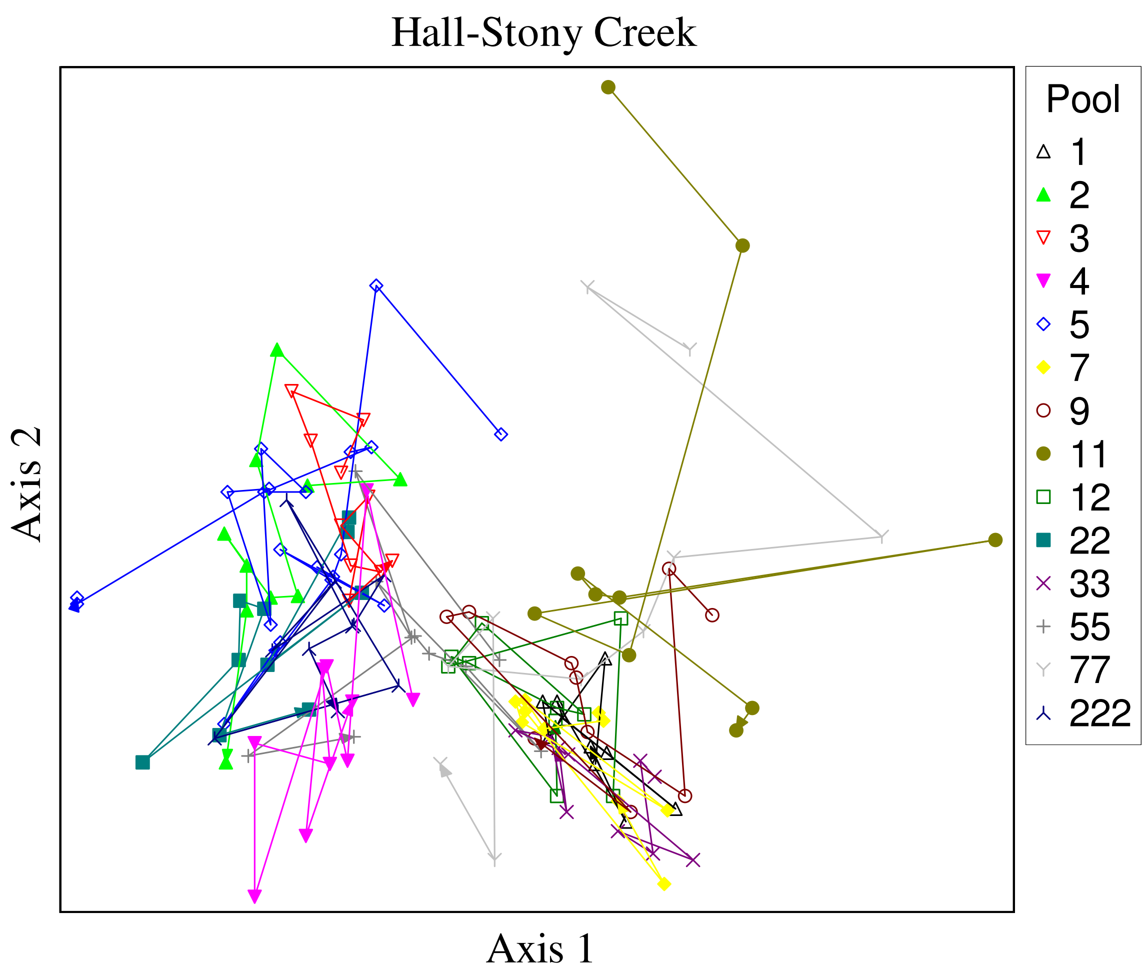


Figure 17. continued

B.

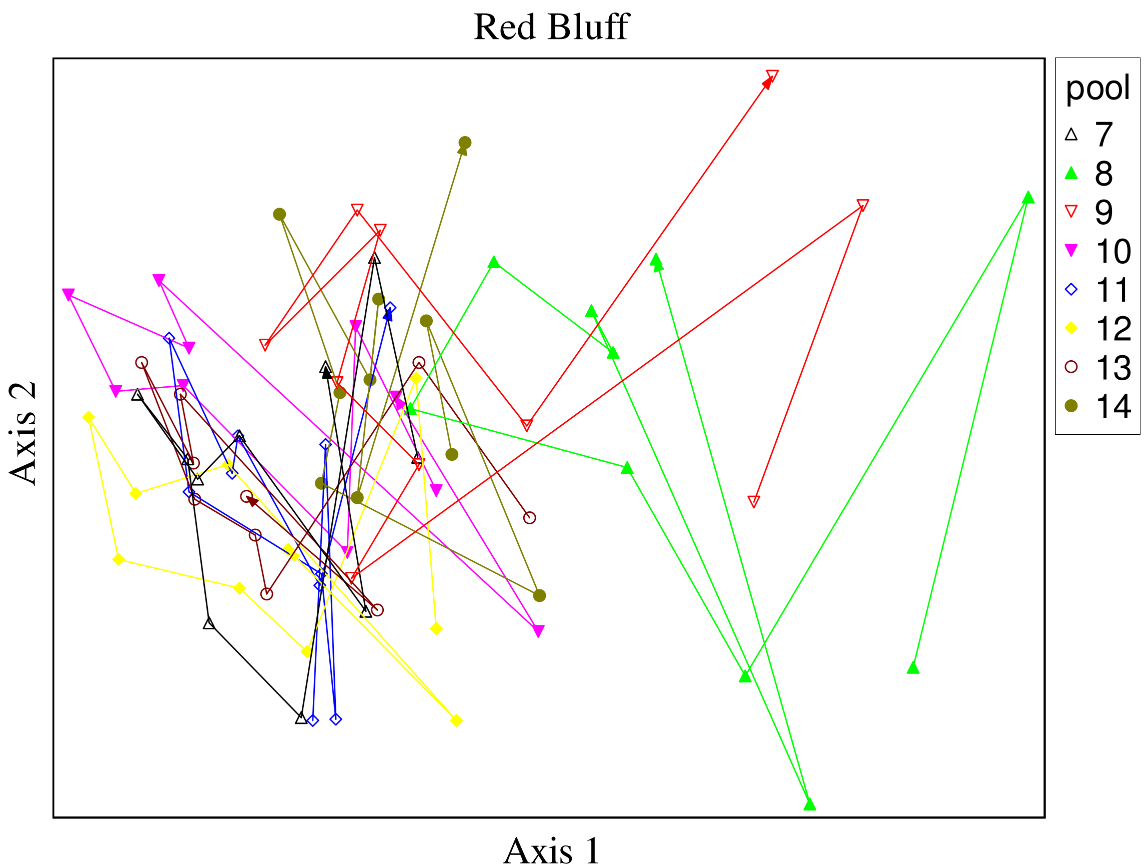
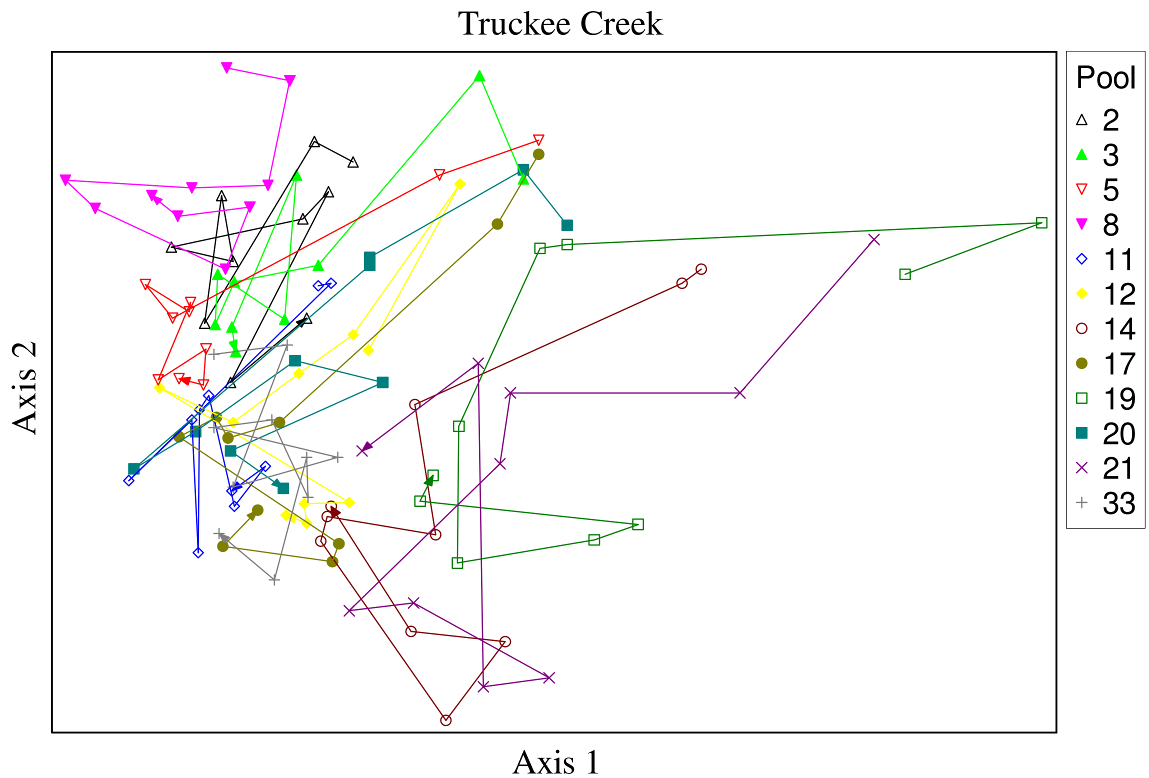


Figure 17. continued

C.



Appendix

FAMILY	SCIENTIFIC NAME	ACRONYM	GUILD	LIFE FORM
Asteraceae	Achillea millifolium	ACHMIL		Perennial Forb
Asteraceae	Achyrachaena mollis	ACHMOL		Annual Forb
Asteraceae	Agroseris heterophylla	AGRHET		Annual Forb
Poaceae	Agrostis avenacea*	AGRAVE		Perennial Graminoid
Poaceae	Agrostis elliottiana	AGRELL	VPA	Annual Graminoid
Poaceae	Agrostis microphylla	AGRMIC	VPA	Annual Graminoid
Poaceae	Agrostis sp.	AGRSPP		Graminoid
Poaceae	Aira caryophyllea*	AIRCAR		Annual Graminoid
Alismataceae	Alisma plantago-aquatica	ALIPLA		Perennial Forb
Liliaceae	Allium amplectens	ALLAMP		Perennial Forb
Poaceae	Alopecurus pratensis*	ALOPRA		Perennial Graminoid
Poaceae	Alopecurus saccatus	ALOSAC	VPI	Annual Graminoid
Amaranthaceae	Amaranthus albus*	AMAALB		Annual Forb
Amaranthaceae	Amaranthus blitoides	AMABLI		Annual Forb
Primulaceae	Anagalis arvensis*	ANAARV		Annual Forb
Asteraceae	Anthemis cotula*	ANTCOT		Annual Forb
Rosaceae	Aphanes occidentalis*	ALCARV		Annual Forb
Poaceae	Aristida oligantha	ARIOLI		Annual Graminoid
Fabaceae	Astragalus tener var. tener	ASTTEN	VPA	Annual Forb
Chenopodiaceae	Atriplex fruticulosa*	ATRFRI	VPA	Perennial Subshrub
Chenopodiaceae	Atriplex sp.	ATRSPP	VPA	Not determined
Poaceae	Avena fatua*	AVEFAT		Annual Graminoid
Brassicaceae	Barbarea orthoceras	BARORT		Perennial Forb
Asteraceae	Blennosperma nanum var. nanum	BLENAN	VPI	Annual Forb
Poaceae	Briza minor*	BRIMIN		Annual Graminoid
Liliaceae	Brodiaea californica	BROCAL		Perennial Forb
Liliaceae	Brodiaea coronaria ssp. coronaria	BROCOR		Perennial Forb
Liliaceae	Brodiaea elegans ssp. elegans	BROELE		Perennial Forb
Liliaceae	Brodiaea minor	BROMIN		Perennial Forb
Liliaceae	Brodiaea sp. (vegetative plant foliage)	BRONIF		Perennial Forb
Poaceae	Bromus diandrus*	BRODIA		Annual Graminoid
Poaceae	Bromus hordeaceus*	BROHOR		Annual Graminoid
Poaceae	Bromus japonicus*	BROJAP		Annual Graminoid
Poaceae	Bromus madritensis rubens*	BRORUB		Annual Graminoid
Poaceae	Bromus tectorum*	BROTEC		Annual Graminoid
Portulacaceae	Calandrinia ciliata	CALCIL		Annual Forb
Callitrichaceae	Callitriche heterophylla var. bolanderi	CALHET	VPA	Perennial Forb
Callitrichaceae	Callitriche marginata	CALMAR	VPA	Annual Forb
Liliaceae	Calochortus luteus	CALLUT		Perennial Forb
Asteraceae	Calycadenia fremontii	CALFRE		Annual Forb
Brassicaceae	Cardamine oligosperma*	CAROLI		Annual Forb
Cyperaceae	Carex sp.	CAREX		Perennial Graminoid
Scrophulariaceae	Castilleja attenuata	CASATT		Annual Forb
Scrophulariaceae	Castilleja campestris ssp. campestris	CASCAM	VPA	Annual Forb

FAMILY	SCIENTIFIC NAME	ACRONYM	GUILD	LIFE FORM
Scrophulariaceae	Castilleja lacera	CASLAC		Annual Forb
Scrophulariaceae	Castilleja tenuis	CASTEN		Annual Forb
Asteraceae	Centaurea solstitialis*	CENSOL		Annual Forb
Gentianaceae	Centaurium muehlenbergii	CENMUE		Annual Forb
Gentianaceae	Centaurium venustum	CENVEN		Annual Forb
Primulaceae	Centunculus minimus	CENMIN	VPI	Annual Forb
Caryophyllaceae	Cerastium glomeratum*	CERGLO		Annual Forb
Euphorbiaceae	Chamaesyce ocellata ssp. ocellata	CHAOCE		Annual Forb
Asteraceae	Chamomilla suaveolens*	CHASUA		Annual Forb
Liliaceae	Chlorogalum angustifolium	CHLANG		Perennial Forb
Gentianaceae	Cicendia quadrangularis	CICQUA		Annual Forb
Onagraceae	Clarkia lassenensis	CLALAS		Annual Forb
Onagraceae	Clarkia purpurea ssp. purpurea	CLAPUR		Annual Forb
Portulacaceae	Claytonia perfoliata ssp. perfoliata	CLAPER		Annual Forb
Scrophulariaceae	Collinsia parviflora	COLPAR		Annual Forb
Scrophulariaceae	Collinsia sparsiflora	COLSPA		Annual Forb
Convulvulaceae	Convulvulus arvensis*	CONARV		Perennial Forb
Asteraceae	Cotula coronopifolia*	COTCOR		Perennial Forb
Crassulaceae	Crassula aquatica	CRAAQU	VPI	Annual Forb
Crassulaceae	Crassula connata	CRACON		Annual Forb
Crassulaceae	Crassula tillaea*	CRATIL		Annual Forb
Convulvulaceae	Cressa truxillensis	CRETRU	VPA	Perennial Forb
Poaceae	Crypsis schoenoides*	CRYSCH	VPA	Annual Graminoid
Cuscutaceae	Cuscuta howelliana	CUSHOW	VPI	Annual Forb
Poaceae	Cynodon dactylon*	CYNDAC		Perennial Graminoid
Cyperaceae	Cyperus eragrostis	CYPERA		Perennial Graminoid
Poaceae	Dactylis glomeratus*	DACGLO		Perennial Graminoid
Poaceae	Danthonia unispicata	DANUNI		Perennial Graminoid
Poaceae	Deschampsia danthonioides	DESDAN	VPA	Annual Graminoid
Liliaceae	Dichelostemma capitatum ssp. pauciflorum	DICCAP		Perennial Forb
Liliaceae	Dichelostemma multiflora	BROMUL		Perennial Forb
Poaceae	Distichlis spicata	DISSPI	VPA	Perennial Graminoid
Primulaceae	Dodecatheon clevelandii ssp. patulum	DODCLE		Perennial Forb
Primulaceae	Dodecatheon sp.	DODSPP		Perennial Forb
Campanulaceae	Downingia bacigalupii	DOWBAC	VPA	Annual Forb
Campanulaceae	Downingia bicornuta var. bicornuta	DOWBIC	VPA	Annual Forb
Campanulaceae	Downingia concolor var. concolor	DOWCON	VPA	Annual Forb
Campanulaceae	Downingia cuspidata	DOWCUS	VPA	Annual Forb
Campanulaceae	Downingia insignis	DOWINS	VPA	Annual Forb
Campanulaceae	Downingia ornatissima var. ornatissima	DOWORN	VPA	Annual Forb
Campanulaceae	Downingia pusilla	DOWHUM	VPA	Annual Forb
Campanulaceae	Downingia sp. (not-in-flower)	DOWNIF	VPA	Annual Forb
Cyperaceae	Eleocharis acicularis var. acicularis	ELEACI	VPA	Perennial Graminoid
Cyperaceae	Eleocharis acicularis var. bella	ELEACB	VPA	Perennial Graminoid
Cyperaceae	Eleocharis macrostachya	ELEMAC	VPI	Perennial Graminoid
Cyperaceae	Eleocharis obtusa var. engelmannii	ELEOBT		Annual Graminoid

FAMILY	SCIENTIFIC NAME	ACRONYM	GUILD	LIFE FORM
Poaceae	Elymus elymoides ssp. elymoides	ELYELY		Perennial Graminoid
Poaceae	Elymus lanceolatus ssp. lanceolatus	ELYLAN		Perennial Graminoid
Onagraceae	Epilobium brachycarpum	EPIBRA		Annual Forb
Onagraceae	Epilobium cleistogamum	EPICLE	VPA	Annual Forb
Onagraceae	Epilobium densiflorum	EPIDEN		Annual Forb
Onagraceae	Epilobium pallidum	EPIPAL		Annual Forb
Onagraceae	Epilobium torreyi	EPITOR	VPA	Annual Forb
Euphorbiaceae	Eremocarpus setigerus	ERESET		Annual Forb
Geraniaceae	Erodium botrys*	EROBOT		Annual Forb
Geraniaceae	Erodium brachycarpum *	EROBRA		Annual Forb
Geraniaceae	Erodium cicutarium*	EROCIC		Annual Forb
Geraniaceae	Erodium moschatum*	EROMOS		Annual Forb
Apiaceae	Eryngium alismafolium	ERYALI	VPA	Biennial Forb
Apiaceae	Eryngium articulatum	ERYART	VPA	Perennial Forb
Apiaceae	Eryngium mathiasiae	ERYMAT	VPA	Perennial Forb
Apiaceae	Eryngium vaseyi	ERYVAS	VPI	Perennial Forb
Papaveraceae	Eschscholzia lobbii	ESCLOB		Annual Forb
Asteraceae	Filago gallica*	FILGAL		Annual Forb
Frankeniaceae	Frankenia salina	FRASAL	VPA	Perennial Subshrub
Rubiaceae	Galium sp.	GALSP.		Annual Forb
Poaceae	Gastridium ventricosum*	GASVEN		Annual Graminoid
Geraniaceae	Geranium dissectum*	GERDIS		Annual Forb
Poaceae	Glyceria declinata*	GLYDEC		Perennial Graminoid
Asteraceae	Gnaphalium palustre*	GNAPAL	VPA	Annual Forb
Scrophulariaceae	Gratiola ebracteata	GRAEBR	VPA	Annual Forb
Asteraceae	Grindelia nana	GRINAN		Perennial Forb
Poaceae	Hainardia cylindrica*	HAICYL		Annual Graminoid
Asteraceae	Helianthus annuus	HELANN		Annual Forb
Asteraceae	Hemizonia congesta ssp. luzulifolia	HEMLUZ		Annual Forb
Asteraceae	Hemizonia fitchii	HEMFIT		Annual Forb
Asteraceae	Hesperevax acaulis var. robustior	HESACA		Annual Forb
Asteraceae	Hesperevax caulescens	HESCAU	VPA	Annual Forb
Asteraceae	Holocarpha virgata ssp. virgata	HOLVIR		Annual Forb
Poaceae	Hordeum brachyantherum ssp. brachyantherum	HORBRA		Perennial Graminoid
Poaceae	Hordeum depressum	HORDEP	VPA	Annual Graminoid
Poaceae	Hordeum jubatum	HORJUB		Perennial Graminoid
Poaceae	Hordeum marinum ssp. gussoneanum *	HORMAR		Annual Graminoid
Poaceae	Hordeum murinum ssp. leporinum*	HORLEP		Annual Graminoid
Asteraceae	Hypochaeris glabra*	HYPGLA		Annual Forb
Isoetaceae	Isoetes howellii	ISOHOW	VPI	Perennial Graminoid
Isoetaceae	Isoetes nuttallii	ISONUT		Perennial Graminoid
Isoetaceae	Isoetes orcuttii	ISOORC	VPI	Perennial Graminoid
Juncaceae	Juncus bufonius var. bufonius	JUNBUB	VPA	Annual Graminoid
Juncaceae	Juncus bufonius var. congestus	JUNBUC	VPA	Annual Graminoid
Juncaceae	Juncus bufonius var. occidentalis	JUNBUO	VPA	Annual Graminoid
Juncaceae	Juncus capitatus*	JUNCAP	VPA	Annual Graminoid

FAMILY	SCIENTIFIC NAME	ACRONYM	GUILD	LIFE FORM
Juncaceae	Juncus hemiendytus var. hemiendytus	JUNHEM		Annual Graminoid
Juncaceae	Juncus leiospermus var. leiospermus	JUNLEI	VPA	Annual Graminoid
Juncaceae	Juncus nevadensis	JUNNEV		Perennial Graminoid
Juncaceae	Juncus tenuis	JUNTEN	VPA	Perennial Graminoid
Juncaceae	Juncus uncialis	JUNUNC	VPI	Annual Graminoid
Juncaceae	Juncus xiphioides	JUNXIP		Perennial Graminoid
Asteraceae	Lactuca serriola*	LACSER		Annual Forb
Asteraceae	Lagophylla glandulosa	LAGGLA		Annual Forb
Asteraceae	Lasthenia californica	LASCAL	VPA	Annual Forb
Asteraceae	Lasthenia fremontii	LASFRE	VPI	Annual Forb
Asteraceae	Lasthenia glaberrima	LASGLA	VPI	Annual Forb
Asteraceae	Lasthenia platycarpha	LASPLA	VPA	Annual Forb
Asteraceae	Layia chrysanthemoides	LAYCHR		Annual Forb
Asteraceae	Layia fremontii	LAYFRE		Annual Forb
Campanulaceae	Legenere limosa	LEGLIM	VPI	Annual Forb
Asteraceae	Leontodon taraxicoides ssp. longirostris *	LEOTAR		Annual Forb
Brassicaceae	Lepidium dictyotum var. dictyotum	LEPDIC		Annual Forb
Brassicaceae	Lepidium latipes var. latipes	LEPLAT	VPA	Annual Forb
Brassicaceae	Lepidium nitidum var. nitidum	LEPNIT	VPA	Annual Forb
Brassicaceae	Lepidium oxycarpum	LEPOXY		Annual Forb
Poaceae	Leptochloa uninerva	LEPUNI		Annual Graminoid
Asteraceae	Lessingia nemaclada	LESNEM		Annual Forb
Juncaginaceae	Lilaea scilloides	LILSCI	VPI	Annual Graminoid
Limnanthaceae	Limnanthes alba ssp. alba	LIMALB	VPA	Annual Forb
Limnanthaceae	Limnanthes douglasii ssp. rosea	LIMDOU	VPA	Annual Forb
Scrophulariaceae	Limosella aquatica	LIMAQU		Annual Forb
Polemonaceae	Linanthus liniflorus	LINLIN		Annual Forb
Polemonaceae	Linanthus sp.	LINSPP		Annual Forb
Boraginaceae	Lithospermum ruderale	LITRUD		Perennial Forb
Poaceae	Lolium multiflorum *	LOLMUL		Annual Graminoid
Poaceae	Lolium perenne*	LOLPER		Perennial Graminoid
Apiaceae	Lomatium caruifolium	LOMCAR		Perennial Forb
Apiaceae	Lomatium nudicaule	LOMNUD		Perennial Forb
Fabaceae	Lotus denticulatus	LOTDEN		Annual Forb
Fabaceae	Lotus micranthus	LOTMIC		Annual Forb
Fabaceae	Lotus purshianus var. purshianus	LOTPUR		Annual Forb
Fabaceae	Lotus wrangelianus	LOTSUB		Annual Forb
Fabaceae	Lupinus bicolor	LUPBIC		Annual Forb
Fabaceae	Lupinus nanus	LUPNAN		Annual Forb
Fabaceae	Lupinus sp.	LUPSP.		Annual Forb
Lythraceae	Lythrum hyssopifolia*	LYTHYS	VPA	Annual Forb
Asteraceae	Madia exigua	MADEXI		Annual Forb
Malvaceae	Malvella leprosa	MALLEP		Perennial Forb
Fabaceae	Medicago polymorpha*	MEDPOL		Annual Forb
Asteraceae	Micropus californicus var. californicus	MICCAL		Annual Forb
Asteraceae	Microseris acuminata	MICACU		Annual Forb

FAMILY	SCIENTIFIC NAME	ACRONYM	GUILD	LIFE FORM
Asteraceae	Microseris campestris	MISCAM		Annual Forb
Asteraceae	Microseris douglasii ssp. douglasii	MICDOU		Annual Forb
Scrophulariaceae	Mimulus guttatus	MIMGUT	VPA	Annual Forb
Scrophulariaceae	Mimulus latidens	MIMLAT	VPA	Annual Forb
Scrophulariaceae	Mimulus tricolor	MIMTRI	VPI	Annual Forb
Caryophyllaceae	Minuartia californica	MINCAL		Annual Forb
Molluginaceae	Mollugo verticillata*	MOLVER		Annual Forb
Portulacaceae	Montia fontana	MONFON	VPA	Annual Forb
Portulacaceae	Montia linearis	MONLIN		Annual Forb
Liliaceae	Muilla maritima	MULMAR	VPA	Perennial Forb
Ranunculaceae	Myosurus minimus	MYOMIN	VPA	Annual Forb
Ranunculaceae	Myosurus sessilis	MYOSES	VPA	Annual Forb
Poaceae	Nassella pulchra	NASPUL		Perennial Graminoid
Polemonaceae	Navarretia cotulifolia	NAVCOT		Annual Forb
Polemonaceae	Navarretia heterandra	NAVHET	VPA	Annual Forb
Polemonaceae	Navarretia intertexta ssp. intertexta	NAVINT	VPA	Annual Forb
Polemonaceae	Navarretia leucocephala ssp. bakeri	NAVBAK	VPI	Annual Forb
Polemonaceae	Navarretia leucocephala ssp. leucocephala	NAVLEU	VPI	Annual Forb
Polemonaceae	Navarretia pubescens	NAVPUB		Annual Forb
Polemonaceae	Navarretia tagetina	NAVTAG	VPA	Annual Forb
Hydrophyllaceae	Nemophila pedunculata	NEMPED		Annual Forb
Liliaceae	Odontostomum hartwegii	ODOHAR	VPA	Perennial Forb
Poaceae	Parapholis incurva*	PARINC		Annual Graminoid
Caryophyllaceae	Paronychia ahartii	PARAHA		Annual Forb
Crassulaceae	Parvisedum pumilum	PARPUM	VPA	Annual Forb
Boraginaceae	Pectocarya pusilla	PECPUS		Annual Forb
Apiaceae	Perideridia sp. (not-in-fruit)	PERNIF		Perennial Forb
Apiaceae	Perideridia sp. 2 (not-in-fruit)	PERSP2		Perennial Forb
Caryophyllaceae	Petrorhagia prolifera*	PETPRO		Annual Forb
Poaceae	Phalaris lemmonii	PHALEM	VPA	Annual Graminoid
Poaceae	Phalaris paradoxa*	PHAPAR	VPA	Annual Graminoid
Polemonaceae	Phlox gracilis	PHLGRA		Annual Forb
Marsileaceae	Pilularia americana	PILAME	VPA	Perennial Forb
Pinaceae	Pinus ponderosa (seedling)	PINPON		Perennial Tree
Boraginaceae	Plagiobothrys austinae	ALLAUS	VPA	Annual Forb
Boraginaceae	Plagiobothrys bracteatus	ALLBRA	VPI	Annual Forb
Boraginaceae	Plagiobothrys cognatus	ALLCOG	VPA	Annual Forb
Boraginaceae	Plagiobothrys cusickii	ALLCUS	VPA	Annual Forb
Boraginaceae	Plagiobothrys fulvus	PLAFUL		Annual Forb
Boraginaceae	Plagiobothrys greenei	ALLGRE	VPA	Annual Forb
Boraginaceae	Plagiobothrys humistratus	ALLHUS	VPA	Annual Forb
Boraginaceae	Plagiobothrys leptocladus	PLALEP	VPI	Annual Forb
Boraginaceae	Plagiobothrys stipitatus var. micranthus	PLASTM	VPA	Annual Forb
Boraginaceae	Plagiobothrys stipitatus var. stipitatus	ALLSTI	VPA	Annual Forb
Plantaginaceae	Plantago coronopus*	PLACOR		Annual Forb
Plantaginaceae	Plantago elongata	PLAELO	VPA	Annual Forb

FAMILY	SCIENTIFIC NAME	ACRONYM	GUILD	LIFE FORM
Plantaginaceae	Plantago erecta	PLAERE		Annual Forb
Plantaginaceae	Plantago lanceolata*	PLALAN		Perennial Forb
Poaceae	Pleuropogon californicus	PLECAL	VPA	Perennial Graminoid
Poaceae	Poa annua*	POAANN		Annual Graminoid
Poaceae	Poa bulbosa*	POABUL		Perennial Graminoid
Poaceae	Poa pratensis ssp. pratensis*	POAPRA		Perennial Graminoid
Poaceae	Poa secunda ssp. secunda	POASEC		Perennial Graminoid
Lamiaceae	Pogogyne floribunda	POGFLO	VPA	Annual Forb
Lamiaceae	Pogogyne zizyphoroides	POGZIZ	VPI	Annual Forb
Polygonaceae	Polygonum arenastrum *	POLARE		Annual Forb
Polygonaceae	Polygonum californicum	POLCAL		Annual Forb
Polygonaceae	Polygonum persicaria*	POLPER		Annual Forb
Polygonaceae	Polygonum polygaloides ssp. confertiflorum	POLCON	VPA	Annual Forb
Polygonaceae	Polygonum polygaloides ssp. kelloggii	POLKEL		Annual Forb
Polygonaceae	Polygonum sp.	POLSP.		Annual Forb
Poaceae	Polypogon monspeliensis*	POLMON	VPA	Annual Graminoid
Asteraceae	Psilocarphus brevissimus var. brevissimus	PSIBRE	VPI	Annual Forb
Asteraceae	Psilocarphus brevissimus var. multiflorus	PSIMUL	VPI	Annual Forb
Asteraceae	Psilocarphus oregonus	PSIORE	VPI	Annual Forb
Asteraceae	Psilocarphus tenellus var. globiferus	PSITEN	VPI	Annual Forb
Poaceae	Puccinellia simplex	PUCSIM		Annual Graminoid
Ranunculaceae	Ranunculus aquatilis var. hispidulus	RANAQU	VPA	Perennial Forb
Ranunculaceae	Ranunculus bonariensis var. trisepalus	RANBON	VPA	Annual Forb
Ranunculaceae	Ranunculus californicus	RANCAL		Perennial Forb
Ranunculaceae	Ranunculus muricatus*	RANMUR	VPA	Annual Forb
Ranunculaceae	Ranunculus occidentalis	RANOCC		Perennial Forb
Brassicaceae	Raphanus raphanistrum*	RAPRAP		Annual Forb
Brassicaceae	Raphanus sativus*	RAPSAT		Annual Forb
Polygonaceae	Rumex conglomeratus*	RUMCON		Perennial Forb
Polygonaceae	Rumex crispus*	RUMCRI		Perennial Forb
Polygonaceae	Rumex pulcher*	RUMPUL		Perennial Forb
Caryophyllaceae	Sagina apetala	SAGAPE		Annual Forb
Caryophyllaceae	Sagina decumbens ssp. occidentalis	SAGDEC	VPA	Annual Forb
Rosaceae	Sanguisorba occidentalis	SANOCC		Annual Forb
Saxifragaceae	Saxifraga integrifolia	SAXINT		Perennial Forb
Poaceae	Scribneria bolanderi	SCRBOL		Annual Graminoid
Asteraceae	Senecio vulgaris*	SENVUL		Annual Forb
Malvaceae	Sidalcea malvaeflora	SIDMAL		Perennial Forb
Caryophyllaceae	Silene gallica*	SILGAL		Annual Forb
Asteraceae	Soliva sessilis*	SOLSES		Annual Forb
Asteraceae	Sonchus asper ssp. asper*	SONASP		Annual Forb
Caryophyllaceae	Spergula arvensis ssp. arvensis*	SPEARV		Annual Forb
Caryophyllaceae	Spergularia macrotheca var. leucantha	SPEMAC	VPA	Perennial Forb
Caryophyllaceae	Spergularia rubra*	SPERUB		Annual Forb
Caryophyllaceae	Spergularia villosa*	SPEVIL		Perennial Forb
Poaceae	Taeniatherum caput-madusae*	TAECAP		Annual Graminoid

FAMILY	SCIENTIFIC NAME	ACRONYM	GUILD	LIFE FORM
Apiaceae	Torolis nodosa*	TORNOD		Annual Forb
Lamiaceae	Trichostema lanceolata	TRILAN		Annual Forb
Lamiaceae	Trichostema laxum	TRILAX		Annual Forb
Fabaceae	Trifolium albopurpureum var. albopurpureum	TRIALB		Annual Forb
Fabaceae	Trifolium barbigerum var. barbigerum	TRIBAR		Annual Forb
Fabaceae	Trifolium bifidum var. bififum	TRIBIF		Annual Forb
Fabaceae	Trifolium ciliolatum	TRICIL		Annual Forb
Fabaceae	Trifolium depauperatum var. amplectens	TRIAMP		Annual Forb
Fabaceae	Trifolium depauperatum var. depauperatum	TRIDEP		Annual Forb
Fabaceae	Trifolium depauperatum var. truncatum	TRITRU		Annual Forb
Fabaceae	Trifolium dubium*	TRIDUB		Annual Forb
Fabaceae	Trifolium fucatum	TRIFUC		Annual Forb
Fabaceae	Trifolium glomeratum*	TRIGLO		Annual Forb
Fabaceae	Trifolium gracilentum var. gracilentum	TRIGRA		Annual Forb
Fabaceae	Trifolium hirtum*	TRIHIR		Annual Forb
Fabaceae	Trifolium microcephalum	TRIMIC		Annual Forb
Fabaceae	Trifolium microdon	TRIMCD		Annual Forb
Fabaceae	Trifolium subterraneum*	TRISUB		Annual Forb
Fabaceae	Trifolium variegatum	TRIVAR	VPA	Annual Forb
Fabaceae	Trifolium willdenovii	TRIWIL		Annual Forb
Scrophulariaceae	Triphysaria eriantha ssp. Eriantha	TRIERI		Annual Forb
Liliaceae	Triteleia hyacinthine	TRIHYC	VPA	Perennial Forb
Poaceae	Triticum aestivum*	TRIAES		Annual Graminoid
Typhaceae	Typha latifolia (seedling)	TYPLAT		Perennial Forb
Typhaceae	Typha sp. (seedling)	TYPSPP		Perennial Forb
Scrophulariaceae	Veronica americana	VERAME		Perennial Forb
Scrophulariaceae	Veronica peregrina ssp. xalapensis	VERPER	VPA	Annual Forb
Fabaceae	Vicia sativa ssp. nigra*	VICSAT		Annual Forb
Fabaceae	Vicia villosa ssp. villosa*	VICVIL		Annual Forb
Poaceae	Vulpia bromoides*	VULBRO		Annual Graminoid
Poaceae	Vulpia microstachys (vars.)	VULMIC		Annual Graminoid
Poaceae	Vulpia myuros (vars.)*	VULMUR		Annual Graminoid
Asteraceae	Xanthium strumarium	XANSTR		Annual Forb