Vernal pool restoration and management issues for Yolo County’s Grasslands Regional Park

Report by: Students of UC Davis’ Restoration Ecology Class (ENH 160), Spring 2010, compiled by Sarah Hoskinson and Valerie Eviner

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Notes

This document is a product from UC Davis' Restoration Ecology class (ENH 160) in the spring of 2010, and is a result of the hard work of the students. Each topic was written by an individual student, as noted at the start of each report. Some of these reports have been modified in an effort to synthesize and streamline this report. Due to logistical issues (inability to import parts) some figures are missing. Synthesis sections derive from class discussion.

Acknowledgements

We thank Kent Reeves and Scott Lines from the Yolo County Parks and Resources Department for guidance on key topics that they needed addressed, lecturing to the lab section, giving tours and background information on the site, and allowing us access to the study site. We also thank Carol Whitham for sharing her knowledge of vernal pools with the lab section during field trips to the study site.

This project was made possible through the University of California, Davis and the USDA NRI CSREES Managed Ecosystem Program through a grant to Valerie Eviner.

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INTRODUCTION TO THE REPORT

The integration of science and management is a highly desirable goal for both the management and scientific communities. There are many obstacles to this goal, but some particularly important challenges include:

1. The need to train students who are familiar with both science and management, and who can balance the tendency of science to be focused and rigorous, with the need for management to consider many factors, many of which are difficult to control or isolate.
2. The difficulty in collecting and synthesizing an overwhelming amount of scientific literature that is scattered across many sources.
3. The challenge in both science and management to consider:
   a. A wide diversity of interacting goals and constraints, and the potential for trade-offs and win-win scenarios
   b. Changes in patterns and controls over biotic and abiotic factors over space and time

This report is a result of the collaboration between the Yolo County Parks and Resources Department and the Restoration Ecology Class (ENH 160) at University of California, Davis. The Yolo County Parks and Resources Department graciously agreed to serve as a test case for this project, and set the stage for it by:

- providing a list of key questions, topics, challenges, organisms, and ecosystem services of concern
- providing access to lab students for monitoring and observational activities
- lecturing in the laboratory section about the challenges of implementing restoration projects, and providing background information on Grasslands Regional Park and its management goals.

The overall goal of class project was to develop a restoration handbook for the Grasslands Regional Park vernal pool complex. Each student was in charge of a different restoration goal (a key organism or vernal pool characteristic), and was instructed to do a thorough literature search to determine:

- the status of that organism or vernal pool characteristic
- the key ecological and socio-economic controls over that goal
- successes and failures of previous management/restoration attempts
- key gaps in knowledge
- possible funding sources for management and restoration of their goal

Using this information, each student was instructed to design a management/restoration plan for their goal. Our hope is that these individual reports provide a handy literature review on key individual restoration and management goals.

These individual projects were just the start of the instructional, and project-wide goal. Our ultimate goal was to develop some overall management options based on *all* of these goals—coming up with alternative management scenarios that carefully stressed the multiple goals they could achieve, and the tradeoffs in other goals. To do this, after the individual phase of the project was completed, each student presented a summary of their individual projects. We then spent a few class sessions integrating all of the individual projects to come up with management scenarios that could attain these multiple goals. Results of these discussions can be found in the "project synthesis" section. In addition, the end of each student's individual report includes a revised management plan to encompass their goal, in addition to a broader suite of goals. A full description of the students' assignment can be found in the Appendix.

While this report is far from perfect or complete, it should be a handy guide for both science and management- providing literature reviews on many important topics in California's vernal pools, and pointing to some key holes in our scientific understanding that will aid with the implementation of restoration and management programs. The management recommendations are very preliminary due to time limitations, but the literature reviews and lists of trade-offs should provide important information for those managing California vernal pools.

<u>Overview of our project on the Yolo County Grasslands Regional Park:</u>

Yolo County's Grasslands Regional Park is an approximately 640 acre area located roughly 2 miles southeast of Davis at the southwestern corner of Yolo County. The Grasslands Park consists of a variety of habitat types and management areas, including vernal pools, grasslands, and an oak planting area that are managed primarily for conservation of plant and animal species and recreation.

Aerial photo of Yolo County Grasslands Regional Park.

Our class project focused on the 184 acre vernal pool management area, which includes the vernal pools, swales and bordering mesic grassland. The class focused on 10 naturally occurring pools and the 5 pools that were created as additional habitat for two listed vernal pool grass species. The general management goals and requirements of the vernal pool complex include:

- conserve key federal and state listed species
- enhance populations of a vernal pool grass species endemic to Grasslands Park (Crampton’s tuctoria) and a listed vernal pool grass species (Colusa grass)
- control invasive plant species
- enhance native diversity
- manage surrounding upland grasslands (e.g. invasive plant control, burrowing owl habitat, recreation) without impacting the vernal pools

Our overall class goals included:

1. How do we manage existing vernal pools to support a broad array of native species and minimize invasives over time? (dealing with high annual variability in rainfall, and potential climate change)
   a. What are the key ecological processes needed for the site to sustain itself over time?
   b. What are the requirements of different target species, and can the existing vernal

pools meet these (individually, and as a complex of pools)?

c. Given the required management goals, which other species are most likely to be promising restoration goals?

d. How do upland habitats need to be managed to support vernal pool goals (without compromising upland restoration goals)?

e. Can the vernal pool complex at this site maintain itself over the long-term, or is there a need to create broader-scale links with other vernal pools across the region?

Two of the natural vernal pools in April 2010 (Pool 9B on the left, pool 9A on the right).

2. What is the potential role of recreated vernal pools in supporting species currently on-site (particularly endangered/ threatened), as well as other species not currently on site?
   a. Is there a need for different depths/inundation periods to be present on site?
   b. What shape should these pools be (deep pools? Shallow swales?)
   c. What size should they be?
   d. Where should they be placed? (Are there key spatial gaps in current vernal pool distribution needed for gene flow/pollination/dispersal, etc.?)
   e. Will the creation of new vernal pools potentially create more problems? (altered hydrology, increased invasion among pools, etc.)?
   f. Can we manage for threatened species and higher diversity of other vernal pool species, or should all pools focus on threatened?

The created vernal pool complex in April 2010. Three of the 5 created pools are shown.

Lab characterization of vernal pools:

The lab section of the class surveyed the 5 created vernal pools and 5 of the naturally occurring pools to determine the current conditions of the pools (e.g. water characteristics, pool size, dry- down rate). The lab also used the 2005 CALFED Conservation and Management Plan for Grasslands Regional Park for information on additional pool characteristics for the 5 focal natural pools that the lab characterized, as well as the 5 other natural pools on site. The pool characteristics that were most critical to designing the restoration and management plan are summarized in the table below. The table contains data collected by the lab (in bold) and information from the 2005 CALFED report. The pools are identified on the map below.

Water temperature, conductivity, and salinity data were collected with a handheld YSI probe from at least three locations within each pool. Topographic complexity and stressor information was collected using the California Rapid Assessment Method for Wetlands and Riparian Habitats as a guideline (Collins, J.N., E.D. Stein, M. Sutula, R. Clark, A.E. Fetscher, L. Grenier, C. Grosso, and A. Wiskind. 2008. California Rapid Assessment Method (CRAM) for Wetlands and Riparian Areas www.cramwetlands.org).

Vernal pool map

Pool complex #	*# pools in complex*	***Estimated pool size (m^2)***	*Max water depth (cm)*	*Avg water depth Feb-May 2005 (cm)*	*Max. inundation length in wet year (20" rain) vs dry year (15" rain)*	*Soil type*	*Depth to hard-pan*	***Topogra-phy***	***Water temp (^0C)***	***Water salinity (ppt)***	***Water condu-ctivity (uS)***	*Listed species known to be present*	***Stressors***
A1	1	Small				Marvin	Deep						
A2	2	Small				Marvin	Deep						
A3	2	Small, moderate			60 days wet yr; 40 days dry yr	Marvin	Deep						
A4	4	**Small, moderate, large (206, 288, 446, 1017)**	34.8			Pescadero	Shallow	**Some complexity**	**High (29.1)**	**High (0.35)**	**High (550)**	Tadpole shrimp, linderiella nearby	**pepperweed**
3	2	Small		21		Marvin & Pescadero	Mixed					High diversity of invertebrates	
4	3	**Small, large (110, 591, 651)**		17	98 days wet yr; 64 days dry yr	Pescadero	Shallow					Colusa grass, tadpole shrimp, low diversity of invertebrates	**Farm drainage, transportation, adjacent agriculture**
6	3-4	**Large (591)**		6, 6, 11	105 days wet yr; 62 days dry yr	Marvin & Pescadero	Mixed	**Uniform**				Tadpole shrimp	**Grading/ compaction, vegetation management, livestock, recreation**
7	1	Small				Marvin	Deep						
9a	1	**Very large (10,804)**	30.4		120 days wet yr; 85 days dry yr	Marvin & Pescadero	Mixed	**Complex, several "subpools" & hummocks**	**Moderate (26.1) vs low (23.8)**	**Moderate (0.18)**	**Moderate (373.1)**	Crampton's tuctoria, Colusa grass, tadpole shrimp, alkali milk vetch in	

												swales	
9b	1	**Very large**	52.5	5, 7, 16, 24, 25	115 days wet yr; 80 days dry yr	Pescadero & Capay	Mixed	**Complex, several “subpools” & hummocks**	**Low (24.3)**	**Moderate (0.15)**	**Moderate (245.3)**	Crampton’s tuctoria, tadpole shrimp, high diversity of invertebrates, alkali milk vetch in swales	**pepperweed**
Created	5	**Small (210-280)**				Marvin	Shallow	**Likely uniform**	**Moderate (27.2)**	**Low (0)**	**Low (1.55)**		**Recreation, upland management, livestock**

Project synthesis

The class focused on management recommendations and considerations to enhance native species diversity on the study site while minimizing invasive species. The class started by listing which species could potentially live in each pool based on pool characteristics (see table above for the key pool characteristics that the class focused on). Then the class considered which species are not likely to co-occur in the same pools to identify key tradeoffs among species (for example, vernal pool fairy shrimp and linderiella vs. conservancy fairly shrimp and tadpole shrimp). Lastly the class considered how management needs for the pools and adjacent upland grasslands may limit where species can live, and how these management tools should be used to manage for the greatest number of species.

Native species diversity- The following table lists the species with specific habitat needs that would be best suited to each pool. The class recommends that special attention be given to managing for/ restoring these species in these pools. Several of the focal native plant species and some of the animal species can thrive in a wide range of conditions, so the class considers them to be "generalist" species and believes that they should be suitable for any pool. The generalist native plant species that are expected to thrive on pool edges include: Marbles, alkali milk vetch, San Joaquin spearscale, and popcorn flower. Marbles, popcorn flower, goldfields, downingia, coyote thistle, vernal pool dodder, and owl's clover are expected to surivive in most of the pools. Most pools are also expected to be able to support dabbling ducks and solitary bees.

Pool complex #	***Suitable plant species***	***Suitable animal species***
A1	Generalist species only	Generalist species only
A2	Generalist species only	Generalist species only
A3	Generalist species only	Western spadefoot toad
A4	Alkali milk vetch, saltgrass, Colusa grass	Tadpole shrimp, conservancy fairy shrimp, linderiella
3	Alkali milk vetch	Generalist species only
4	Colusa grass, alkali milk vetch, San Joaquin spearscale	Tadpole shrimp, conservancy fairy shrimp
6	Colusa grass, tuctoria, San Joaquin spearscale	Tadpole shrimp, conservancy fairy shrimp
7	Generalist species only	Generalist species only
9a/9b	Tuctoria, Colusa grass (not currently in 9b), Alkali milk vetch	Tadpole shrimp, conservancy fairy shrimp, Vernal pool snail, Dabbling ducks (fall/winter- feeding in pools)
Created	San Joaquin spearscale, alkali milk vetch, Colusa grass	Conservancy fairy shrimp (in deepest pool)

Invasive plant management- Unfortunately, most pools are also suitable for the invasive plant species that are on site. Russian thistle, Mediterranean barley, Perennial pepperweed, and Manna grass are all able to thrive on the pool edges and bottoms if not controlled, and Bindweed and Italian ryegrass are threats to pool edges.

The class discussed several management options to control the invasive plants on site. The class recommends continuing to hand weed invasive plants within 50 ft of the vernal pools due to concerns of the effects of herbicide on other vernal pools species. An important exception is applying herbicide by hand specifically to perennial pepperweed late in the season when the pools are drying out to avoid contaminating the pool. Installing larger fences may be an option to keep tumbleweeds from establishing in the vernal pool area. Although the class recommends grazing to control invaders, there are several important tradeoffs to consider:

1) Grazing pools in the spring may be the most effective time to control many invaders, but it would negatively impact many of the key native plant species, especially the natives that are active later than the invaders (e.g. Colusa grass, Hedge hyssop). Although grazing in the winter can also help control invaders, grazing from January-March can crush Western spadefoot toad eggs. One solution may be to time the grazing to manage different pools for the Western spadefoot toad vs. the key native plant species that are impacted by grazing (e.g. Colusa grass).
2) Grazing in the wet season creates microdepressions which may increase the survival of marbles, downingia, popcorn flower, and fairy shrimp in dry years. However, grazing in the wet season increases erosion and pool turbidity, which can negatively impact linderiella.
3) It is recommended to graze the upland area surrounding the pools in the spring to control invaders with high evapotranspiration rates in order to lengthen pool inundation periods. However, grazing around the pool edges in the spring can interfere with the dabbling duck nesting sites. One solution may be to rotate the timing of grazing among pool edges. Also, grazing may compact the soil in the areas surrounding the pools, which would interfere with the solitary bee nesting. Sheep could be used instead of cows to minimize compaction, but then there potentially wouldn't be as many microdepressions.
4) Other methods of control may be necessary for some of the key invaders on site because of toxicity to grazers. For example, bindweed may be toxic to cattle and horses, Russian thistle may be toxic to lambs.

Other management considerations- Other management considerations that are important to meet the multiple goals for the vernal pool complex include:

1) Maintaining the fire break by discing 20 ft around the vernal pools.
2) Occassional disturbances around the pool edges may help promote Alkali milk vetch and San Joaquin spearscale. However, these disturbances may also make the edges more susceptible to invaders. This is especially a concern around the newly disturbed edges of the created pools.
3) Minimizing soil compaction and decreasing road use in the upland areas may help promote the pool edge/ upland species (e.g. Western spadefoot toad, solitary bees, alkali milk vetch).
4) Owl's clover may decrease the establishment of other native species through parasitization, so the class recommends planting owl's clover after other species have established.

Regional vernal pools overview

The distribution of vernal pool types across the Central Valley

Jen Balachowski

Part I: Rationale and Literature Review

I. Background and Need for Spatial Considerations in Restoration

Vernal pools are seasonally flooded, ephemeral wetlands that host a diverse assemblage of organisms, and occur under specific climatic, geological, and hydrological conditions. They form in preexisting landscape depressions, and persist through the wet season because they are underlain by a minimally permeable subsurface layer that prevents rapid drainage (Keeler-Wolf et al. 1998, Rains et al. 2006, Rains et al. 2008). In California, vernal pools occur along coastal terraces, on basaltic lava flows, and in broad, alluvial valleys (in particular, the Central Valley) (Zedler 1987). California's vernal pools are home to many rare, endemic, and ecologically sensitive plant and animal species, and as such, they are a concern for environmental policymakers and conservationists (Holland 1998, Keeler-Wolf et al. 1998).

State of Vernal Pools

Land use change in California poses a formidable threat to vernal pools and vernal pool landscapes. While it is unknown exactly how much vernal pool area has been lost over the past 200 years, it has been estimated that roughly 65-90% of the vernal pool landscape in the Central Valley has been destroyed by practices like mineral extraction, agriculture, heavy grazing, and urbanization (Goettle 1997, Holland 1998, Barbour et al. 2005). While the preservation of existing vernal pool complexes is the most reliable way to ensure long-term persistence of the ecosystem and its native species (Witham, personal communication), regulatory agencies and environmental non-governmental organizations have begun to consider and engage in vernal pool restoration and mitigation in the hope of recovering lost landscapes.

Spatial Concerns for Restoration

Successful vernal pool conservation and restoration programs will consider not only the pools and pool complexes themselves, but also the distribution, dynamics, and roles of pools and complexes across the broader landscape (Keeler-Wolf et al. 1998, Zedler 2003). While the outright destruction of vernal pools and complexes is of major concern for conservation and restoration practitioners, anthropogenic land use change has also impacted the ways in which existing vernal pools interface with one another and their surroundings. Hydrological connections between vernal pools and upland habitat, other vernal pools, ephemeral streams, and entire watersheds have been demonstrated, but their nature and significance are still relatively poorly understood. For this reason, it is still difficult to predict how small, local land use change will affect vernal pool ecosystems (Rains et al. 2006). Understanding the nature of connectivity in vernal pool systems will be a critical component of any research program designed to inform and improve conservation and restoration.

Complexes are often spatially correlated with specific geological features because the location of vernal pools is dependent upon the presence of a low permeability subsurface soil layer (e.g., hardpan, claypan, etc.) (Rains et al. 2008). Successful conservation and restoration efforts in the Central Valley will also require thorough inventories of existing pool and complex distributions, and a better understanding of how geological and hydrological factors influence function at the landscape level (Keeler-Wolf et al. 1998). Because pool type also has the potential to influence species composition, restoring and mitigating the effects of anthropogenic activities will require an understanding of how pools are arranged across the landscape.

Classification and location of vernal pool types is also necessary if restoration efforts are to be made representative of historical landscape composition. This is particularly true if mitigation via the creation of new vernal pools is to be considered a viable conservation method. In a survey of vernal pool mitigation projects in California, Wacker and Kelly (2004) discovered that project-by-project edaphic considerations often do not scale up to landscape-level conservation of vernal pool types. The authors concluded that mitigation had inadvertently made common types (i.e. hardpan) more common, while making rare types (i.e. volcanic) even rarer. Though more often than not, mitigation sites replicate edaphic conditions of destroyed pools, they often fail to cover the same total area. When mitigation projects are not completed on similar edaphic conditions, it is often because the developer purchased credits from a mitigation bank in which only common types were available. By considering the distribution of vernal pool types, further loss of rare pools may be prevented, and mitigation efforts may be made more representative of restoration goals.

Though ecologically, vernal pools are often regarded as isolated, island-like populations or metapopulations (Holland and Jain 1981, Zedler 2003), connectivity among pools and with surrounding lands has and will continue to play an important role in population dynamics and evolution (Zedler 2003, Rains et al. 2006). When conserving and restoring vernal pools, genetic considerations like the maintenance of evolutionary potential and important corridors for gene flow should be included, particularly for species that are obligate outcrossers (Neale et al. 2008). Genetic concerns affecting small populations (e.g., inbreeding depression, outbreeding depression, antagonistic gene flow) must also be considered to avoid the creation of genetically depauperate restored populations. At the community level, important, spatially-dependent species interactions (e.g., plant-pollinator) must also be maintained if restoration efforts are to be successful (Keeler-Wolf et al. 1998).

The review that follows offers a brief summary of the distribution of vernal pool types, geological and hydrological factors affecting vernal pools, and influence of connectivity on vernal pool ecology.

II. Literature Review

Distribution of Vernal Pool Types in the Central Valley

Vernal pools have been classified on the basis of geological, edaphic, and biological characteristics (Holland 1986, Barbour et al. 2005). In an unpublished, preliminary report for the California Department of Fish and Game, Holland (1986) developed a seven-category system of classification for vernal pools that is still widely cited in scientific literature. A key feature of the Holland system is that it delineates vernal pools based on subsurface substrate—hardpan, claypan, and volcanic (basalt flow or lahar).

Vernal pool types, as defined by the Holland system, are summarized below:

- Northern Hardpan—old and very acidic hardpan soils with hummocky microtopography; typically found on old alluvial terraces in the eastern Great Valley
- Northern Claypan—old and alkaline soils with lower microrelief than Northern hardpan; typically found in the central San Joaquin Valley
- Northern Basalt Flow—thin soils with frequent filling and emptying of pools; typically found in western Sierra foothills
- Northern Volcanic Mudflow—pyroclastic flows and lahars with shallow soils; typically found on mesas in Blue Oak-Foothill Pine woodland

- Southern Interior Basalt Flow—shallow soils over bedrock that empty by evaporation; found only on the Santa Rosa plateau
- San Diego Mesa Hardpan—similar to Northern Hardpan but with coarser and stonier soils; believed to be extirpated by urbanization
- San Diego Mesa Claypan—less saline/alkaline than Northern Claypan; found on marine terraces between San Diego and Mexico

A more recent report from the California Department of Fish and Game (Keeler-Wolf et al. 1998) amended the Holland system by considering the presence of key endemic species, and resulted in the creation of 17 vernal pool regions (vernal pools types within each region are still classified according to the Holland system). An updated report on vernal pool classification and types has been compiled by the Department of Fish and Game, but has yet to be released or published (need citation).

Below is a list of vernal pool regions located within the Central Valley, along with their associated types, ecological threats, and restoration potential, according to the most recently available system developed by California Fish and Game (1998):

- Northwestern Sacramento Valley Region
    - Counties: Shasta, Tehama, Glenn, Colusa,
    - Vernal pool types: primarily Northern Hardpan; limited Northern Volcanic Mudflow near Black Butte Reservoir
    - Threats: ranching, urban expansion, and conversion of land to *Eucalyptus* farms
    - Restoration potential: limited on graded agricultural land; may be possible to alter timing and intensity of grazing on rangelands
- Northeastern Sacramento Valley Region
    - Counties: Tehama, Butte, Yuba, Colusa
    - Vernal pool types: Northern Hardpan, Northern Basalt flow, Northern Volcanic Mudflow
    - Threats: Volcanic types are not highly threatened, though grazing does occur; owing to its lower valley location, Northern Hardpan is affected by urbanization, agriculture, and long-term, intensive grazing
    - Restoration potential: urbanized and subdivided land cannot be restored; privately owned and managed rangelands may benefit from shorter grazing periods
- Southeastern Sacramento Valley Region
    - Counties: Nevada, Placer, Sutter, El Dorado, Sacramento, Amador, Calveras, San Joaquin
    - Vernal pool types: Northern Hardpan and Northern Volcanic Mudflow
    - Threats: development and conversion of rangelands to vineyards; fragmentation of protected pools is likely unsustainable
    - Restoration potential: much restoration has been undertaken in this region and was deemed unsuccessful; best prospects are in large, less disturbed complexes south of Sacramento
- Solano-Colusa Region
    - Counties: Glenn, Colusa, Yolo, Solano
    - Vernal pool types: Northern Claypan, Northern Hardpan (many alakaline and saline)
    - Threats: agriculture, water diversion, road building, residential developent

    - Restoration potential: areas with over-grazing show best potential; conversion to agriculture or housing are less likely to be restored
- Livermore Region
    - Counties: Contra Costa, Alameda, San Joaquin, Santa Clara
    - Vernal pool types: Northern Claypan, perhaps some Northern Hardpan; some strongly alkaline
    - Threats: residential development, paving, agriculture, grazing, water diversions, and degradation of overall water quality
    - Restoration potential: little prospect exists due to a small proportion of soil types
- Central Coast Region Counties:
    - Counties: San Mateo, Santa Clara, Santa Cruz, Stanislaus, Merced, San Benito, Monterey, Fresno,
    - Vernal pool types: "Northern Vernal Pools" (vague due to lack of information gathered); some on serpentine
    - Threats: military operations, road development, agriculture
    - Restoration potential: best opportunities on military reservations
- Carizzo Region
    - Counties: Monterey, Kern, San Luis Obispo
    - Vernal pool types: Northern Claypan
    - Threats: most pools are viable; grazing is isolated and moderate
    - Restoration potential: livestock management to prevent overgrazing may be helpful
- San Joaquin Valley Region
    - Counties: San Joaquin, Stanislaus, Merced, Fresno, Kings, Tulare, Kern
    - Vernal pool types: Northern Claypan, many alkaline
    - Threats: agriculture, urban development, conversion to vineyards and orchards
    - Restoration potential: many chances have been destroyed by agriculture and urban development
- Southern Sierra Foothills Region
    - Counties: San Joaquin, Calaveras, Tuolumne, Merced, Mariposa, Madera, Fresno, Tulare
    - Vernal pool types: Northern Hardpan, Northern Basalt Flow, some Northern Claypan
    - Threats: Basalt Flow pools are least disturbed because soil is untillable; housing development and drip irrigation (vineyards and orchards?) pose threats
    - Restoration potential: moderately grazed basalt flow and hardpan pools offer the best chances

While the above regions (along with soil phase maps) are helpful in determining what type of vernal pools may be located within a given area, they should not be regarded as "management regions." According to Keeler-Wolf et al., data at a scale fine enough to manage pools and pool complexes must still be gathered in the field for individual sites. While edaphic conditions (i.e. pool "types") are helpful in understanding the general characteristics of a pool or pool complex, it is impossible to generalize that ecological conditions will be the same across similar edaphic zones.

<u>Geology and Hydrology of Vernal Pool Types</u>

Vernal pools and vernal pool complexes may differ in both their foundational geology (e.g., claypan or hardpan, alluvial valley or mountain mesa) and governing hydrological processes (e.g., hydroperiod, dry-down frequency, depth of water) (Keeler-Wolf et al. 1998, Zedler 2003, Rains et al. 2008). While the basics of vernal pool geology and edaphic conditions were discussed in type classification, hydrological processes, particularly as they may relate to type, warrant closer consideration.

Vernal pools can be filled by top-down (rainfall) or bottom-up means (upward flow of groundwater via capillary action), and can empty due to surface-level (evapotranspiration) or belowground processes (seepage). The three basic types of vernal pool subsurface layers—hardpan, claypan, and volcanic—may have different implications for hydrologic function, and as a result, for conservation and restoration. Rains et al. (2008) conducted a study to determine whether claypan and hardpan vernal pools differ in their chemical and physical hydrology. Hardpan soils were found to fill more slowly in the presence of rainfall than claypan; those with claypan filled quickly and experienced outflow through swales. Hardpan layers are formed from larger particles than claypan, and as a result, exhibit higher permeability to water. Water loss via seepage through the subsurface layer was possible in hardpan pools, while claypan pools were more likely to retain and subsequently lose water through surface evapotranspiration. The authors determined that claypan pools are driven by surface-water hydrology, and often contain more saline, turbid surface waters with nitrogen- and light-limited conditions. Hardpan pools were more likely to be ground- and surface-water driven, providing fresh, non-turbid surface waters and phosphorous-limited conditions.

<u>Connectivity in Vernal Pool Systems</u>

Changes in geological features, edaphic characteristics, and hydrological flow regimes can alter patterns and degrees of connectivity between individual pools and pool complexes across a broader landscape. Vernal pools can be connected hydrologically through surface water flows (e.g., overflow across swales from excessive rainfall), groundwater flow, and in some cases they may connect to regional water systems (Zedler 2003). Biologically, pools can connect to one another and to upland habitat through the movement of individuals (e.g., animal migration; seed dispersal via wind, water, or animal) or the transfer of genetic material (e.g., pollination) (Keeler-

Wolf et al. 1998, Neale et al. 2008, Wang et al. 2009). For any of these connections, the scale at which connectivity is apparent and important will depend on the species and the specific linkage mechanism. For example, it is believed that ground-nesting, solitary bees are responsible for pollinating many vernal pool annual herbs. Because evidence suggests that the bees' typical flight distance is no more than 80 meters, gaps larger than 80 meters between pools and pool complexes would restrict gene flow between populations (Neale et al. 2008). Wind- or animal-mediated (e.g., bird) seed dispersal may still be possible at the same level of fragmentation.

Historical evidence suggests that vernal pools were at one point highly interconnected. An examination of the disparate distribution of vernal pool endemic genera across the world (e.g., *Downingia, Lasthenia, Blennosperma*) suggests that pools must have experienced some degree of worldwide connectivity in the remote past, and that the Central Valley was likely the center of adaptive radiations in the late Tertiary Period and Pleistocene Epoch. Because all of California's vernal pool endemics occur in the Central Valley, it is likely that the region was the center of the Tertiary and Pleistocene radiations responsible for much of the observed diversity vernal pool native species (Zedler 2003). The historical landscape in the Central Valley was likely a 'wetland complex' of marshes and lakes (Zedler 2003) that were further connected by periodic flooding (Neale et al. 2008).

Land use change can significantly alter connectivity in vernal pool systems. In the recent past, the influx of humans and subsequent conversion of land for agriculture in the 1800s degraded and destroyed much of hydrological connectivity in the Central Valley (Zedler 2003, Neale et al. 2008). Topographic alteration (e.g., leveling to make fields or deep ripping for vineyard or orchard planting) can impact surface water movement and groundwater flow to deeper layers (Zedler 2003).

It is hypothesized that reduced connectivity could affect vernal pool complex biota, as

many populations appear to depend on metapopulation dynamics (e.g., rescue effects) for persistence. Evidence that some species switch between large and small pools for refuge during wet and dry years suggests that they depend on some degree of connectivity, the extent of which would depend on the species in question (Zedler 2003). For example, waterfowl may be able to traverse larger distances than amphibians or aquatic invertebrates. Additionally, many species, particularly amphibians, depend upon connectivity with and quality of upland habitat (e.g., lack of unpalatable or inhospitable invasive species, lack of human modifications that reduce area for habitat or safe travel like roads or disked fields, etc.) for portions of their life cycles (Keeler-Wolf et al. 1998, Wang et al. 2009). Reductions in upland habitat and connectivity between pools may also reduce attractiveness to waterfowl, an important factor in the dispersal of many pool endemics' seeds (Zedler 2003).

While connectivity is important, effects of reduced connectivity are not always immediately apparent. For example, after finding no apparent genetic consequences (greater within population variation than among population variation, indicating a relatively high level of gene flow) of reduced connectivity in vernal pool endemic *Lasthenia conjugens*, Neale et al. (2008) hypothesized that changes in flood regimes that used to connect isolated populations were too recent to possess a clear genetic signature.

While genetic work may not always reveal the extent of recent reductions in gene flow, it can help identify complexes, pools, and genotypes of particular significance for conservation. This is particularly important because it is often impossible (or undesirable as it may increase antagonistic gene flow and reduce among population diversity) to restore connectivity to sites that are highly developed, disturbed, or on private lands. Molecular genetic analyses may allow practitioners to select seed sources for restoration that simulate natural gene flow across landscapes., and can also help target key areas of genetic diversity. For example, Neale et al. (2008) calculated the probability of loss for several alleles found in *L. conjugens* to determine which populations should be sampled for conservation or ex-situ restoration (seed banking). The goal of their recommendations was to conserve as much rarity and as many private alleles as possible to maintain genetic diversity in the species [rare and private alleles may still be found in subpopulations even when gene flow is present].

In an earlier paper, several of the same authors discussed the importance of selecting seed stock for restoration that is not only genetically diverse, but also a good match to the genetic structure of the reference site (Ramp et al. 2006). They caution against the selection of source material based on geographic location and proximity to the reference site alone. While genetic considerations are important, McKay et al. (2005) remind that local adaptation to specific environmental conditions is often a key determinant in project success. They recommend a restoration program that combines genetic information with an understanding of how local ecotypes are partitioned across a landscape.

Part II: Restoration Goals, Constraints, and Further Research Needed

Goal 1: Select Sites to Conserve Vernal Pool Types

Description of Goal

While descriptions of vernal pools often include considerations like presence of endemic species, plant community composition, and edaphic conditions (Holland 1986, Keeler-Wolf et al. 1998, Barbour et al. 2005), vernal pool types are commonly defined based on subsurface substrate (Holland 1986). Because subsurface substrates (e.g. hardpan, claypan, or volcanic substrate) are typically associated with certain geologic features and landforms (Rains et al. 2008), an understanding of the spatial configuration of the vernal pool landscape at both large and small scales is necessary when designing plans for conservation and restoration.

Like species and specific ecological communities, types of substrate can also be described as rare or common across California's Central Valley. Vernal pool conservation and restoration projects—particularly those that involve the creation of new, manmade pools as mitigation for degraded or destroyed pools—must account for the preservation of rare types of hardpan in their protocols. In a review of vernal pool restoration projects, Wacker and Kelly (2004) determined that mitigation shifts the proportion of pool types at the landscape scale, making rare types (e.g. volcanic lahar) rarer overall. While project planners do consider edaphic conditions and hardpan type when delineating areas appropriate for new pool creation, they rarely account for changes occurring at larger scales. Often, project-by-project edaphic considerations do not scale up, and rare types lose area little by little.

Though it is optimal to conserve and restore existing vernal pools, rapid land use change and economic considerations often necessitate the creation of new pools. When restoring vernal pools and vernal pool complexes in the Central Valley, distributions of the various types of hardpan and associated edaphic conditions should be considered at both small and large scales. In this way, managers can be assured that mitigation projects do not shift the proportion of types further toward the more common subsurface substrates. This can be accomplished by compiling data on vernal pool edaphic conditions into a central database and updating the database each time new pools are created and natural pools are degraded to ensure that data is "up-to-date." The database can then be consulted when new projects are proposed, and the effects of each project on landscape scale edaphic conditions can be assessed. Because it is preferable from an ecological perspective to conserve existing pools rather than to mitigate losses by creating new pools (C. Witham, personal comm.), preference should of course be given to conservation. One caveat that comes with the creation of such a database is that it would be unwise to use it as evidence that created pools are an "even trade" for lost natural pools on the basis of conservation of edaphic conditions alone.

GIS-based analysis can also be incorporated to correlate changes in land use to edaphic conditions, and further to correlate land use to likelihood of successful vernal pool recovery. A GIS-based system would facilitate easier identification of areas that have desirable edaphic conditions (i.e. those needed to ensure conservation of rare vernal pool types). It could also be used to incorporate other data on anthropogenic and environmental stressors (e.g. proximity to urban development; proximity to land that may be used for orchards, vineyards, or other practices that require deep-ripping of hardpan) that could help determine which sites are more likely to host successful created pools.

Constraints and Further Research

Though accounting for edaphic conditions at multiple spatial scales is important for the conservation of rare vernal pool types, problems exist that may make such considerations difficult or problematic. Many pools and mitigation projects exist on private lands; as such, it may not be possible to know the full distribution and proportion of types across the Central Valley, or to include all of the monitoring data collected in a central database (Solomeshch et al. 2007). Additionally, if a correlation exists between rare pool types and certain land use associated with changes that are ecological or economically difficult to reverse (e.g. deep-ripping of hardpan and other agricultural practices), it may be difficult to prevent their decline.

Further research is needed to determine the distribution of vernal pool types at a finer scale than is currently available (Keeler-Wolf et al. 1998). Vernal pool data tends to come in on a project-by-project basis, and many pools (as they exist on private property) remain unexplored. While it would be desirable to have data at the pool (or even pool complex) level, this may be unrealistic to accomplish in the near future. Encouragement of vernal pool research (through outreach to researchers and additional funding) may help fill data gaps. A database that scientists can update as new information comes in would be advisable. Interdisicplinary collaboration with social scientists may also help facilitate positive relationships with farmers and other landowners who have vernal pools on their property. "At-home" monitoring techniques could be developed and implemented to learn more about pools on private property. As it stands, it is difficult to gain access to pools on private property as many farmers and landowners feel that allowing research is akin to opening the door to stricter regulation (e.g., if species are found that qualify for protection under the Endangered Species Act).

Additionally, while it is known that vernal pool type can influence ecological conditions within and among pools, it is not fully understood how precisely edaphic conditions influence pool ecology (Wacker and Kelly 2004). More research is needed to better understand how shifts in the proportion of vernal pool types will affect ecological conditions at large and small spatial and temporal scales. Ecological studies that examine how species compositions within and among pools are correlated with edaphic conditions could help fill this knowledge gap. Also, understanding how shifting pool types changes the spatial layout of vernal pools and complexes across the Central Valley would also be advisable. For example, created pools are often concentrated in predetermined "mitigation banks." It is not unreasonable to hypothesize that the destruction of pools and subsequent creation in concentrated banks alters landscape connectivity (with some areas that used to have patchy pool habitat becoming vacant, and others receiving abnormally high concentrations of pools). This shift could influence plant species, migratory birds, and other organisms that use vernal pools as permanent or temporary habitat.

Social science research can also provide important insights into how best to manage vernal pools with limited and uncertain ecological knowledge. For example, Solomeshch et al. (2007) advocate the use of financial incentives to encourage the reporting of monitoring data gathered on private lands. Economic, anthropological, and policy studies could illuminate how best to incentivize ecological monitoring and data reporting to better understand the status of vernal pools throughout the Central Valley. Social science research may also help pinpoint policies and programs that are most likely to abate vernal pool destruction and alleviate some of the need for mitigation projects.

Goal 2: Establish Seed Zones

Description of Goal

Restoration of existing vernal pools and the creation of new pools and pool complexes requires the identification of appropriate sources of seed (and other living materials used in the restoration process like cuttings for vegetative growth, soil inoculants, and introduced animals). When selecting locations to collect seeds and cuttings, genetic factors must be taken into account. Because it is believed that vernal pools in the Central Valley experienced higher degrees of hydrologic connectivity as little as 150 years ago (Neale et al. 2008), pools may be experiencing increased levels of genetic isolation. With fewer new genotypes entering populations from abroad, local adaptation is increasingly likely. Evidence of local ecotypes exists in plant populations (McKay et al. 2005), and in a restoration context, the use of maladapted genotypes could result in projects that are unsuccessful and costly.

Establishing seed zones based on local ecotypes is a critical step toward restoring threatened plant communities like vernal pools and vernal pool complexes. Because local adaptation can occur at different scales and to varying degrees, it is ideal to determine its scope before beginning a restoration project. This can be done using a series of common garden and reciprocal transplant experiments. However, such experiments require time and resources that are not always available to restoration practitioners. As a "commonsense" alternative, McKay et al. (2005) advocate the use of seed collected as locally as possible, and discourage the use of vague, one-size-fits-all seed collection radii (e.g., seed collected from within 50 meters of the restoration site). Collecting as locally as possible is a site-dependent recommendation, and will be determined by the availability of seed, resources (financial, human labor, etc.) for collection, and most likely, the immediacy with which the project must be completed. They also suggest using information about plant breeding systems (selfing/clonal vs. highly outcrossing) to inform the establishment of collection zones. For example, for clonal species it would be appropriate to designate smaller collection zones than for species that are obligate outcrossers (to ensure maintenance of genetic diversity). In Grasslands Regional Park, collecting from other pools in the park may be sufficient. Since the park is relatively isolated from other areas with vernal pools, practitioners may discover that seed collected from outside of the park is maladapted (of a different ecotype) in which case collecting from within the park would be necessary. Scientists are actively defining seed zones for graminoids (K. Rice, personal comm.); it would stand to reason that research is also underway for forbs commonly used in restoration and perhaps for vernal pool endemics as well (California Fish and Wildlife is currently seeking genetic information pertinent to restoration on several vernal pool endemics).

Vernal pool restoration may also benefit from the collection of seeds for ex-situ seed banking. In this case, collecting to maximize genetic diversity is desirable. The conservation of rare and private alleles may be important for evolutionary potential. Because collecting seed representative of every genotype is unrealistic, Neale et al. (2008) offer suggestions (e.g. running transects from pool edge-to-edge) that may maximize diversity in an ex-situ seed bank of *Lasthenia conjugens*. Similar techniques may be applied for other species, particularly if genetic information is available. Vitt et al. (2010) outline a framework for seed collection that includes the careful recording and consideration of geographic provenance of collected seed so that restorationists may select stock that is most likely to contain local ecotypes.

Constraints and Further Research

Seed zones have already been developed for many woody species, but progress has been slower for herbaceous forbs and graminoids. The establishment of seed zones for vernal pool restoration will require additional population and landscape genetic research. Several studies have used molecular methods to make restoration recommendations for specific vernal pool endemic plant species (Ramp et al. 2006, Neale et al. 2008). Similar studies could be developed for other species of concern. Additionally, more studies could be undertaken to determine whether local adaptation or the maintenance or restoration of genetic diversity is typically most important (McKay et al. 2005). Because the interplay of local adaptation and the maintenance of evolutionary potential is dynamic and likely different for each species, these studies will need to occur on a species-by-species basis.

A final area of concern when developing seed zones is rapid environmental change. Changes in land use, land cover, and perhaps most notably, climate change, may alter seed zones, impact local adaptation, and demand that evolutionary potential be given a greater role than would ordinarily be the case. Because modelling efforts cannot predict the effects of climate change on species distributions with certainty, restorationists must be prepared to act with incomplete information. Modelling how seed zones may shift as a result of rapid environmental change should also be an important component of any long-term restoration plan.

Goal 3: Replicate Historical Levels of Connectivity

Description of Goal

Evidence suggests that vernal pools experienced higher levels of connectivity historically than are apparent in the Central Valley today (Zedler 2003, Neale et al. 2008). Many vernal pool restoration plans (like that in place for Grasslands Regional Park) suggest that hydrologic connectivity be accounted for by the construction of linking features like swales. It is advisable that new plans to restore and create pools and pool complexes also consider connectivity as an important feature of landscape structure. Because many floodplains (like the Putah Creek floodplain on which Grasslands Regional Park was established) have been so dramatically altered, consideration of all aspects of hydrology is important. Groundwater flow and the absence of large-scale periodic inundation may also impact connectivity, and only focusing on swales may not fully capture the impacts of large-scale hydrologic change.

Connectivity via means other than hydrology is also important in vernal pool restoration. Many species, particularly amphibians, require upland habitat for parts of their life cycle (Keeler-Wolf et al. 1998, Wang et al. 2009). There is also evidence that some species (particularly amphibians) switch habitats based on yearly hydrologic conditions, and that fragmentation of upland habitat may reduce attractiveness to waterfowl (Zedler 2003). The removal of barriers to connectivity, including the implementation and maintenance of recommended mowing and grazing regimes to control invasive weeds, will be an important component to maintaining suitable matrix between vernal pool patches. At Grasslands Regional Park, matrix species (including several invasive grasses) were allowed to grow higher than is typically advisable. This may impact the formation of swales between pools or the ability of seed-dispersing animals to move through the matrix from pool to pool within and among complexes. Perhaps most significantly, it may also affect the timing of emergence by ground-dwelling solitary bees that are believed to pollinate many vernal pool endemics (C. Witham, personal comm.). If this were to happen, connectivity through cross-pollination would be further reduced and could compromise the viability of many obligate or highly-outcrossing species.

Constraints and Further Research

Restoring connectivity is often difficult as alterations to flood regimes and land use change may be physically irreversible or economically and politically difficult to overhaul. Additionally, their ecological impacts may be so severe that simple reinstatement of prior conditions is insufficient to restore desired function. More research should be conducted to better understand the extent of historical connectivity and its impacts on affected species. Techniques like network analysis have been used to identify important pathways for connectivity (Fortuna et al. 2009) and may hold promise for vernal pool restoration. The genetic impacts of connectivity and fragmentation should also be further explored. While connectivity is an important factor in rescue effects (genetic rescue of isolated subpopulations), and can play a key role in maintaining genetic diversity, it may also introduce genetic pollution (maladapted genotypes) through antagonistic gene flow (McKay et al. 2005).

Part III: Synthesis

Overall, this plan is well aligned with other goals of the restoration project; however, as with any project that involves managing for multiple interests, there are tradeoffs for which managers will need to account. One tradeoff that has already occurred was the creation of pools on Marvin silty clay loam as opposed to the recommended Pescadero series. Two of the smaller pools (R-4 and R-A4) that have been compromised by human activity (i.e. removal of a concrete block and possible breaking of hardpan, and driving vehicles through the center of the pool) occur on Pescadero series and seem to be doing poorly as a result. If these pools continue to decline in size and inundation, fewer pools will remain on Pescadero series. If new pools are to be created, recommendations for specific soil series should be heeded. Another problem that may arise is the maintenance of genetic diversity in very rare species like Crampton’s tuctoria. Because the species exists in such a limited number, seed collection will be extremely local, and will need to be limited to avoid compromising existing populations. This could result in restored populations that are genetically depauperate and subject to inbreeding depression.

There are also several win-win situations apparent in the synthesized restoration plan. The plan calls for more vigilant grazing and mowing of upland habitat, which will improve conditions for ground-dwelling, solitary bees. The bees are believed to pollinate many vernal pool endemics, and as a result, they facilitate genetic connectivity between pools. This will ensure that within-pool genetic diversity is maintained. Because vernal pool obligates typically produce seeds with low dispersal capacity (the high probability of landing in unsuitable matrix leads to a higher cost of long-rage dispersal), bees can ensure that gene flow is maintained among pools. Many species will also benefit from clearer establishment of seed zones. Managers will have a better understanding of where to collect seed for created pools, which will in turn lead to higher rates of establishment and more successful restoration efforts.

To ensure that this restoration plan remains well aligned with the synthesized plan, adaptive management and further research are recommended. As previously mentioned, seed zones will need to be species specific, and as more information on local ecotypes for each species is collected, collection areas may need to be changed. Also, if it is found that activity in the matrix impacts the timing of solitary bee emergence, other methods for maintaining gene flow (like seed transfer from pool to pool) may need to be implemented. Finally, because the hydrology of Putah Creek has been so dramatically altered, vigilant attention must be paid to hydrologic connectivity. While pools may appear connected this year (an unusually rainy, El Nino year), dry years may result in lower inundation levels and less connectivity via aboveground swales. If this were to happen, gene flow between plant species could be cut off, and animals like fairy shrimp and spadefoot toads that may be able to move from pool to pool via swales may become isolated.

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Distribution of Vernal Pools in the Central Valley- Fact Sheet

Vernal Pool Classification

- Pools often grouped based on (Holland 1986, Barbour et al. 2005):
  - Geology: low-permeability subsurface soil layer; correlated with geologic features (Rains et al. 2008)
  - Edaphic conditions: effects on pool biota
  - Biological characteristics: plant communities
- Holland System for California Fish and Game: seven types based on subsurface substrate

1) Northern Hardpan

2) Northern Claypan

3) Northern Basalt Flow

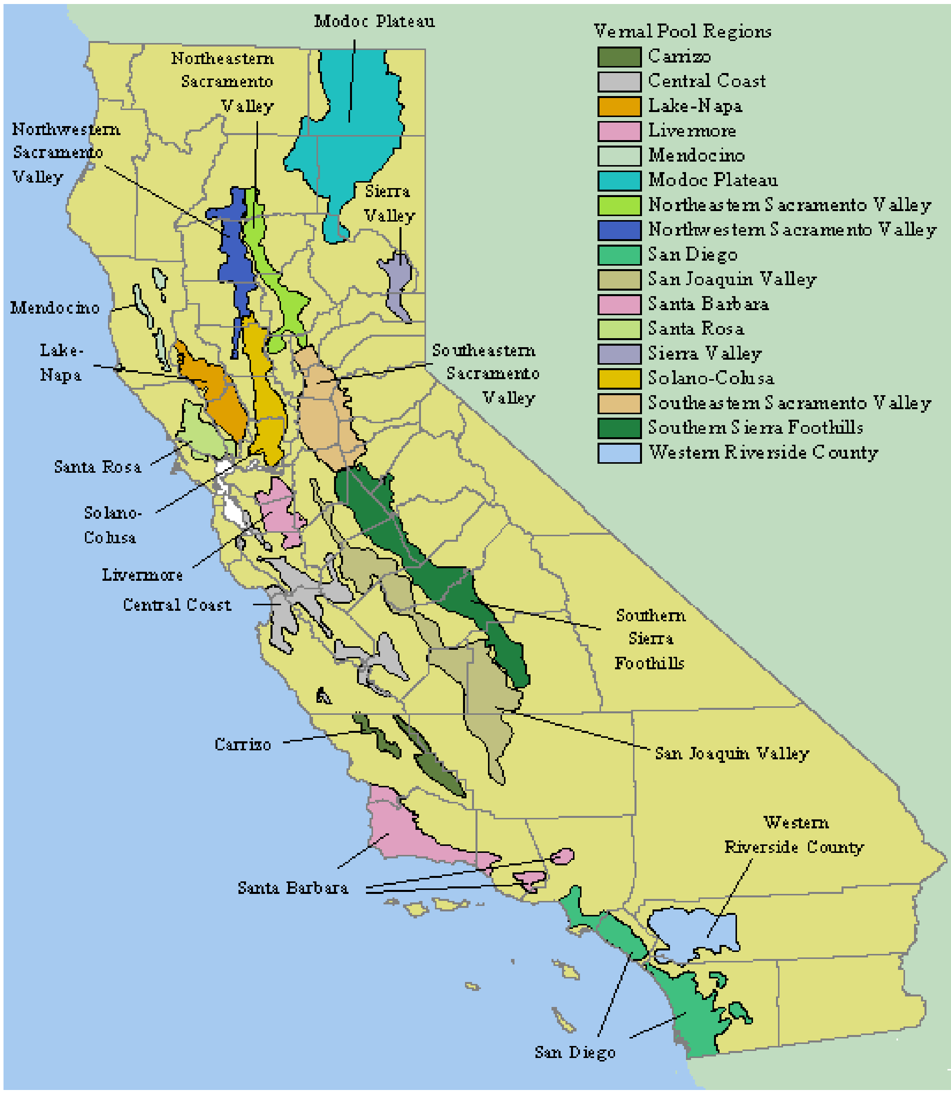
4) Northern Volcanic Mudflow

5) Southern Interior Basalt Flow

6) San Diego Mesa Hardpan

7) San Diego Mesa Claypan

- Vernal Pool Regions: seventeen types based on biota, Holland's types, and correlation to geologic features



(image source: http://interwork.sdsu.edu/fire/resources/images/vernal_pools.gif)

- Vernal pool regions are not intended as management regions; finer scale data must be collected in the field on a site-by-site basis (Keeler-Wolf et al. 1998)
- Updated reports on vernal pool status are pending

Vernal Pool Hydrology

- Filling: top-down processes (rainfall); bottom-up processes (upward flow of groundwater via capillary action)
- Emptying: surface-level processes (evapotranspiration); belowground processes (seepage)
- Vernal pool hydrology depends on subsurface substrate (Rains et al. 2008):

- Hardpan—coarser soil particles, more permeable, fills more slowly, empties faster through seepage
- Claypan—finer particles, less permeable, fills quickly, empties through evapotranspiration

Connectivity in Vernal Pool Systems

- Evidence suggests pools historically connected (Zedler 2003)
    - Global distribution of endemic genera suggested of historical genetic connectivity
    - Possibly connected by periodic flooding (Neale et al. 2008)
- Land use change alters connectivity
    - Land conversion and flood regime alteration in 1800s (Zedler 2003, Neale et al. 2008)
    - Topographic alteration like leveling and deep ripping destroy hardpan and swales (Zedler 2003)
- Significance of Connectivity
    - Pool-to-pool connections (Zedler 2003)
        - Metapopulation dynamics—persistence of subpopulations through rescue effects
        - Seasonal habitat switching in wet vs. dry years can be important for organisms
    - Pool-to-matrix connections
        - Amphibians depend on upland habitat (Keeler-Wolf 1998, Wang et al. 2009)
        - Fragmentation can decrease attractiveness to waterfowl (Zedler 2003)

Questions for Restoration

- Source material collection
    - *"How local is local?"*
        - Is a high degree of connectivity always indicative of a low degree of local adaptation?
        - Isolation may lead to more local ecotypes, rare/private alleles, etc.
    - *How important are genetics for fitness?* (i.e. inbreeding depression, outbreeding depression/antagonistic gene flow)
- *How does vernal pool type influence community composition?* (i.e. species, functional groups, etc.)
- *At what spatial and temporal scales do different mechanisms of connectivity operate?*
    - Vernal pool pollinators (ground-nesting bees) travel short distances (Neale 2008)
    - Other animals, seeds may be able to travel farther
    - *How does each species perceive its environment?*
- *Does mitigation (creation) change the distribution and proportion of types?*
    - At broad scales, yes (Wacker and Kelly 2004)
    - *How can we prevent rare types from becoming rarer?*

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Vernal pool hydrology

Omar Sadik

BACKGROUND AND RESEARCH

Geological features of a vernal pool landscape are the framework on which all other physical, chemical and biological processes operate in the site(Rains, 2008). The fundamental properties of wetland geology are the physical and chemical hydrology of the site. In vernal pool sites, physical hydrology is largely controlled by the rates of infiltration and transmissivity of the soils and bedrock, especially where shallow perching layers reduce rates of recharge to underlying regional aquifers and redirect water flow along subsurface horizontal flowpaths (Rains, 2008). Chemical hydrology in vernal pools and other wetlands is initially influenced by the interactions between water and the parent rock. Accelerated weathering through processes such as the production of acids, the uptake and release of nutrients by soil microorganisms and vegetation, solute interactions with organic and mineral colloids, and the concentration of solutes by evapotranspiration may further modify chemical hydrology (Rains, 2008). This paper will discuss the various physical and chemical characteristics of vernal pool hydrology in California that play a key role in management and design practices.

Elements That Affect Vernal Pool Hydrology

Within a vernal pool ecosystem, the physical properties of the hydrology play a fundamental role in all processes. Pool formation, landscape ecology, morphology, ecological diversity and site preservation are all affected by the underlying importance of vernal pool hydrology. Therefore, when considering preservation and restoration of vernal pool sites, hydrology must be recognized. The five major factors that affect physical hydrologic characteristics (i.e. water level, inundation period, pool distribution, connectivity, etc) are precipitation, groundwater, evapotranspiration, basin morphology and soil. (Liebowitz, 2008)

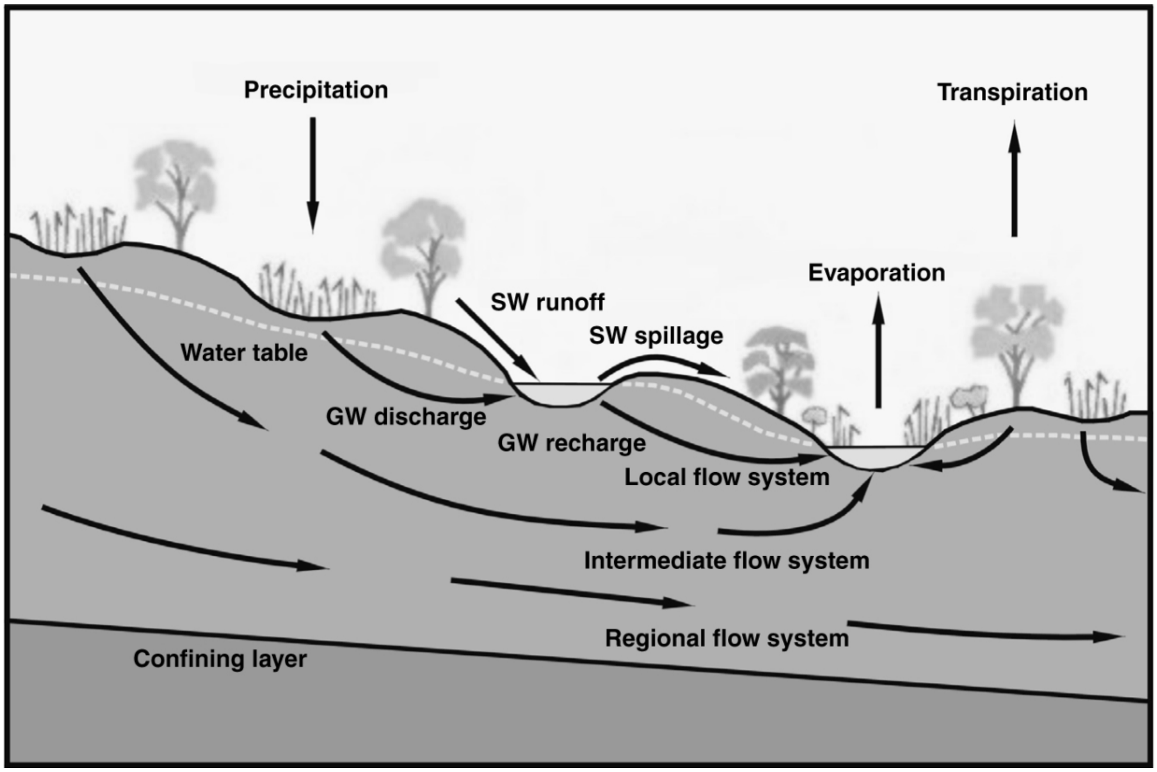
Precipitation

Precipitation is a major source of water input to several types of wetlands and other terrestrial water systems including vernal pools (Liebowitz, 2008). Precipitation can enter a vernal pool directly at the surface or indirectly as runoff from adjacent catchments (Liebowitz, 2008). Precipitation directly affects daily water levels during high and low rain events through the vernal pool inundation period.

Groundwater

Groundwater – surface water interactions occur in almost all terrestrial freshwater systems (Liebowitz, 2008). Several elements of this interaction affect the physical hydrology of a vernal pool. The position of groundwater level relative to the pool influences the pool water levels. Geologic properties, such as parent rock and soil, along with climatic characteristics of the region determine groundwater levels and flow and therefore the hydrology of the pools (Liebowitz, 2008).

Groundwater flows can occur on regional to local scales. On the regional scale, topographically high locations function as recharge areas and topographically low areas discharge (Liebowitz, 2008). Similarly, in a local scale, basins or depressions perched above the groundwater level function as groundwater discharge areas to the basins or depressions perched below the groundwater level (functioning as groundwater recharge areas), which in a vernal pool landscape, are the vernal pools. Therefore, when determining groundwater relation to vernal pool dynamics, one must understand both regional and local topography. Features not related to topography that affect groundwater relation to vernal pools, such as direction of groundwater flow and pool to groundwater flow, are primarily climate driven elements, as long-term weather patterns determine groundwater levels (Liebowitz, 2007). From where it has been investigated, groundwater exchange occurs mostly at the margins of the pools (Liebowitz, 2008).



(Liebowitz, 2008)

Evapotranspiration

Evapotranspiration is the sum of evaporation and plant transpiration from land surface to atmosphere.This includes evaporation of pool surface water, soil, canopy interception and transpiration from vegetation. The primary constituent of water loss in vernal pool systems is evapotranspiration, therefore making it a key factor in hydrology and more specifically, pool inundation.

Evapotranspiration is primarily a temperature-driven process, and varies among regions with diverse climates, daily temperatures and season variability (Liebowitz, 2008). Potential evapotranspiration, which is the measure of the evapo-transpiration rate of a crop assuming all environmental variables (sun, soil moisture, wind, shade, etc) are of “typical” value, peaks in the late spring and early summer months as vegetation begins to leaf out (Liebowitz, 2008). As potential evapotranpiration begin to exceed water input during late spring and summer, vernal pools begin to slowly dry out. The evapotranspiration and water input relationship is the quantitative hydrological factor that determines annual water levels in vernal pools.

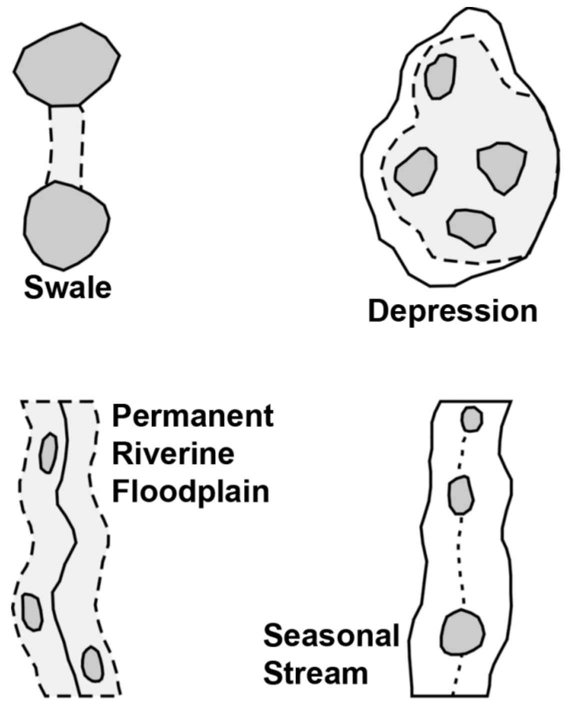
Basin Morphology and Connectivity

Vernal pool basin morphology is the geometric component to hydrology. How a pool is shaped, sized and related to other pools plays a very important role in a successful ecosystem. Both the effects of precipitation and groundwater input and evapotranspiration losses on vernal pool hydrology are dependent on basin and catchment characteristics (Liebowitz, 2008). Clearly, basin volume determines storage capacity. Additionally, soil characteristics play a major role in storage qualities (as will be discussed in the next section).

Basin surface area and volume, and the relationship thereof, is the most understood geomorphological factor to vernal pool hydrology. Pools with a larger perimeter-to-area ratio, which tend to be smaller pools, tend to have higher rates of water loss relative to maximum pool volume (Liebowitz, 2008). Typically, this is due to water loss from perimeter vegetation and/or groundwater leakage (Liebowitz, 2008). Pools with smaller perimeter-to-area ratios tend to be inundated for longer periods.

Little is understood of the direct effect of basin and catchment characteristics on pool hydrology. However, correlations between basin characteristics and other physical features have been derived. For example, impermeable bedrock underlying vernal pools may play a role in shaping natural pools. Vernal pools with gabbro bedrock, which is a more easily weatherable bedrock, tends to support shallower vernal pools with shorter hydroperiods. On the other hand, pools with a sturdier gneiss bedrock tend to support deeper volumebowl-shaped basins with longer hydroperiods (Liebowitz, 2008).

Basin connectivity also plays a role in vernal pool hydrology. In order to maintain species genetic diversity through hydrologic distribution, pools must "communicate" and connect via water contact. The four primary ways pools stay connected are through swales, depressions, floodplains and seasonal streams (Liebowitz, 2008). These factors are what maintain successful landscape ecology of vernal pool systems.



Soil Characteristics

Soil is the template on which vernal pools form. Hydraulic conductivity is determined by the permeability of the soil and therefore controls the exchange of pool and ground water (Liebowitz, 2008). Vernal pools typically occur due to low hydraulic permeability in local soils (Liebowitz, 2008). Given that this is an important necessity for vernal pools to form and function, soil hydraulic conductivity can be considered the primary physical factor, which determines water levels and inundation periods. Clearly, basin soils with low permeability will be inundated for longer periods. However, studies have shown that vernal pools with more permeable soils may still maintain productive vernal pools (Liebowitz, 2008).

Soils that concern the California Central Valley are typically either clay-rich or hardpan soils (Rains, 2008). The physical properties of these two types of soils are significant due to the chemical features that they denote.Clay-rich soils with marine derived sedimentary alluvium tend to contain turbid water that is salic and sodic (Rains, 2008). Conversely, igneous derived hardpan soils in the Central Valley typically contain clearer non-turbid water with low phosphorous levels (Rains, 2008).

Challenges to vernal pool hydrology

Hydrology in vernal pools undoubtedly affects its ecological success. Because vernal pools serve all subsequent water systems along a watershed chain, maintaining natural vernal pool hydrology is important not only to the success of vernal pool ecologies, but all succeeding water-based habitats tied to vernal pools (Rains, 2008). Several factors in contemporary development have changed and detrimentally affected the hydrology of vernal pools.

Timber harvesting can have a significant affect on the hydrological relation between the upland watershed and vernal pool basins. Clearing of nearby forests changes the rate and method of which water flows and is absorbed into the landscape. Timber harvesting increases erosion and flood events and significantly changes groundwater levels (Liebowitz, 2008). This plays a direct role in changing the temporal inundation and water level of vernal pools, and ultimately modifies the entire watershed system.

As timber harvesting changes the properties of how water flows through an entire watershed system, so does urbanization and land development (Liebowitz, 2008). In the case of urban development, however, permeable soils throughout the landscape are paved over, and are therefore completely impermeable (Barry, 1998). As a result, this significantly impacts groundwater recharge by decreasing the amount of surficial water penetrating the surface, directly affecting vernal pool hydrology. Additionally, loss of soil absorption and permeability increases the potential of drastic flood events, in which runoff from urban sites is collected and directed into designated areas. This, in effect, relocates water on and below the soil surface altering natural hydrologic cycles. This is a major disruption to natural watershed properties and again has a detrimental affect on vernal pool hydrology.

Finally, a powerful challenge faced by many types of ecological and environmental issues today is the effect of climate change. The exact effect of climate change on the environment is not completely understood and is a subject in high priority today. However, it is clearly understood that industrial pollutants are changing historical climate patterns, which eventually will play a role in all habitats throughout the world. In the case of vernal pools, changes in annual weather patterns will surely change temporal inundation patterns and storm/weather events throughout the year (Liebowitz, 2008). These effects will play an emerging role in the maintenance of vernal pool sites.

Conclusion

Vernal pools are rich ecological sites that should, without a doubt, be a significant focus for preservation efforts in California. Approximately 10% of the original vernal pools still remain in California, therefore, powerful efforts must be undertaken to preserve these mysterious banks of ecological diversity. Beyond the moral aspects of preserving species diversity and rarity, vernal pool sites also directly serve us directly. They provide the landscape with natural flood management, erosion control and improve local water quality.

Hydrology is the foundation of vernal pool sites, and should be a key focus in the

maintenance of vernal pool sites. By understanding the physical and chemical properties that affect vernal pool hydrology, design and management concepts can be derived to provide a “blueprint” for successful vernal pool practices and preserve the vernal pool biota.

GOALS AND MANAGEMENT PRACTICES

As a fundamental building block for vernal pools, hydrology should be an initial consideration in a restoration and management plan. Only with well-managed hydrology can a vernal pool site, and all of its biodiversity, thrive. Following the considerations in Part 1 of this report, several goals and successive design implementations will be discussed in this paper.

Goals

1. Identify constraints to vernal pool hydrology
2. Identify design and management opportunities for vernal pools and determine the successful and unsuccessful components of each
3. Research and discuss alternate design and management plans
4. Create a conceptual guideline plan

Constraints

As discussed in part 1 of this paper, the most limiting factor to the hydrology of vernal pools is the clearing and/or development of nearby landscapes of vernal pools. Urban development, water supply/flood control activities, and conversion of land to intensive agricultural use are events that can directly alter the infiltration, drainage, and general hydrology of a vernal pool (Barry, 1996). These factors are all part of the land planning process, and therefore can be regulated and prevented to preserve vernal pool habitats. Other activities that may threaten vernal pools may be overlooked because their impact to vernal pool hydrology is indirect. In particular, some land management activities alter surface and soil organic matter, soil bulk density, or other factors that influence hydrology. (Barry, 1996) Additionally, the contemporary proliferation of invasive weeds throughout many natural landscapes has caused several issues. Vernal pool hydrology has been significantly affected by invasive flora due to the significance of evapotranspiration in hydrological processes. (Rains, 2008) Finally, the emergence of climate change is continuously playing a role in vernal pool hydrology. This global phenomenon directly affects local and regional weather patterns, which may directly effect pool inundation. Climate change is an important constraint to be aware of, due to its delicate yet disastrous potential, and ambiguously understood prospects.

Livestock Grazing

One management decision, either intentional or otherwise, that is often overlooked and may indirectly amend vernal pool hydrology by threatening its native plant species is complete rest from livestock grazing. Under complete rest the vernal pool landscape is fenced off from grazing livestock, and otherwise left alone. Although complete rest may seem like an appropriate way to protect a vernal pool and its associated biota, removing grazing livestock from the vernal pool landscape of the Sacramento Valley has consequences for the vegetation and hydrology of the vernal pool landscape. (Barry, 1996)

Although native vernal pool plants may not have evolved under extensive grazing, the current landscape surrounding the vernal pools of the Sacramento Valley has been subject to various levels of grazing (Barry, 1996). Consequently, most of large open areas of the valley not under cultivation have been grazed for more than 150 years (Barry, 1996). Management of livestock in the Sacramento Valley however, has changed during the past 150 years. In the early years most grazed areas were not fenced. Today most of the acreage is fenced and cross-fenced. This allows for rotational grazing of livestock. Additionally in the early years livestock may have remained in the valley all year long. Today the valley, including those areas with vernal pools, is typically grazed from November to May. (Barry, 1996)

An experiment undertaken in 1993 in Vina Plains, Tehama County demonstrated the importance of grazing in the management of vernal pool sites. Four sites, two of which were fenced and rested from grazing for 15 years and two of which were fully or partially open to local seasonal cattle grazing, were part of the experiment. The two sites without grazing showed a growing population of medusahead and other invasive non-natives, significantly in dense patches in the uplands and the margins of the pools. Conversely, the two sites that were exposed to seasonal grazing seemed to show a consistent balance of native and non-native flora and a stronger abundance of native diversity than the other two non-grazed sites. (Barry, 1996)

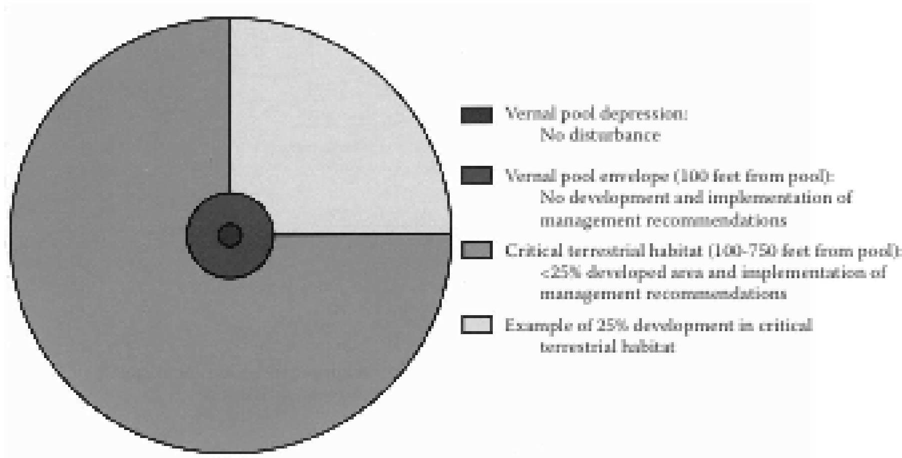
In a similar experiment conducted by Jaymee Marty, results proved the importance of grazing in the management and relationship between vernal pool hydrology and native flora. Most of the exotic grasses in vernal pools cannot tolerate extended periods of inundation, so hydrology plays a major role in controlling grass encroachment into the pools (Marty, 2004). Results from the experiment show, however, that prolonged inundation in the absence of grazing is notenough to keep exotics out of the pools. Moreover, the decreased inundation period in the pools may make the habitat more suitable for exotic grass growth and invasion(Marty, 2004). The edge and upland zones were the most negatively affected by grazing removal with marked declines in native species richness and relative cover of natives. As discussed in Part 1, both pool edges and upland zones play key roles in vernal pool hydrology. As the upland landscape acts as the primary means in which local surface water is absorbed and transported into the pools, pool margins are the zones of primary water loss through groundwater and evapotranspiration. The loss of native plant species diversity on the upland and edge of the poolmay adversely affect other hydrologic characteristics and inundation levels of vernal pools. The primary cause of the dramatic decrease in pool hydroperiod in the ungrazed and seasonally grazed treatments may be increased evapotranspiration rates that resulted from the abundance of vegetation, principally grasses, in and around the pools. (Marty, 2004)

When resource managers and landowners develop plans to conserve vernal pool habitats, it is imperative that they recognize that the current vernal pool landscape has been altered with the proliferation of exotic plant species and the impact of livestock grazing (Barry 1996).

Landscape Development

The most direct and influential affect on vernal pool hydrology is the alteration of the local landscape. Typically, this includes timber harvesting, agriculture, urban development and watershed modification through water management (i.e. levee systems, dams, etc.). All play a direct role in local and regional hydrology and will have an effect on the hydrology of vernal pools.

Proper management practices in the area of landscape development all fall back on the planning process. Developers and designers easily ignore the implications of the many revisited contemporary methods of development that affect local vernal pools. Managing vernal pool hydrology is no easy task, especially in a developing world. However, the most simple and effective method to preserve hydrological factors of vernal pools is to “avoid and minimize” development near vernal pool sites. As adequate terrestrial habitat cannot be maintained around all vernal pools, conservation efforts will require the use of some system of ranking the relative ecological value of vernal pool systems (Windmiller, 2008). The most commonly adopted measures of the ecological importance of vernal pools are the presence of locally rare or threatened species, egg mass counts of target amphibian species, and species diversity measures. Because these measures vary locally and regionally, they must be adapted to local conditions and needs (Windmiller, 2008). Therefore, Best Management Practices (BMPs) for conserving vernal pool habitats generally use a concentric-circle model that represents a pool as a circle surrounded by radial management zones at distances established from data on pool-breeding amphibian movement patterns (Windmiller, 2008). (see Figure on next page)



(Windmiller, 2008)

Current scientific data suggest conserving terrestrial habitat in zones extending 150 to 300 m (500 to 1000 feet) from vernal pool boundaries. Above all, the purpose of BMPs and regulations is not to prevent development, but to redirect it (Windmiller, 2008) which will ultimately help sustain healthy pool hydrology.

Direct loss of wetlands owing to filling or other alteration must be mitigated to ensure “no-net-loss” of wetland resources. Compensatory tools include preservation of other wetlands, restoration or enhancement of wetlands, wetland creation, and in some cases, monetary compensation through mitigation banks or in-lieu fee programs (programs that require the developer to pay into an environmental fund administered by not-for-profits or government agencies) (Windmiller, 2008). If loss is unavoidable, mitigation should focus on preservation of lands with existing natural vernal pool habitat (off-site or on-site), and restoration or enhancement of existing vernal pools and adjacent terrestrial habitat (Windmiller, 2008). Thecreation of vernal pools should be used as a last resort or should be coupled with one of the above strategies. Without extensive management, most created pools fail to provide acceptable ecological requirements to sustain a productive habitat. Created pools tend to have improper basin morphology (i.e. steep grading, pool size) and poor connectivity, directly affecting vernal pool hydrology. Therefore, they lack habituation from preferred native flora. Because created pools often fail to replicate vernal pool hydrology, they may lure breeding amphibians away from more appropriate breeding areas (Windmiller, 2008).

Given the complexity of vernal pool habitat (pool and adjacent terrestrial zones) and the spatial and temporal needs of pool-breeding amphibians, conservation of intact habitat should be the primary goal of pool mitigation projects. However, preservation still results in a net-loss of wetlands and is often expensive due to high land prices associated with rapidly urbanizing areas. (Windmiller, 2008)

The restoration and enhancement of degraded vernal pool habitats is another option. Agricultural fields, clearcuts, pasture, and other lands lacking impermeable surfaces, but that have historically supported pools, are good options for mitigation, assuming that there is suitable adjacent habitat. Additionally, there is much room for creative study and practice of restoration and enhancement techniques for adjacent terrestrial habitat around vernal pools (Windmiller, 2008).

Climate Change

The dominant effect of weather patterns, namely precipitation and evapotranspiration, on pool hydrology means that these systems will be affected by climate change (Liebowitz, 2008). Furthermore, vernal pools and their biota are likely to be affected by climate change early on, due to their relative hydrologic isolation and location at the land/water interface. Climate change predictions of more episodic precipitation and increased evapotranspiration would cause pools to dry earlier in the year and remain dry longer (Liebowitz, 2008). In addition, climate change could increase the frequency of extreme rainfall events and cause more frequent and longer intermittent droughts. This could increase the frequency of the drying and refilling cycle, compared with the slow, extended drying that now occurs (Liebowitz, 2008). Increasing magnitude and variability of temperature could alter quantities and timing of snowmelt. This could potentially affect many species, especially early spring migrants that deposit eggs around the time of snow melt. Finally, any of these hydrologic changes could affect stream flow, thereby impacting riverine pools.

Direct management for global climate change is an ongoing developing process. This is an issue much broader and more powerful than the local or regional scale. As professionals throughout the world attempt to tackle this issue, however, management practices can be taken at a smaller scale. Continuous monitoring of site data will help determine the effect of the changing climate. This, in turn, would help determine adaptive management practices that may help solve emerging issues as climate patterns change.

Conclusion and General Guidelines

- Minimize and control development around vernal pool sites
- Use all available geographical data to identify the “zone of influence” of vernal pool sites near developments to help manage the landscape
- Prioritize natural vernal pool conservation and use created vernal pools as a last resort supplement to natural pools rather than a replacement
- Minimize soil alteration and impervious materials in developments near vernal pool sites
- Site analysis is the most important step when determining restoration and/or enhancement projects for vernal pool mitigation
- Seasonal grazing, especially in upland and pool margin habitats, is a key component to maintaining native flora and avoiding affects to hydrology via evapotranspiration of invasive weeds

Management of vernal pool hydrology is a complex matter. Further research must be conducted to identify the most efficient timing and methods of grazing to help reduce invasive plants. Additional research in the field of hydrology and the affects caused by the local landscape context will help determine the importance of various types of development and practices near vernal pools. Despite these enduring questions, it is clear that current practices in landscape planning are not being effectively implemented to ensure the most efficient management of vernal pool sites. Simple practices beginning in the design and planning stages will help to maintain these rare and beautiful habitats.

Management Synthesis

There is a strong correlation between improving vernal pool hydrology and benefitting native vernal pool species. Managing for the improvement or maintenance of vernal pool hydrology provides a foundation for all vernal pool species to succeed. Being such a fundamental feature of vernal pools, hydrology plays a strong role in tying together the overall ecological success of a vernal pool site. In addition to benefitting various native species, management of hydrology will help maintain proper distribution among local and regional vernal pool sites by means of landscape connectivity, as discussed in the paper.

Species that may take advantage of hydrology management are the plants in upland depressions and along pool margins. Subsequently, the fauna that depend on these plants and geographic locations will experience success as well. Conclusively, proper management of vernal pool hydrology is the groundwork on which more explicit species management can take place.

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Vernal Pool Hydrology **Fact Sheet** Omar Sadik

Basic Facts

- Vernal pools typically form in clusters or groups of pools due to the association of low permeable layers in large scale landforms
- Surface water flows through integrated seasonal swales among the pools and eventually to seasonal streams.

Natural elements that affect pool hydrology

- **Precipitation** can enter directly into the pool or indirectly through surface runoff. Typically affects short term water level variation.
- **Groundwater** flow has a direct relationship with vernal pools and its influence varies depending on position of pool in relation to groundwater level, climatic characteristics which affects groundwater levels, and soil permeability qualities.
  - Loss of pool water from adjacent catchment groundwater has been found to be driven by transpiration of plants along the emergent margins of the pool.
- **Evapotranspiration** is driven by climate and is the sole form of water loss for vernal pools. As vegetation leafs out during the spring, vernal pool water levels slowly drop.
- **Basin Morphology and Connectivity** is the geometric component to hydrology. Smaller and shallower basins have higher relative water loss while larger and deeper pools do not. Pools can be connected through swales, depressions, floodplains or seasonal streams, which define vernal pool landscape ecology.
- **Soil** characteristics also affect water chemistry and properties. Central Valley vernal pools typically have clay-rich or hardpan soils. Clay-rich soils with marine derived sedimentary alluvium have turbid, salic and sodic surface water and are nitrogen limited. Hardpan soils with igneous origins have relatively fresh non-turbid water with low phosphorous levels.

Justification and purpose

- Hydrologic processes are a fundamental building block for vernal pools.
- Provide habitat to rare and endemic species and important native flora.

- Vernal pools can provide natural water management by helping to prevent floods, erosion, and protect water quality.

Constraints

- Any adverse affect on vernal pools will have a significant impact to all subsequent down-gradient pools and streams.
- **Timber Harvesting**: alters hydrologic system in the upper watershed. Runoff, erosion, and groundwater levels change, varying pool temporal inundation
- **Urbanization** increases impermeable surfaces (roads, buildings, etc) deteriorating natural groundwater flows and causing drastic flow events
- **Climate change** will adversely change seasonal dry/wet patterns
- Removal of single pools or small portions of vernal pool sites may deteriorate the entire vernal pool landscape and its biological interface due to the importance of pool connectivity

Opportunities, Design and Management

- Livestock grazing helps control invasive weeds and manage transpiration levels.
- Large regional aquifer changes (i.e. groundwater well pumping) have no affect on vernal pool water levels due to groundwater flow characteristics. Local landscape development (i.e. agriculture) does however, and therefore should be the management focus.
- Because vernal pool hydrology is very site specific, historic evaluation for each pool is necessary. Management goals should focus on avoiding unseasonal runoff by implementing buffers and perhaps perimeter drainage plans to maintain water quality.
- 7:1 to 10:1 side slopes are necessary when designing pool basins. New pools may temporarily be inundated for longer periods than natural pools due to compacted soil.
- In constructing pools, swales or depressions may help pool connectivity and morphology.

Amy Gillett

6/3/10

Part One: Vegetation Characterization of Vernal Pool Types in California

Common Vegetation Characteristics in all Vernal Pool Types

Over 100 different types of plant taxonomy are found more frequently in vernal pools in California than in other habitats (Solomeshch et al. 399). A single pool will usually support 15-20 different species (Splash 2008), over half (60%) of which are endemic to specific regional environments within California: For example, Sebastopol meadowfoam *(Limnanthes vinculans)* are found only in Sonoma County and Contra Costa goldfields *(Lasthenia conjugens)* are found only in certain areas of the Bay Area (Barbour et al. 2007).

The following 15 vernal pool plant species are listed by the State of California as threatened or endangered; *Castilleja campestris ssp. succulenta, Chamaesyce hooveri, Eryngium constancei, Limnanthes floccose ssp. califomica, Navanetia leucocephala ssp. pauciflora, Navarretia leucocephala ssp. plieantha, Neostapfra colusana, Orcuttia inaequalis, Orcultia pilosa, Orcuttia tenuis, Orcuttia viscida, Palisedum leiocarpum, Tuctoria greenei* and *Tuctoria mucronata* (Solomeshch et al. 399). According to Platenkamp (1988), although *Legenere limosa* and *Downingia pusilla* are not listed as endangered, they are considered threatened by the California Native Plant Society.

Vegetation within different vernal pool environments are a combination of native annuals, threatened species, exotic species, algae, bacteria, and herbs. On average, native annuals usually comprise close to 70% of the species within a given pool (Schlising 1982). Because plant species within the same pool share similar vegetation characteristics and moisture tolerance levels, species diversity is much greater between pools than within pools. Species with different moisture tolerance levels and germination rates bloom at different times as a pool dries out, producing a distribution of colorful concentric zones around the pool as flowers bloom when the pool begins to decrease (Schlising 1982). Most species have survival seed dormancy mechanisms because while some pools fill up and dry out multiple times throughout the year, others may stay dry for more than a year at a time.

Some species, such as Alkali Health (*Frankenia grandiflora*) which requires high salinity levels, grow only in very specific conditions while other species have broad tolerance levels and can survive in multiple environments (Zedler 1984). Correlation of plant species to pool type is based on a combination of multiple factors: depth, salinity, size, inundation time, elevation, sun, shade, exposure to wind, type of soil, geomorphic variation etc. (Barbour et al. 2007).

Plant Classification Systems

Some studies classify plant diversity of different vernal pool types according to biological factors, while other studies focus on regional or geomorphic variation. There is no single uniform system used to classify plant diversity within different vernal pool types, but there is a consensus among research that plant species correlate to different pool types according to their sensitivity to inundation levels and frequency, salinity levels, pool size and depth, regional variation and geomorphic variation.

According to Barbour et al. (2007) vernal pool vegetation belongs to a single class: *Downingia-Lasthenia*. Diagnostic species of the class, which occur throughout all vernal pool types include: *Lasthenia fremontii, Navarretia leucocephala, Downingia bicornuta, Plagiobothrys stipitatus, Psilocarphus brevissimus, Deschampsia danthonioides, Pilularia americana, Elatine californica, Veronica peregrina ssp. xalapensis, Alopecurus saccatus, Eryngium vaseyi, Isoetes orcuttii, Pogogyne zizyphoroides, Juncus bufonius, Eleocharis acicularis, Callitriche marginata, and Crassula aquatica* (Barbour et al. 2007).

Vernal pools in California can be broken down into the following three groups (each are further broken down into alliances and associations according to families and environmental influences on plant diversity) (Barbour et al. 2007):

- <u>Lasthenia glaberrima</u> (*Lasthenia glaberrima and Eleocharis macrostachya*) - unique in high constancy and abundance of the extremely flood-tolerant taxa.

- Downingia lasthenia (*Cicendia quadrangularis, Blennosperma nanum, Triphysaria eriantha, Lasthenia californica,* and *Trifolium variegatum*) - found in short-inundated pools or at shallow edges of deeper fresh-water pools.
- Frankenia lasthenia (*Distichlis spicata, Frankenia salina, Cressa truxillensis, Eryngium aristulatum, Pleuropogon californicus,* and *Crypsis schoenoides*) - found in the presence of saline/alkaline pools.

Vegetation Variation by Seasonality

While plant diversity changes with different pool types and their given environment, it also varies within a pool from season to season as the pool dries out. Water levels and therefore vegetation and species diversity within vernal pools fluctuates seasonally causing three main phases with different vegetation patterns: the wet phase in Winter when the water level is deep; the flowering phase in Spring when the pool begins to shrink; and the dry phase in Summer when the pool completely dries out. A deep vernal pool usually does not exceed water levels higher then 50cm (Solomeshch et al. 402). In our Mediterranean climate in California, a typical vernal pool will be inundated with water January-March, begin to shrink April-June and most likely be dried out by September. The species found in vernal pools changes drastically as the environment and inundation levels fluctuate from wet to dry. Major changes in vegetation throughout the different phases can be characterized as follows:

- During the wet phase when a vernal pool is inundated with deep water, various layers of vegetation and species characterize the pools and can be found from the surface to the bottom layer. At the beginning of the Winter when the pool begins to fill up with water again, seeds that have germinated begin to sprout and eggs that have survived the Summer spawn creating an abundance of life. Out of the three phases the wet phase has the most species diversity of vegetation and animals. The surface layer and lower layer of inundation in a vernal pool provides different ecotypes appropriate for different vegetation and animals:

- On the surface layer a typical vernal pool, highly inundated, has a small aquatic annual herb called Water starwort (*Callitiche heterophylla)* that floats on the surface of the pool. The plant has an ethnobotanical use as a diuretic for kidney and bladder infections (Henriette's Herbal Homepage 2010). Also found on the surface of a vernal pool is an abundance of algae such as nostoc ball's which are nitrogen fixing blue and green algae (Layne 6). While algae is present at all levels and phases of the vernal pool habitat, a common algae found at the surface of the pool in the Winter months is zygnema which grows in a mat like formation and provides a shelter for hiding for the aquatic species found under the surface of the pool. Checkerbloom flowers (*Sidalcea malvaeflora*) are found in some vernal pools on the edge of the surface and bloom in the Spring months as the pool begins to decrease (Splash 2010). In a similar fashion, White meadowfoam (*Limnanthes alba ssp. alba*), Vernal pool buttercup *(Ranunculus bonariensis var. trisepalus),* Water starwort (*Callitriche palustris*) and Red maids (*Calandrinia ciliata)* germinate at the bottom layer and grow to the surface of deep waters where they bloom. Pale spikerush (*Eleocharis macrostachya)* is of particular interest because it grows in the deepest vernal pools where it will often be a dominant species (Splash 2008).
- Below the surface layer are an array of vegetation and exotic species specialized to vernal pool habitats that vary with specific pool characteristics. Thousands of

species of algae and bacteria inhabit vernal pools and contribute to the habitat as a valuable food web and decomposer by providing energy and oxygen for other species to feed on and by breaking down dead bodies and matter (Splash 2008). Some common species found at the bottom of vernal pools include: *Lasthenia fremontii, Navanetia leucocephala, Pogogyne douglasii,Limnanthes alba an Layia fremonti* (Solomeshch et al. 402).

- During the flowering phase, as rains and inundation levels in the pool begin to shrink in the Spring, meadow grasses start to replace the water, flowers bloom and the habitat and its inhabitants being to change. As the temperatures warm a little, the following plants which germinate under water begin to bloom: Popcorn flowers (*Cryptantha angustifolia*), Soaproot (*Chlorogalum pomeridianum* var. *p.)*, Spokepod (*Thysanocarpus radians)*, Owl's clover (*Castilleja densiflora*), White hyacinth (*Triteleia peduncularis*), Biscuit root (*Lomatium caruifolium var. caruifolium*), Fiddleneck (*Amsinckia menziesii var. intermedia*), Fremont's tidy tips (*Layia fremontii*), Frying pan poppy (*Eschscholzia lobbii)*, Narrow leaf mules-ear (*Wyethia angustifolia*), Vernal pool dodder *(Cuscuta howelliana)*, storksbill *(Erodium cicutarium)*, Vernal pool monkey flower (*Mimulus tricolor)*, White tipped clover *(Trifolium variegatum)*, Wally basket *(Triteleia laxa)*, Little quaking grass *(Briza minor)*, Purple needlegrass *(Nassella pulchra)* and Miniature lupine (*Lupinus bicolor Lindl)* (Splash 2008).
- Close to Summer, when pool water levels reach a very low level and before they become completely dry, Field owl's clover (*Gratiola ebracteata*), hawkbit (*Leontodon taraxacoides* ssp. *longirostris*) , Vernal pool goldfields (*Lasthenia californica*), Field cluster lily (*Dichelostemma congestum*), Vasey's coyote thistle (*Eryngium vaseyi*),

Winter vetch (*Vicia villosa*), Medusahead (*Taeniatherum caput-meedusae*) and Woolly marbles (*Psilocarphus tenellus var. tenellus*) bloom (Splash 2008)(USDA 2010). By the end of the Summer, a vernal pool is usually completely dried out and changed to a dry grassy meadow environment. At the beginning of the Summer when all of the water is dried up White navarritia (*Navarretia leucocephala*), Vernal pool buttercup (*Ranunculus bonariensis var. trisepalus*) and Sacramento beardstyle flower (*Pogogyne zizyphoroides*) (U.S Fish and Wildlife Service 9). In late Summer months, when the pool is completely dried up, Douglas beardstyle (*Pogogyne douglasii*) and dry Downingia's (*Downingia pusilla*) germinate at the bottom of the pool basin and bloom in the late Summer months (Splash 2008). Scarlet pimpernel (*Anagallis arvensis*) is unique in that it germinates all year round.

Key indicator species for each pool type stay present within the pool from year to year while other vegetation will vary annually according to changing environmental factors. Ultimatly, the seasonal cycle and fluctuating inundation levels control the always changing vegetation and species composition of a vernal pool. The pools are the most alive with species when inundation levels are high in the Winter and early Spring because multiple ecotypes are present that provide habitats for different types of species (Barbour et al. 2007). The unique environment means that plant species are always racing to reach certain stages of their live cycle and reproduce before the pools disappear.

Vegetation Variation by Pool Inundation Time

Vernal pools typically do not stay inundated with water for longer then two months in a row (Solomeschch et al. 394). Factors that influence vernal pool inundation time include: sunlight exposure, soil permeability, annual precipitation, transpiration and water depth (MAD Scientist 2009). Plants have difference levels of tolerance for flooding, the number of consecutive days of flooding, therefore is directly related to plant distribution (Zedler 1984). Pools with longer levels of inundation are less susceptible to invasions by exotic species. Some species are tolerant to broad levels of inundation, while others require very specific levels to flower (Solomeshch et al. 402):

- Species that can tolerate longer periods of inundation (36-65 days): *Myosurus minimus, brodiaea orcuttii, Pogogyne abramslii, Psilocarphus brevissimus, Crassula aquatica, Eleocharis macrostachya, Plagiobotrys undulates, Elatine brachysperma, Downingia cuspidate, Eryngium artistulatum, Pilularia americana, Isoetes howellii and Lilaea scilloides* (Zedler 1987)(Solomeshch et al. 402).
- Species that can tolerate shorter periods of inundation (0-35 days): *Lotus hamatus*, *Bromus rubens*, *Silene galica*, *Crassula erecta*, *Selaginella cinerascens*, *Orthocarpus purpurascens*, *Filago gallica*, *Plantago erecta*, *Erodium moschatum*, *Vulpia myuros*, *Hypochoeris glabra*, *Erodium botrys*, *Hemizonia fasiculata*, *Bromus mollis*, *Gastridium ventricosum*, *Trifolium amplectens*, *Navarretia hamata*, *Sisyrinchium bellum*, *Agrostis microphylla*, *Centaurium venustum*, *Juncus bufonius*, *Avena barbata*, *Microseris douglasli*, *Ophioglossum californicum*, *Psilocarphus tenellus*, *Lythrum hyssopifolia*, *Plantago bigelovi*, *Eleocharis bella*, *Anagallis minimus*, *Callitriche marginata and Deschampsia danthonioides* (Zedler 1987) (Solomeshch et al. 402).
- Species that require specific periods of inundation (this is not an exhaustive list – please see reference for additional species): *Hemizonia fasciculate* is most abundant in areas with 5-20 days of flooding; *Deschampsia danthonioides* is most abundant in areas with 20-45 days of

flooding; *Pogogyne abramsii, Psilocarphus brevissimus, Crassula aquatica,* and *Eleocharis macrostachya* are the most abundant in areas with 35-40 days of inundation. *Downingia cuspidate* is most abundant in areas with more than 65 days of flooding (Solomeshch et al. 402).

Vegetation Variation by Pool Depth and Size

Vernal pools vary greatly in size from extremely small to extremely large. Some vernal pools can be as large as several hectares (vernal lakes), while others may be smaller than 100m2 (terrace vernal pools) (Solomeshch et al. 398). According to The Vernal Pool Association (2010) the average vernal pool is approximately “30 feet by 100 feet long and 3 feet in depth.”

Pool depth greatly impacts species diversity. Generally, species with longer life cycles prefer deeper pools and they have more diversity because they provide multiple ecotypes (Plantenkamp 155). There is a correlation between pool depth and size. Most species that dominate deep pools will also be present in large pools (because they tend to be deep) and species that dominate small pools will also be present in shallow pools (because they tend to be shallow) with a few exceptions: *Castilleja campestris* prefer large shallow pools and *Gratiola ebracteata* prefer small deep pools (Plantenkamp 155).

Rarer plant species are correlated with small, shallow pools that have high plant cover: *Legenere limosa, Navarretia myersii, Downingia pusilla*, and *Castilleja campestris* ssp. *succulenta* (Barbour et al. 2007). Shallow/medium species, such as *Deschampsia danthonioides* can tolerate a wider range of pool depth and will appear in all pools around the edges as the water level drops and the pool dries. Many deep pool species are restricted to only deep basins: *Eleocharis, eryngium, Isoetes marsilea, Alopecurus saccabts, Downingia omatissima, Navanetia leucocephala, Pilularia americana, Ranunculus borcriensis var. trbepalus, Downingia cuspidate, and Downingia bicornuta.*

Species with longer life cycles prefer deeper pools because they have longer periods of inundation (Plantenkamp 158). Some species have a broad tolerance and can survive in all different pool depths, while others can only survive in only shallow or deep pools:

- Species found only in shallow pools: *Downingia cuspidate, Hemizonia fasciculate, Hypochaerisg labra, Deschampsia danthoniodes, Pogogyne zizyphoroides and Lasthenia fremonti* (Plantenkamp 156) (Solomeshch et al. 399).
- Species found only in medium pools: *Deschampsia danthonioides.*
- Species found only in deep pools (mostly perennials): *Eleocharis eryngium, Alopecurus saccabts, Downingia omatissima, Navanetia leucocephala, Pilularia americana, Ranunculus borcriensis var. trbepalus, Downingia cuspidate, Lasthenia navarretia, Downingia bicornuta, Lasthenia glaberrima,* and *Ranunculus bonariensis var. trisepalus* (Solomeshch et al. 399) (Bauder 1989) (Plantenkamp 156).
- Species found only on the edges of pools: *Limnantlrcs sp., Sidalcea sp., Hypochaerisg labra or Trifolium sp.* (Solomeshch et al. 399).

Vegetation Variation by Pool Salinity

Soil type within a vernal pool impacts water chemistry and changes the plant community composition. According to the Barbour et al. (2007) classification system plant communities that can survive in saline vernal pools are in the order Frankenia-Lasthenia and are dominated by halophytes. Associations of plant species in this community are unique in their ability to thrive in conditions where water has a concentration of greater than 0.5% NaCl. Some saline pool plant species cannot survive in fresh water pools and other plant species can tolerate both saline and fresh water pools (Keeley and Zedler 1998):

- Diagnostic species found in saline pools include: *Distichlis spicata, Frankenia salina, Cressa truxillensis, Myosurus minimus, Crypsis schoenoides, Plantago elongata, Downingia insignis, Cressa truxillensis, Distichlis spicata, Frankenia salina, Eryngium aristulatum, Crypsis schoenoides, Cotula coronopifolia*. (Barbour et al. 2007).
- Rare species associated with only saline pools: *Astragalus tener* var. *tener, Downingia pusilla, Lasthenia conjugens, Lasthenia ferrisiae, Navarretia leucocephala* ssp. *bakeri* (Barbour et al. 2007).
- Species that can survive in both fresh water and saline pools include: *Eryngium castrense/vaseyi, Lasthenia fremontii, Psilocarphus brevissimus* var. *brevissimus* (Barbour et al. 2007).

Vegetation Variation by Regional and Geomorphic Variation

Variations in geomorphic surface impacts vernal pool plant diversity and species richness (Platenkamp 1998) because they influence factors that change pool characteristics: depth, inundation time, soil permeability, depth to hardpan, solute concentration, hydrological regime etc.) Different geomorphic surfaces will create different vernal pool types with very different plant species composition. However, the average number of vernal pool plant species per pool does not change much among different geomorphic surfaces (Platenkamp 1998).

Vernal pools primarily occur in Mediterranean climates such as California and are found in valleys (Great Central Valley), coastal terraces (Southern California) and volcanic mudflows (Tehama and Riverside counties). Because vernal pools are distributed in a wide variation of regions (West coast of North and South America, Northwest Africa, West Africa and Southern Australia), some species are common in all vernal pool environments irrespective of the region, others are found only in California's cool and warm climates while yet others are only common to regions outside California (Solomeshch et al. 399):

- Species with widespread distribution patterns in environments other than pools: *Eleocharis acicularb, Luttctts bufonius, Montia fontana* and *Myosurus minimus.*
- Species common only in California pools: *Alopecunu, callitriche, Crassula, deschampsia, Downingia, elatine, Erynytum, isoetes, Lasthenia, Navanetia pilularia, Plagiobothrys, Pogogyne, Psilocarpfuu, and Veronica.* Vernal shrimp are primarily only found in pools in the Central Valley and Coastal Mountain ranges (U.S Fish and Wildlife Service 7).
- Species specialized for pool habitats that are found in multiple regions:
  - California, North and South America: *Downingia, Lasthenia, Navanetia, Plagiobothrys, Pogogyte, and Psilocarphils.*
  - California, North and South America, Northwest Africa, West Africa and Southern Australia: *Isoetes, Marsilea, Pilularia, Callitriche, Crassula, Elatine, Eleocharis, and Limosella* (Keeley and Zedler 1998).

Plant diversity is greatly impacted by regional differences in Winter temperatures, Summer precipitation levels and soil chemistry (Bauder et al. 1996). Vernal Pools within California are known to have some of the highest levels of vegetation and species diversity. (Solomeshch et al. 398). While some species can survive in a variation of climates, others prefer warmer or cooler climates. An example of this can be seen in the vernal pools species distribution within Northern and Southern California (Solomeshch et al. 415):

- Species found only in warmer climates of Southern California: *Lrymgium aristulatum ssp. parishii, Pogogyne abramsii, Navarretia fossalis, Pogogyne nudiuscula and Orcuttia californica.*

- Species found only in cooler climates of Northern California: *Downingia bacigalupii, Eryngium mathiasiae, Polygonum polygaloides ssp. esotericum, Polygonum polygaloides ssp. confertiflorum, Pogogyrc floribunda* and *Mimulus pygmaeu.*

Part Two: Goals and Management Plans to Restore Vernal Pools

Vernal pools are a unique habitat that not all species can inhabit. Some specialized species adapted to the fluctuating ecosystems can only survive in vernal pools. The increase in threatened habitat loss of up to 90% (Buck 4), due to poor land use systems, makes restoring and protecting the unique wetland ecosystems imperative.

Vernal pools are generally protected under wetland laws. According to the US Environmental Protection Agency the following laws regulate and protect vernal pool habitats: Clean Water Act (CWA), National Environmental Policy Act (NEPA, Rivers and Harbors Appropriation Act, Federal Agriculture Improvement and Reform Act, Endangered Species Act, Transportation Equity Act, Coastal Wetlands Planning, Protection and Restoration Act (CWPPRA) and the North American Wetlands Act (NAWCA) (2009).

To amend the drastic decline in vernal pools, many restorationalists and environmentalists are protecting and restoring land where they are found. According to Barry (1996), successful management practices must fully understand current abiotic and biotic factors impacting the current state of endangered pools. It is equally important to know past management practices that have been implemented at the site in order to create an appropriate restoration/conservation goal. Clark et al (1996), explains that the foundation for restoring vernal pools is promoting awareness and education of their importance and endangered species.

The California Coastal Conservancy implemented a restoration plan to expand vernal pools on protected land in hopes of helping to mitigate the historical loss of the unique habitat. Steps were taken to create specific topography mimicking that of a natural vernal pool in hopes that vegetation and habitat would begin to form a resemblance of a natural vernal pool environment. Long term evaluations and conclusions from the study showed that the methodology for vernal pool restoration and enhancement was a success (Ferren and Hubbard 207). While the restoration practice of constructing vernal pools is in need of further research and modifications, success rates demonstrate that the methodology is a constructive tool to restore vernal pool habitats.

A Closer Look at Constructing Vernal Pools for Restoration

According to Sutter and Francisco (1998), vernal pools were first created by humans on wetlands in the 1980's in an attempt to restore the diminishing habitats. While some efforts to re-create the natural habitats have been successful, many have not. The complex characteristics that impact plant species diversity within and between vernal pool types means that the methodology of creating a man-made pool that successfully mimics the natural habitat is not an easy task. Common reasons of unsuccessful implementation include: poor understanding of the magnitude of diversity that must be included, poor understanding of what a successfully created pool should look like, poor soil analyses, limited understanding of the required geomorphic characteristics and poor management and monitoring strategies (Sutter and Francisco 1998).

With the continual loss of vernal pool environments and the need to isolate successful restoration practices that can improve vernal pool restoration models, efforts must identify those activities that have been successful in the past in creating and preserving vernal pool habitats. The U.S Fish and Wildlife Service conducted an evaluation of vernal pool construction projects in the

Central Valley and established that over 75% of the projects were successful in both creating a vernal pool habitat and also complying with environmental laws and policies regulating construction practices. The Highland Reserve pools in Roseville, California, and the Parkway pools in Folsom, California, were listed as successful examples of vernal pool construction (Sutter and Francisco 1998). Ultimately, a successfully constructed pool should be difficult to identify from a natural vernal pool (Deweese 1998). A review of literature and case studies, that have been successful in restoring vernal pools, reveals key critical steps that one must consider in order to be successful in creating a vernal pool habitat: appropriate site selection, a thorough understanding of the sites history and clearly defined goals and objectives, construction criteria, appropriate plant species selection, and project evaluation and monitoring to ensure long-term sustainability.

Suggested Steps to Create a Vernal Pool

Site selection: To construct a vernal pool a site with appropriate soils that has historically supported the unique wetland habitats must be located (Deweese 1998): Aerial photography provides a useful tool for identifying appropriate wetland topography with claypans that will support the construction of pool habitats (Biebighauser 1999). The following three publications provide useful information on the use of aerial photography for this purpose: Vernal pools in Massachusetts: Aerial photographic identification, biological and physiographic characteristics, and State certification criteria (Stone 1992), Massachusetts aerial photo survey of potential vernal pools (Burne 2001), and Remote and field identification of vernal pools (Burne and Lathrop 2008).

To ensure compliance with environmental regulations and facilitate knowledge of the identified site, private landowners, local/national environmental stakeholders that are active within the area, research organizations, and environmental laws and policies within the area need to be identified and contacted (Oscarson and Calhoun 2007). Talking to local landowners that are familiar with the area can offer valuable information of previous existing natural vernal pool characteristics and help in the design for the constructed pool (Biebighauser 1999). Additionally, involving local stakeholders offers a more extensive network to thoroughly understand the site, its seasonal fluctuations and abiotic and biotic characteristics and limits.

The following factors and their relationship to inundation level and frequency must be considered: Annual precipitation in the region, amount of sunlight, transpiration from trees and plants around the watershed, soil permeability (the soil must have a low permeability) and water depth of the pool (Biebighauser 1999). The area must be measured for appropriate pool dimensions, soil must be sampled to determine its pH level, and native vegetation must be removed from the area that the pool depression will be created on (U.S Environmental Protection Agency 2009). It is my opinion that it is better to identify wetland sites for construction that are slightly removed from the types of development (roads, parks, infrastructure, agricultural development, housing etc.) that destroyed the original vernal pools. Creating a buffer zone away from disturbances will increase the likelihood of success.

Within the Central Valley, restoration efforts must comply with "federal regulatory requirements under Section 404 of the Federal Clean Water Act and the Federal Endangered Species Act" (Sutter and Francisco 192). In most cases the restorationist that is spear-heading the project must apply for a permit long before they are allowed to begin construction. Local regulations primarily provide a permit-by-permit response to inquiries for vernal pool construction

(Oscarson and Calhoun 2007). The better the understanding of the history and natural structure of the ecosystem the more likely the project will be successful.

Clearly defined goals: It is my opinion that a critical step to ensure success of constructing a vernal pool requires clearly defined and understood goals between the involved stakeholders prior to any type of pool design and construction. If the project lacks clearly defined goals and objectives it is not likely to be successful, and it will be impossible to gauge the outcome of the projects success and to learn important lessons for future projects. The goals should include specifics on the long-term and short-term vision of targeted native species and endangered species that the pool should restore. For example: a short-term goal may be to establish the pool environment with certain species that can tolerate various pool environments and therefore have a better chance of survival during the first year, helping to establish the vernal pool ecosystem at which time the long-term goal of having pool characteristics that mimic a natural system and allow more sensitive species to exist can be achieved. A clear separation of short and long-term goals allows monitoring and evaluation of the pool to be more accurate.

Construction techniques: Once the site is selected and surveyed for natural pool characteristics, construction techniques and dimensions need to be identified. The size of constructed pools generally ranges between 5-520 acres: the majority of constructed pools are 25-50 acres (Deweese 1994). Because natural vernal pool landscapes have pools of varied depths with different species richness, it is important that restorationists restore pools on different geomorphic surfaces that mimic different pool dimensions (Plantenkamp 1998).

According to DeWeese (1994), in order to mimic inundation periods of a natural pool, pool depth should not exceed 18 inches. If pools are too deep, they will be inundated for longer periods than natural pools and only very deep pool species will be able to survive. In order for the pool sides to support species with different depth preferences, side slopes of the pool should be sloped. The range of depth on sloped pool sides supports multiple species, while a straight pool side that is one depth will support only deep pool species (DeWeese 1994). Once the optimal depth and size of the pool is determined that will provide a habitat for different species in varied rainfall levels, a tractor is used to create pool sides and bottom (DeWeese 1998). The depression made must not penetrate the claypan in the soil (Jones 1987). Excavation spoils should be taken off-site after the construction is complete (DeWeese 1998).

Due to the varied systems of plant classification in vernal pool types, it is important that multiple models are considered in the design and construction process. Sutter and Francisco explain, "if a mean value rather than a mean plus variant (e.g., depth of created pools) is used as the standard for pool design, the diversity of habitat and the ability of the pool complexes to be buffered against climate variability is reduced" (192).

Plant selection: Although a single project, will not have to reproduce all vernal pool types, there must be a thorough understanding of which dominant species correlate to which pool type and their range of preferences. Pool characteristics must be determined in conjunction with the dominant species found within the vernal pool environment (Oscarson and Calhoun 2007). Identified habitat goals according to the needs of the dominant species must be supported by the site capabilities otherwise the project will not be successful (Oscarson and Calhoun 2007).

To maximize chances of success, the establishment of biological variability and plant diversity should be verified by comparing the constructed pool with characteristics of natural reference vernal pools within the area (DeWeese 1998): diversity within natural pools, dominant species, maximum depth of pools, average size of pools, salinity levels, vegetation cover, pool connectivity, and water storage function. Plant species abundance and hydrological data must be cross referenced to isolate species that will survive in the pool given its dimensions and characteristics. The following publications provide useful information on the history and preferences of vernal pool plant species: Vernal pools: natural history and conservation (Colburn 2004), and A field guide to the animals of vernal pools (Kenney and Burne 2001).

In cases of pre-existing degraded pools, there may already be an established seed bank at the pool. However, for newly constructed pools there is not usually an established seed bank at the pool and hydro-seeding can be used after construction to shorten the time needed to establish plant communities (DeWeese 1994). Introduction of seed bank that is obtained from natural vernal pools located close to the site is often an effective method to establish appropriate vegetation. Generally, up to 1cm of material is scrapped from scattered areas of natural pools and transferred to the constructed pool (Berger 1990). This is a sensitive process and care must be taken not to disturb the species balance and composition at the natural pool where the seed bank is taken from. Additionally the natural pool species must be considered against the characteristics of the created pool to ensure their survival in the new environment.

Maintenance and Monitoring: The created vernal pool site should function for a minimum of 10 years before the pool can be labeled as sustainable. The functioning level of the pool should be measured against previously identified goals and objectives that are evaluated through annual and seasonal monitoring and maintenance, and in comparison to natural vernal pools in the area (Sutter and San Francisco 191). The vernal pool should be monitored annually for: floral and fauna inventories, vegetation transects, photographic documentation, site maintenance, and monitored hydrology flow in the wet season.

To monitor the pool hydrology, staff gauges should be installed in both created and natural pools and monitored weekly during the wet season. Depth, area, and inundation results should be documented with hydrographs, and aerial photography. The performance standards for pool hydrology are: maximum depth of inundation within range of reference pools and longest period of inundation not greater than 125% of reference pools (DeWeese 1998).

Vegetation cover and species abundance in comparison to total plant species composition should be documented seasonally with transects, square meter quadrats, and photo graphing: species with 20 percent cover or greater should be used to identify endemic species and hydrophytics (Deweese 1998). The number of species and absolute and relative cover of key pool species in the constructed pool should not be lower than the minimum recorded in natural reference pools. Wildlife diversity around the pool should be monitored on a case by case basis depending on resources, time, goals and objectives.

Although routine site maintenance is often not done it is an important part of protected a created vernal pool environment. Any human action that has a negative impact on the pool functions and desired characteristics must be documented and regulated, where possible (Mitchell et al. 2007). Performance standards should be based on comparing the hydrology and vegetation of the constructed pool to natural reference pools selected according to their proximity and level of disturbance (Deweese 1998). Reference pool data is important because it provides a basis for comparing performance standards of constructed pools. Cover by pool endemics (identified in the goals) of created pools should not be less than their cover in natural reference pools (DeWeese 1994). Typically, by the third year the pool should have an established species cover of species that prefer longer inundation periods such as *Eleocharis macrostachya*. A key to maintaining the vernal pool site is to maintain the forested or wetland habitat of several hundred meters surrounding the constructed pool (Mitchell et al. 2007). The following publications provide useful information pertaining to effective monitoring and evaluation of constructed vernal pool environments: <u>Vernal Pool Constructed Monitoring Protocol and Habitat Replacement Evaluation</u> (DeWeese 1998), and <u>Wetland Mitigation Monitoring Report</u> (Huffmann 1994).

According to DeWeese (1998) pool construction projects are more cost effective if they construct fewer larger pools instead of a direct replication. Vernal pool construction project costs vary greatly depending on the size, region, pool characteristics, and species composition and it is likely that no two pools will cost the same amount. There is limited data available on costs associated with constructing a vernal pool. The following price budget is a projection that includes hiring a professional pond builder to construct the pool. It is only a sample budget of baseline costs and does not reflect costs required for the permit, variation in pool characteristics, plant diversity, and maintenance and evaluation.

Sample Budget to Construct a Vernal Pool (PondMagic 2010):

Feature:

16’ X 10” Pool: stone, aquatic plants and water lilies included	$10,000.00

Landscaping:

Landscape prep, soil amendments, top dress and all plantings	$ 5,000.00
Flagstone and Boulders	$ 500.00
Excavation of existing soil and vegetation	$ 1,000.00
Total	$ 16,500.00

Part Three: Synthesis of Constructed Vernal Pools within Yolo Grasslands County Park

I believe that Yolo Grasslands fits much of the criteria identified in my research as a good environment for vernal pool construction due to its following characteristics: previously supported vernal pools, wetland topography with claypans, low salinity in created pools supports greater species diversity, varied low and high inundation pools allows for greater species preferences, good pool connectivity, compliance with related regulations/laws, identified key stakeholders and land history, and the presence of natural reference pools on site. However, the site does provide constraints that must be addressed, such as the fact that the area is also heavily used for recreational activities (archery, dog walking, and horse riding). If activities are not properly regulated close to the pools then the level and type of disturbance will be detrimental to the sustainability of the constructed pool habitats. It is also apparent that further evaluation and research is required to understand the success of pool species composition in relationship to the environments fluctuating climate, missing data on salinity levels, annual variation in species abundance, lack of detailed plant surveys, and impact and control of invasive species (Perrenial Pepperweed, Swamp Grass, Yellow Starthistle, Barbed Goatgrass, and Medusahead). With continued research and monitoring the constructed pool characteristics could be modified to improve the success of restoring the pool habitats. For example, species survival may be improved in the constructed pools by creating sloped pool sides as an alternative to the current more uniform pool sides.

I believe that the methodology of constructing vernal pools offers an exciting an effective restoration tool to restore vernal pools in Yolo Grasslands and other wetland habitats. However, it is a growing area capable of improvement and in need of further research on best practices. As Berger explains (1990), effective long-term evaluation and monitoring of constructed pool projects will provide a means to more effectively evaluate best practices of creating vernal pools and enhance our success in restoring the unique wetland habitats.

Fact Sheet: Vegetation Characteristics of Vernal Pool Types

• Pool vegetation belongs to a single class Downingia-Lasthenia (Barbour et al. 2007).

• Diagnostic species of the class, which occur throughout all vernal pool types include: *Lasthenia fremontii, Navarretia leucocephala, Downingia bicornuta, Plagiobothrys stipitatus, Psilocarphus brevissimus, Deschampsia danthonioides, Pilularia americana, Elatine californica, Veronica peregrina* ssp. *xalapensis*, *Alopecurus saccatus, Eryngium vaseyi, Isoetes orcuttii, Pogogyne zizyphoroides, Juncus bufonius, Eleocharis acicularis, Callitriche marginata, Crassula aquatica* (Barbour et al. 2007).

• Vernal pools in California can be broken down into the following three groups (each are further broken down into alliances and associations according to families and environmental influences on plant diversity (Barbour et al. 2007):

  • Lasthenia glaberrima (*Lasthenia glaberrima* and *Eleocharis macrostachya*) - unique in high constancy and abundance of the extremely flood-tolerant taxa.

  • Downingia lasthenia (*Cicendia quadrangularis, Blennosperma nanum, Triphysaria eriantha, Lasthenia californica,* and *Trifolium variegatum*) - found in short-inundated pools or at shallow edges of deeper fresh-water pools

- Frankenia lasthenia *(Distichlis spicata, Frankenia salina, Cressa truxillensis, Eryngium aristulatum, Pleuropogon californicus, and Crypsis schoenoides)* - found in the presence of saline/alkaline pools.

• Pool type plant species composition is based on multiple factors, not only one: inundation time and frequency, pool size and depth, salinity levels, regional variation and geomorphic variation.

• Pools are characterized by different rings of plants that flower at various phases as the pool dries out. Different seeds germinate at different rates causing different sequencing.

• Some species of plants grow only in very specific conditions, such as Alkali heath *(Frankenia grandiflora)* which requires high levels of salinity, while others can survive in a broad range of conditions.

• Correlation of plant species to pool type is rarely specific to one aspect of pool type but rather a combination of multiple factors (depth, salinity, size, inundation time, elevation, sun, shade, exposure to wind, type of soil etc.).

• Over 200 species of plants are found in vernal pools (Splash 2008).

• A single pool typically supports 15-20 species and no two vernal pools are exactly alike (Splash 2008).

• Plants are primarily annuals with different blooming times (Schlising et al. 1982).

• Most species have seed dormancy mechanisms.

Inundation Time and Frequency Variation

• Factors that influence inundation time include: sunlight exposure, soil permeability, annual precipitation, transpiration and water depth (MAD Scientist 2009).

• Pools are usually not inundated for longer than two months. The number of consecutive days of flooding is directly related to plant distribution (Zedler 1984).

• Edge or shallow pool species require or tolerate 15-35 days of inundation: *Cicendia quadrangularis, Blennosperma nanum, Triphysaria eriantha, Lasthenia californica,* and *Trifolium variegatum.* Deep pool species require or tolerate 36-65 days of inundation.

• The month in which the seeds are wetted, relative to appropriate seed germination timing and temperature, is the most important factor in successful germination (Bliss and Zedler 1988).

• Inundation times in vernal pools have one of the biggest impacts on species composition as some species are very tolerant and others are extremely sensitive (Solomeshch et al. 402).

• Pools with long levels of inundation are less susceptible to invasion be exotic species.

Pool Depth and Size Variation

• Pool depth greatly impacts species diversity. Deeper pools have more species because they provide more habitats (Plantenkamp 155).

• Species that dominate deep pools can be expected in large pools (because most large pools are generally deep) with the exception of a few species (Platenkamp 156): *Castilleja campestris* prefer large shallow pools and *Gratiola ebracteata* prefer small deep pools.

• Deep pool species are distinctive to deep pools where as shallow/medium species will appear in all pools around the edges as the water level drops. Shallow pool plant species form a distinctive ring around the edge of deep pools as the water level drops and edges of the pool dry. Medium pool species can tolerate a wider range of pool depth (*Deschampsia danthonioides*).

• Deep pool plant species (mostly perennials) are generally restricted to the deepest basins *(Eleocharis, eryngium, Isoetes marsilea, Alopecurus saccabts, Downingia omatissima, Navanetia leucocephala, Pilularia americana, Ranunculus borcriensis var. trbepalus, Downingia cuspidate, Lasthenia, Downingia bicornuta).*

• Species with longer life cycles prefer deeper pools because they have longer periods of inundation (Plantenkamp 158).

• More rare species are correlated with small, shallow pools that have high plant cover: taxa such as *Legenere limosa, Navarretia myersii, Downingia pusilla*, and *Castilleja campestris* ssp. *succulenta*. Few rare plant species are correlated with large deep pools (Barbour et al. 2007).

Regional and Geomorphic Variation

• They are most abundant in the Central Valley, but occur in 30 California counties. They are known to occur in 17 regions that differ in climate each with different variations in species composition (Barbour et al. 2007).

• Soils, topography and Mediterranean climate are dominant factors determining if vernal pools will form in the given environment (Bauder 1996).

• Plant distribution is greatly impacted by regional differences in winter temperatures, summer precipitation levels and soil chemistry (Bauder 1996).

• Pool types in California with species that have a very limited distribution include pools in inland valleys (*Atriplex coronata*), montane depressions (*Downingia concolor)* and coastal mesas (*Eryngium* sp. nova.) (Bauder 1996).

• Narrow endemic plant species are limited to one pool sub-type with a unique combination of soils and climate that differentiate it from others (Bauder 1996).

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Special Status Invertebrates

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ENH 160

Species Report

Spring Quarter 2010

The Conservancy Fairy Shrimp (*Branchinecta conservatio)*

Kingdom: Anamalia

Phylum: Arthropoda

Subphylum: Crustacea

Class: Branchiopoda

Order: Anostraca (fairy shrimp)

Family: Branchinectidae

Status: Endangered

SUMMARY

ECOLOGY

- First described in 1990, and named for the Nature Conservancy
- Large Branchiopod at ½ inch to 1 inch long
- Swims upside-down by beating its 11 pairs of legs in a wave-like motion
- Deposits egg cysts in sediment at bottom of pools. Desiccated cysts can last years, and not all cysts hatch each year. When re-hydrated, hatch and develop into adult shrimp
- Life cycle duration highly dependant on pool temperature
    - Average: reproduce 46 days after initial pooling
    - Average: die 113 days after initial pooling
- Cyst banks are important to yearly succession of pools and recovery after environmental disturbance
- Important Food source for migratory birds, amphibians, and other vernal pool invertebrates
- Range over-laps with other vernal pool branchiopods, but does not usually share pools with other fairy shrimp species. Usually co-exists with vernal pool tadpole shrimp
- Frequently associated with Colusa and Orcutt grasses

- Inhabits large, deep, longer-lasting vernal pools with moderate turbidity
    - Average area 27,865 square meters, depth 19.7 cm
- Occurs at eight known sites in the Central Valley and southern California

THREATS

- Listed as Endangered on September 19, 1994 along with the vernal pool tadpole shrimp, longhorn fairy shrimp, and vernal pool fairy shrimp
- Critical habitat assigned August 6, 2003
- Specifically threatened by:
    - habitat loss
    - introduced mosquitofish and bullfrogs
    - water oxidation from decomposition of non-native grass thatch
    - high water temperatures cause by global climate change
    - loss of bird vectors

POSSIBLE CONSERVATION EFFORTS

- Control of non-native predators
- Control of non-native grasses producing heavy litter
- Further research and preservation of a range of vernal pool types
- Development of brachiopod cyst bank

SPECIES ACCOUNT

DESCRIPTION AND LIFE HISTORY

The Conservancy fairy shrimp *Branchinecta conservatio* is a freshwater crustacean endemic to California's threatened vernal pools. It was first described in 1990 (Eng et al. 1990), and was named to honor the Nature Conservancy for their conservation work with California vernal pool systems.

Conservancy fairy shrimp are large branchiopods between a half and inch and an inch long. They have long, delicate bodies, no carapace, and eleven sets of legs that they beat in a wave-like, anterior-to-posterior motion to swim upside-down through the water. They eat a variety of algae, bacteria, rotifers and other microorganisms, and detritus.

After mating, Conservancy fairy shrimp females carry their eggs in a brood patch which may be dropped as an egg cyst into the sediment or may remain attached to the mother's body when she dies and likewise sinks to the sediment. The eggs cysts desiccate and remain dormant in the soil when vernal pool habitats dry up for the summer. Cysts can hatch within a week after pools fill with water again in the winter (Fish & Wildlife Species Account). Cysts can remain viable for years. Precisely how long cysts can last is unknown, but there is recorded evidence of cysts surviving at least eight years under natural conditions and as much as 25 years in dry sediment samples stored in the lab (Belk 1996). Furthermore, not all cysts will hatch every year, meaning residents of a pool may represent offspring from several years worth of breeding seasons. This allows a population to "hedge its bets" against the possibility that a low- rain year yields a short inundation period, shortening the breeding season or even terminating it before the next generation can be successfully fertilized. A long inundation period can increase the cyst bank dramatically, but a single bad year will not significantly inhibit population growth (Ripley 2004). It is unclear what triggers cysts to hatch or remain dormant in a given year.

Conservancy fairy shrimp reach the age of their first reproduction a mean of 46.2 days after a pool fills with water (with a 95% confidence interval of +/- 18.9 days) and die a mean of 113.9 days after initial pooling (with a ninety-five percent confidence interval of +/- 49.4 days) (Helm 1998). Development time and life span are highly dependant on water temperature: In 1995, Helm recorded a Conservancy fairy shrimp population reproducing a mere19 days after pooling and dieing after 28 days. this year was unusually warm, holding around 25ºC for the life span of the shrimp. The pool dried up approximately five days after the last individual was found alive.

HABITAT AND ECOLOGY

Conservancy fairy shrimp occupy vernal pools, vernal lakes, and alkali pools. We found no data on what alkalinity levels are tolerated. Their large size makes them highly vulnerable to fish predation in larger bodies of water (Peck 2004**)**, and the required desiccation of egg cysts makes them ill-suited for colonization of permanent waters. They are generally found in large, deep, moderately turbid vernal pools. Helm 1998 observed individuals in pools ranging from 30 to 356,253 square meters; that study also asserts that this species prefers Anita Clay on high terrace landforms, Pescadero clay on basin rim landforms, or Peters Clay on volcanic mudflow landforms.

Conservancy fairy shrimp commonly co-occur with Colusa grass and Orcutt grass (Helm 1998). Though they have extensive range over-lap with several of California's other fairy shrimp species, they rarely share a pool with other Anostracans. This may be due to the Conservancy fairy shrimp's relatively large size for a Californian Anostracan, which allows them to out-compete other species. They do, however, frequently co-habitate pools with Vernal pool tadpole shrimp, which are a common fairy shrimp predator. (Yolo Natural Heritage Program) Additionally, vernal pool invertebrates are an important source of nutrition for migrating ducks (Green et al. 2001).

Predators, including birds and amphibians, aid in dispersal by ingesting and excreting cysts in new locations. Cysts can also be transported in mud that sticks to the feet of pool visitors and by wind.

RANGE

California is home to twenty one large branchiopods. Fourteen of these are Anostraca (fairy shrimp), and eight are endemic to California. Of these eight, three are listed as endangered, one as threatened, and one as a species of special concern (Helm 1998). Overall, California has the highest level of Anostracan endemism in the United States, probably due to ecological factors creating high species diversity, including the high diversity of available habitats (Eng et al. 1990) and low rates of dispersal between available habitats, creating low gene flow between divergent populations.

Today, the Conservancy fairy shrimp is known from several small, isolated populations: Vina Plains, Sacramento National Wildlife Refuge, Yolo Bypass Wildlife Area, Jepson Prairie, Mapes Ranch, University of California, Merced, and Grasslands Ecological Area ins Northern California, and Los Padres

National Forest in Ventura County. Because it was only described twenty years ago in 1990, it is difficult to know precisely how much Conservancy fairy shrimp populations have declined from historical levels. However, it is estimated that as much as ninety percent of California's historical vernal pool habitat may be lost in California (Recovery Plan for Vernal Pool Ecosystems), and it is assumed that Conservancy fairy shrimp have experienced similar declines. This species is particularly known to occupy pools on Basin and Basin Rim landforms, which have been especially heavily impacted by agriculture and urban development (Helm 1998); this means that it is likely that their habitat has been especially heavily reduced compared to other vernal pool types.

On November 19, 1990, Ms. Roxanne Bittman was the first to petition the United States Fish and Wildlife Service to list the species as endangered, along with longhorn fairy shrimp, the vernal pool fairy shrimp, and the California linderiella. On October 9, 2007, Fish and Wildlife published a 5 year review recommending that the Conservancy fairy shrimp remain listed as endangered (Yolo Natural Heritage Program). Critical habitat was designated August 6, 2003 (FR 68:46683) and revised in 2005, and species-specific unit designations were published on February 10, 2006 (FR 71:7117).

THREATS TO CONSERVANCY FAIRY SHRIMP POPULATIONS

As a resident of California's highly threatened vernal pools, the Conservancy fairy shrimp experiences many of the same threats as other vernal pool species, including habitat destruction, fragmentation, pollution from urbanization, agriculture, and mining, invasive plant species that out-compete essential native species, and poor grazing regimes. In general, most vernal pool systems lack the management and monitoring necessary to combat anthropogenic influence and invasion by non-native species.

There are also many threats that are more specific to vernal pool invertebrate populations. It has been demonstrated that non-native mosquitofish, which have been introduced throughout

California to control mosquito populations, reduce fairy shrimp populations through predation, and non-native bullfrogs (*Rana catesbeiana)* may feed on fairy shrimp as well. Non-native Manna grass (*Glyceria declinata)* and Italian rye grass (*Lolium multiflorum)* both produce heavy thatch which oxidizes upon decomposition, altering water chemistry. Anthropogenic activities can loosen soil, filling in pools as well as increasing water turbidity. The reduced light inhibits photosynthesis, which hinders growth of essential native plants and decreases production of the algae that makes up some of the shrimp's diet.

Additionally, reduced visitation to vernal pools by bird species due to habitat reduction, fragmentation, and human disturbance results in reduced cyst distribution. This reduces gene flow for vernal pool invertebrates, and because reduced gene flow leads to a smaller gene pool, individual populations are less adaptable to environmental change.

The delicate nature of vernal pools make them susceptible to climatic variability as well. Specifically, the shallow, low volumes of water in vernal pools can drastically change temperature over the course of a day. While vernal pool invertebrates are adapted to withstand a wide range of temperatures, the extended warmer temperatures predicted in the future due to global climate change pose a risk both to free-swimming adult shrimp and to the cyst banks deposited in the soil every year. (Recovery Plan for Vernal Pool Ecosystems). Furthermore, warmer temperatures drastically accelerate maturation and reproduction and reduces longevity (Helm 1998), meaning vernal pool fairy shrimp are an available food source to migratory birds for a much shorter period.

Vernal pool tadpole shrimp are known to be host to flukes of an undetermined species which reduce gonad size (Recovery Plan for Vernal Pool Ecosystems**)**, and it is likely that Conservancy fairy shrimp are also subject to parasites, as well as fungus and disease, although none have been documented, and there is no evidence that any of these factors pose a serious conservation threat.

POSSIBLE SOURCES OF FUNDING FOR CONSERVATION EFFORTS

- ❖ The Nature Conservancy
- ❖ U.S. Fish and Wildlife Service
- ❖ California Department of Fish and Game
- ❖ Mitigation projects by companies looking to offset environmental footprints
- ❖ Audubon Society (preservation of bird vectors and blanket preservation of bird habitats that include Conservancy shrimp populations)

MANAGEMENT INITIATIVES

Here we detail considerations for management of the Conservancy fairy shrimp.

(1) PROTECTION AND PRESERVATION

1. Protection of all known inhabited pools.

Habitat preservation includes both protection from direct habitat destruction due to agricultural and urban development, and degradation by pollution, invasive species, altered hydrology, and other factors.

Action:

a. Provide legal protection for currently unprotected populations.

Five of the eight populations the Sacramento Office of the U.S. Fish and Wildlife Service

identifies are protected on public lands or by conservation easements (U.S. Fish and Wildlife 2007). The Sacramento Office currently lists eight core areas designated for federally–listed vernal pool species protection that include the Conservancy fairy shrimp. These zones are designed to take into account pool connectivity and increase the potential for dispersal of federally-listed species, and they are ranked by recovery priority. They encompass areas larger than the Conservancy fairy shrimp's known ranges. Additionally, although they are not protected by under conservation easements, two Jepson Prairie locations are currently managed for vernal pool species (U.S. Fish and Wildlife 2007). However, the Mapes Ranch population, as well as parts of the University of California, Merced, Vina Plains, and Jepson Prairie are unprotected.

b. Reduce habitat pollution from anthropogenic sources.

There is very little data on the precise physiological effects of pollution on Conservancy fairy shrimp, but high concentrations of pesticides from agricultural run-off are known to be lethal (Brausch 2009), and it is assumed that high concentrations of run-off pollutants from other anthropogenic sources are likewise harmful. Run-off pollutants directly affect other vernal pool species, which could, for example, reduce availability of the microorganisms, rotifers, algae, and bacteria Conservancy fairy shrimp prey upon. Additionally, pollution may allow non-native grasses to out-compete weakened native grass species; these non-native grass species can use more than their fair share of water, alter pool topography, and change water chemistry. Angeler et al. found that fairy shrimp densities were effected by landscape effects including slope, water catchments, vegetative cover, and cropland presence within a 10 km radius.

Developments, roads, agricultural fields, mining operations, and other sources of run-off pollution should not be allowed within a range that makes pollutants readily able to contaminate pools due to topography and drainage patterns. Furthermore, polluted run-off water should be directed away from pools via run-off ditches and directed to water treatment plants wherever possible.

2. Protection of potential habitat.

Some vernal pools contain seemingly favorable conditions for Conservancy fairy shrimp, but do not contain any individuals of this species. These pools should receive the same treatment as pools populated with Conservancy fairy shrimp for potential natural or human-assisted establishment of new populations.

3. Protection of habitat connectivity and dispersal vectors.

Connection between habitats creates gene flow, keeping each population's genetic variation higher, giving them more resources for adaptation in the event of local environmental change.

Actions:

a. Protection of connective swales.

Swales connected to inhabited pools should receive the same treatment as inhabited pools.

b. Monitoring of bird vectors.

Conservancy fairy shrimp and other vernal pool invertebrates are an important food source for many migratory birds, particularly many waterfowl. In turn, birds act as vectors between viable habitats by ingesting and excreting invertebrate cysts into new locations, or by carrying cysts to new locations in mud stuck to legs or feathers.

Migratory birds should be monitored to ensure they are, in fact, moving between viable habitats. This can be done by tag and re-capture techniques or by tagging with GPS monitors. If birds are not visiting certain populations, actions should be taken to encourage bird visitation, such as control of invasive grass species to open better nesting habitats.

4. Development of a cyst bank.

Desiccated fairy shrimp egg cysts can last years and remain viable. There are few studies on precisely how long fairy shrimp cysts last, but there is definite documentation of cysts lasting eight years under natural conditions and fifteen years under laboratory conditions, and anecdotal evidence suggests potential viability on the order of decades longer (Belk 1996). This presents an ideal opportunity for long-term preservation in the laboratory. A cyst bank provides a stock for re-introduction in the case of population destruction decline. It also provides a source of genetic diversity in the case of loss of genetic variation due to genetic drift in reduced populations, population bottlenecks, and populations no longer suited to their environment because of some environmental change.

Establishment of a cyst bank requires extracting cysts from sediment samples taken from dry pool beds. While fairy shrimp have been raised in the laboratory, we did not find information on ease of culturing, but if captive breeding is possible, it may be worthwhile to preserve cysts from laboratory cultures because age and lack of disease and parasites can be better recorded. Additionally, while genetic analysis of cysts is not possible because the process destroys cysts, analysis of parental DNA is possible. Furthermore, species-level identification of cysts may be difficult, so laboratory culturing allows easier identification of mature adults.

(2) RESEARCH AND MONITORING

Assessing the stability and health of Conservancy fairy shrimp as a species requires consistent monitoring. Ideally, monitoring would occur on a yearly basis because populations die and re-seed themselves every year. Several years of consecutive data on each known population is highly recommended to gain an understanding of yearly population fluctuations. Once these have been established, we recommend monitoring at least every three to five years for each population.

5. Determine the full range.

Several established populations of Conservancy fairy shrimp are know, but some are not as well studied or documented. Additional sampling is needed to determine if this species is present in less well-studied pools. Residence of Conservancy fairy shrimp in Placer County is suggested by only a single individual documented in 2007; surveys of this area should be taken to determine if this individual represents an anomaly or mis-identification or resident population. Additionally, while most Conservancy fairy shrimp are known from California's Central Valley, there is one population documented as far south as Ventura County. Sampling of habitat closer to the Ventura population is necessary to determine precisely how isolated southern shrimp are.

6. Determine population densities at known locations.

While presence of Conservancy shrimp species is recorded at vernal pool study sites, very rarely is any data taken to determine population density. A knowledge of density is essential for analyzing health and stability of a population.

Several methods of sampling Branchiopods have been described in the literature. During the wet season, Helm 1998 implemented dipnetting for mature adults. However, while this method may be adequate for detecting the presence of invertebrate species in a given pool, variable ease of capture due to differences in swimming ability or preferred microhabitat may give inaccurate proportions of the different invertebrate species. The same study also collected soil samples during the dry season and identified present species by looking at cysts under a microscope. This method eliminates sample error due to behavioral differences. For Spanish Branchiopod found in seasonal wetlands, Angeler et. al. likewise collected sediment samples during the dry season but also hatched all cysts present in the laboratory. This method allows for easier identification of individuals. Additionally, it provides data on how many individuals hatch from a given cyst for each of the different species collected, which would be beneficial at least once for calculating population densities for future surveys of cysts in soil samples.

7. Assess community interactions

Before considering introducing Conservancy fairy shrimp to new areas, it is essential to be able to predict how it will interact with the other species already present. For example, this species usually co-occurs with at least one of the following species: the California fairy shrimp *Linderiella occidentalis*, the vernal pool tadpole shrimp *Lepidurus packarki,* and the California clam shrimp *Cyzicus californicus* (Helm 1998), although rarely with other fairy shrimp species (Anostraca) (Yolo Natural Heritage Program 2009). The vernal pool tadpole shrimp is known to prey on Anostraca, including the Conservancy fairy shrimp. Due to their large size for Anostracans, Conservancy fairy shrimp have the potential to out-compete other fairy shrimp species. When selecting new areas for introduction, a thorough survey of current invertebrate habitat is essential to ensure that the addition of Conservancy fairy shrimp would not upset the populations of current inhabitants and that this species would be able to thrive.

Additionally, the Conservancy fairy shrimp is common in pools also favored by the endangered Colusa and Orcutt grasses endemic to California (Helm 1998). Presence of these two grass species is a possible indicator of potential for a successful introduction.

The more information about co-habitation and direct interactions of Conservancy fairy shrimp with other vernal pool species, the better our ability to analyze habitat for possible introductions. Further information on interactions with other invertebrates is likely to be especially helpful due to the potential for close trophic interactions and competition for similar ecological niches. Additional data about the types of vegetation associated with viable habitats will be useful for the same reason.

(3) CONSIDER INTRODUCTIONS OR RE-INTRODUCTIONS

The long-term historical range of Conservancy fairy shrimp is unknown, and there has been no recorded loss of habitat since its initial description in 1990. However, there is no doubt that it was once far more extensive than it is now due to the extreme loss of vernal pool systems from human land use. Land fragmentation and stress from human activity and invasive species may have caused declines or extinction of populations, but with some management, these areas may make suitable habitat once again. Especially if it is determined that preservation efforts are not enough and existing populations are in decline, introductions or re-introductions may be necessary. It should be noted that preservation and health of current populations should be maximized before introduction to a new habitat is attempted.

8. Assess abiotic factors of target habitat

When selecting possible habitat for introduction, abiotic factors must be carefully considered. Conservancy fairy shrimp require large, deep pools with long inundation periods; Helm 1998 documented this species in vernal pools ranging from 3,975 to 356,253 m^2. Helm also asserts that they are usually found in clay-bottom pools in wind-exposed areas with fine soils, making favored habitat very turbid.

9. Assess biota of target habitat

The invertebrate community of the target habitat is the most important biotic factor to consider, and should be carefully documented before introduction of Conservancy fairy shrimp is considered. Because Conservancy fairy shrimp compete for many of the same resources that other vernal pool invertebrates (including several other endangered species) use, introducing them to a pool containing an incompatible invertebrate community can disrupt other species or result in poor or no establishment of a Conservancy fairy shrimp population. Because of their large size, Conservancy fairy shrimp usually out-compete other fairy shrimp species, but they do co-habitate well with Vernal pool tadpole shrimp (Yolo Natural Heritage Program).

Regular presence of waterfowl is a positive indicator of pool health and will assist in further expansion of the new shrimp population, but is not mandatory.

A healthy vegetative community is also essential. Presence of plants associated with the deep, turbid pools Conservancy shrimp prefer is a good indicator that the target habitat will support this species. Minimal presence of invasive plants is also crucial. Invasive plants leaf litter can oxidize water and cause of build up of plant detritus, which might, for example, cause a build-up of soil over egg cysts, burying them too deep to hatch the following year. They can encroach on the pool, changing the topography and amount of open water available to shrimp. Regular management of invasive grass species, through grazing, burning, hand pulling, or herbicide, is essential before introduction of any vernal pool species should be attempted.

10. Choose a source or sources of shrimp for introduction

If there is high genetic variation between populations of any given organism, it is likely that populations are adapted to their specific local conditions. We did not find any records of phenotypic genetic analysis and comparison of Conservancy fairy shrimp at a population level. However, due to the high degree of isolation between Conservancy shrimp habitats, it is likely that there is significant genetic difference between different populations. Successful introduction is more probable if introduced animals come from the populations with the closest possible conditions to the target introduction habitat. In the absence of genetic data, close comparison of target habitat to potential source population habitats is essential.

(4) RECOMMENDATIONS FOR GRASSLANDS PARK

Conservancy fairy shrimp are not currently found in any of the vernal pools in Grasslands Park, and I know of no data to suggest that this species has ever been found on the property. Due to their large size, depth, and the presence of Vernal pool tadpole shrimp, pools 9a, 9b, and R4 may be suitable habitat. The recently created pools may pose potential habitat as well due to their depth. However, I do not recommend introducing Conservancy fairy shrimp to any of the pools at this time. Resources would be better spent on controlling invasive grass species, which negatively effect virtually all vernal pool species . Invertebrate management should focus on species currently found in Grassland Park's pools.

COMPARISON OF CONSERVANCY FAIRY SHRIMP MANAGEMENT GOALS TO THOSE OF OTHER VERNAL POOL SPECIES

Because Conservancy fairy shrimp compete with other fairy shrimp species for the same resources, management of invertebrate species has the potential to conflict with Conservancy fairy shrimp; management to promote other species like the Vernal pool fairy shrimp is not recommended in the same pools that Conservancy fairy shrimp are promoted. Management of Conservancy fairy shrimp is compatible with management of most non-invertebrate animal species. Because predation by native species is not known to pose a threat to fairy shrimp, management to increase large predators like waterfowl and native amphibians does not conflict with this species' interests. Generally, control of non-native vegetation and promotion of native plant species can only help Conservancy fairy shrimp. However, some methods of non-native control may have adverse effects. Herbicides can run off into pools and poison Conservancy fairy shrimp and other invertebrates. I am unaware of any data on the subject, but controlled burning during summer dry seasons may kill egg cysts in the sediment as the cyst bank is mostly found in the first few centimeters of soil.

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Eviner

ENH 160

June 2, 2010

A World within a World

(Branchinecta *lynchi* The Vernal Pool Fairy Shrimp)

Within these inconspicuous puddles of water called vernal pools lies a very amazing ecosystem, and within that ecosystem there is a rare crustacean called a Vernal Pool Fairy Shrimp. These crustaceans are an endemic to California and are a threatened species. *Branchinecta lynchi* and other fairy shrimp are classified in the Branchiopda order. (Unknown, 2008) *B. lynchi* can range in size from 0.4- 1 inch. These fairy shrimp are clearly visible to the naked eye and are so named because of their peculiar swimming habits. They swim on their backs, and the fact that they are transparent makes them look like something whimsical out of a child's imagination. A lot of the time they can be red-orange due to the amount of hemoglobin present in their bodies, but they can be anywhere from translucent white or gray, blue or even green. This characteristic is individual to the pool, but constant to the group of shrimp living there. (Green, 1990)

Branchinecta lynchi has compound eyes, two sets of antennae and twenty-two legs to help them swim and eat. This fairy shrimp lives in conditions that are only found in the vernal pools in California. They are only found in water depth of about a meter, and the water usually has a significant amount of alkalinity compared to that of normal bodies of fresh water. This fairy shrimp occurs in pools with alkalinity ranging from 22 to 274 ppm (parts per million), 48 to 481 ppm TDS, and a pH range from 6.3 to 8.5 (Eriksen and Belk 1999). The U.S. Fish and Wildlife Service (1994) described the water in pools occupied by vernal pool fairy shrimp as having low conductivity and chloride, though specific numbers were not given. Vernal pool fairy shrimp have been found in pools ranging from 0.1 acre to 0.05 acre (Eriksen and Belk 1999). Each pool varies slightly, so for example, if an allopatric speciation situation occurred, meaning if the shrimp were to somehow be transported to another pool, they may or may not survive depending on their ability to acclimate. The contents of the water are important to the fairy shrimp. Their leg movements help them collect algae, bacteria and protozoa that swim in the water which are then scraped off and consumed. The dart like movement of the fairy-shrimp also helps them take oxygen from the water. The Vernal Pool Fairy Shrimp requires cold winter waters to hatch. Fairy shrimp require vernal pools that have swales and rock outcrops, ephemeral pools, playas and alkali flats. They also require pools that have sandstone, grass and mud at the bottom so that they can hide and lay their eggs. The pools are often on basalt which is critical to reach the alkali conditions *B. lynchi* needs to survive and reproduce (Yolo Natural Heritage Program, 3).

In reproduction it is found that in any vernal pool the amount of females usually will be dominant. When the shrimp mate, the male will grasp on to the female and grip hard. The male can stay clasped with the female for up to several days. Actual mating only takes a few minutes, but the semelparious attempt by the male leads to successful fertilization. In the case of *Branchinecta lynchi* the male dies and the female will carry her eggs in her relatively large brooding pouch. (Unknown 2008) They will stay with her for several days until they are dropped to the bottom of the pool or until the female dies. The female can live as long as the pool is inundated. Her lifespan depends on when she successfully mates. This can be anywhere from one week to seven weeks. Females have been observed carrying anywhere from ten to one-hundred-fifty eggs in her pouch. (Green, 1)

The fairy-shrimp eggs or cysts can withstand a lot of environmental pressures. These eggs or cysts can withstand long periods of desiccation, and cool temperatures. The eggs have been tested as high has 99 degrees Celsius and as low as -190 degrees Celsius and have remained viable. They can even pass through animals and use that as a means of dispersal. When the pool dries these eggs manage to get stuck on the bodies of many species of fowl and dropped off or can be consumed and passed through their digestive tract. These birds may pass the eggs on at an entirely new pool. The eggs can dry out and also blow into other pools by the wind. They are reported to have been successfully hatched after being dry for fifteen years and their viability was tested after they had been in outterspace and were also reported to still be viable. (Belk, 1998) One would wonder if they can withstand such harsh conditions why is it that they can't survive in other environments such as marsh lands where there is water year round. The reason is somewhat uncertain, but it is hypothesized that they can not have water year round or the cysts will grow fungus. Temperature plays the largest role in survivability. The fairy shrimp eggs reach a certain temperature during the spring, which cues them to hatch. The dry period is just the part of the season the eggs need to survive until the water returns and reaches that temperature.

Depending on the population of males in the pool, it is possible for the female to lay one of two types of eggs. One type is the thinner-shelled eggs called the "summer" eggs. These are produced when there are fewer males in the pool, though no number is known on how many is too few. These young hatch out much more rapidly to help re-populate the pool. They hatch out, reproduce and die all in the same season that they are laid. The other type of eggs called the "winter" eggs stay at the bottom of the pool and dry out along with everything else and remain dormant until the pools fill up with water again in the winter/spring. The resting period can be between 6-10 months. (Green, Erikson and Belk 1990)

The largest threat to this aquatic animal is habitat loss. The Central valley has lost nearly 75% of the vernal pools which is a critical habitat that supports it. These pools are flat which make the area suitable for housing development and agriculture. Other threats include off-road vehicles, and inappropriate livestock grazing. Cattle can cause disturbance that is good for the pool, but if they heavily graze the area they can cause trenching which muddies up the pool and damages the topography within it. (Witham, 2010, Green 1990 and U.S. Fish and Wildlife, 1998) Wetland draining and invasion of non-native plants such as Perennial Pepper Weed, Fillary Storksbill, Italian Rye Grass and others also threatens habitat. If the pools are not managed, the non-native grasses can encroach on the pools and create thatch which will quickly decrease the quantity of water. This decreases the time needed for the shrimp to complete its life-cycle. When the water level starts to go down, temperature rises because there is less water that needs to be heated up by the sun. This causes faster evaporation. The volume of water in the pool is also very important to maintain the correct dissolved oxygen level. Another issue is water run-off that has pollutants such as bleach, antifreeze, oil and fertilizers. (Witham, 2010,Green, 1990 and The U.S. Fish and Wildlife, 1998)

B. lynchi can act as an indicator species. As previously mentioned they can vary in color depending on their food source and how much of it actually exists in a specific pool. This can help us determine whether enough food is sustaining the population. The amount and development of the thinned-shelled eggs reflects how much time will be left before the pool dries up. The reason for a lot of eggs could mean two things one: that there may only be a week or so before the pool dries. Or two the population of males is too few. The amount or type of predator can affect the mortality of the shrimp. There are a lot of non-native amphibians that consume the shrimp faster then they can reproduce. If there is disturbance in the pool the shrimp try to reproduce faster instead of going through the seasonal life-cycle and they try to hatch their eggs in the same season. The behaviors observed can indicate red-flags that there is something wrong in the pool. *Branchinecta lynchi* is also the food source of many species at the vernal pools including the endangered vernal pool tadpole shrimp. (Green, 1990)

There have been efforts to re-create vernal pools, but without much success. Millions of dollars are spent on creating new environments when we should spend money on conserving what we already have. Conservation efforts are being made. The conservation is focusing on rare and endangered plants and invertebrates. In 1994 the Vernal Pool Fairy Shrimp was federally listed. *Branchinecta lynchi* is also protected under the clean water act. The Fish and Wildlife service preserved habitat for the shrimp in 2008. And in the case of the University of California Merced, the Nature Conservancy was able to set aside land or at least shift the University away from the hot spots. (Unknown, Witham) The whole mind set of conservation has to be changed with regards to the Fairy Shrimp. Instead of conserving individual species it won't matter unless we protect the land. The land is threatened, the land is endangered. It is all connected.

Management Plan for *B. lynchi*

The main goal to protect B. lynchi is to conserve any remaining vernal pools it currently resides in. There has not been much done in conserving or restoring environments for the species. The only thing for a fact is that the species is federally listed. As far as I know and what I have read, management is still in its experimental stages.

1) **Land management** – Based on the articles I have read, grazing seems to be a good management technique and I suggest that a contract be created to have the site grazed or the site could be privately owned. In either case, the land manager would be someone who is familiar with this landscape. They could work with the Bureau of Land Management and the Fish and Wildlife Service on possible monitoring and restoration. Currently, the pools need to be grazed extensively to remove the significant amount of non native plants. Vernal pool researcher Carol Witham suggested that cow-calf pairs graze the site at the start of November through early spring. I suggest a very low amount of livestock to start

with to see how much disturbance they will create. It is unclear whether Carol Witham has done studies on this specifically, but due to her experience researching vernal pools, it could be a good place to start.

2) The Right Stock – It is important that we have the right amount of animals and the right kind of animals. Some of the pools we were working with, in my and Carol's opinion, were inappropriately grazed. The previous year, they had 1,200 sheep grazing in and around the pools. For B. lynchi in particular, that is too much disturbance and the hoof prints of the sheep are an inappropriate size for microhabitat. That is why we suggest cattle because with fewer animals, we can still create disturbance but make better-sized microhabitats. I believe sheep and goats to be inappropriate to be used for management of vernal pools because they compact too densely. They have also been known to eat the native plants.

3) Laws and Lists – B. lynchi should be listed as endangered on as many lists as possible (both federal and state-level). Legislation needs to be created that restricts collection and access to the pools by everyone but the land manager. There already exists legislation that prevents the collection of B. lynchi but there needs to be legislation that protects the habitat from any development. For the already nearby roads which are a source of polluting runoff, we could direct the runoff away by building drainage that directs pollution away from the site. Anyone who pollutes or litters should be punished by law. This may include a fine or jail time.

4) Restoration – As previously mentioned, restoration for this site is still experimental. The literature I have read has mentioned conservation but not restoration. In California, the pools currently containing B. lynchi are stable but for our site, there is no B. lynchi and the pools are severely overrun by non-native plants. I suggest that we try different restoration techniques to make the habitat more suitable for B. lynchi. First, we have to see what species B. lynchi can coexist with and what species can complement the shrimp. Unfortunately, not every species can coexist with B. lynchi. B. lynchi doesn't do well with the conservancy fairy shrimp and are often outcompeted. It has also been mentioned that conservancy fairy shrimp do well with vernal pool tadpole shrimp and as far as I know, at our site, there are already vernal pool tadpole shrimp (Steinberg, 2010). Some methods that I would suggest to eradicate the non-native plants would be to graze with cow-calf pairs and rotate them to the different pools. For example, 20 cow-calf pairs could be placed in pools 9A and 9B in November through early spring the first year and then the following year those pools would have a rest period from grazing. I wouldn't go without grazing any longer than every other year since the invasives can repopulate so readily. I believe that a little disturbance every other year will be beneficial to B. lynchi. Not all invasives can be grazed out. Other methods we could implement are fire and herbicides. I would implement fire for a two year stretch and see how the land fares. The risks with that are the fire could kill off the vegetation we desire to keep such as Colusa grass the fairy shrimp uses for shelter. Since these methods haven't really been used, we would have to experiment as gently as possible. We could use herbicides to prevent our desired vegetation from being killed by individually swabbing the invasive plants. As previously mentioned, the goal is to prevent the encroachment of the non-native species on the pools which further increases the rate of evaporation. We could possibly alternate between herbicides and prescribed burnings. If we use herbicides, we cannot use livestock, for it may be harmful to the animals.

5) Introduction of B. lynchi – As far as I know, the pools are currently not suitable to support B. lynchi. Pools 9A and 9B seemed to be the closest in requirements for the existence of the shrimp. Unfortunately, due to the current population of tadpole shrimp, it may be wise to either not introduce B. lynchi at all or find another pool without the tadpole shrimp to introduce B. lynchi. If we should commence with introduction, the population should be monitored yearly to see whether summer eggs or winter eggs are being laid. If the introduction is successful, I wouldn't add any more crustaceans to the pool. To prevent the risk of a bottleneck effect, I suggest that the shrimp that we introduce should be from different locations.

6) Funding – I don't know where the money is going to come from. Perhaps we could start with volunteer work to get the pools healthy. Should no one want to volunteer, the California Department of Fish and Game can fund monitoring and restoration of the vernal pools. The California Department of Fish and Game currently has an Invasive Species Program and since slowing the spread of invasive species is an important part of my management plan, maybe they can incorporate this specific site.

Synthesis with Class

A lot of my classmates had similar requirements for their species such as the need for moderate disturbance and the removal or eradication of invasives. For example classmates who had other fairy shrimp or the vernal pool snail needed Perennial Pepper Weed and Italian Rye eradicated to prevent thatch build up in the pools. If those were removed all of those species including mine would benefit. I could talk to Clare Steinberg about my species because she had the Conservancy Fairy Shrimp. Our requirements were almost identical. I unfortunately can't adjust any of my goals any further to accommodate others. The requirements are so specific there isn't much room to change. This was a very difficult and emotional project; I hope we made a difference.

Vernal Pool Fairy Shrimp notes

- What is a vernal pool fairy shrimp
  - *Branchinecta lynchi*
  - *B. lynchi* is in the order Branchiopoda (primitive crustacean group)
- Why called fairy shrimp
  - A typical swimming habit is swimming upside down
  - Gently flutter their legs
  - Color

        - Depends on food source within the pool, can be red, green, blue, gray, translucent white
        - Commonly red-orange due to hemoglobin content
        - All fairy shrimp in the same pool are generally the same color
- Diet
    - Consumes algae by filtering water with their legs, by scraping into their mouths
    - Have been known to scavenge on dead fish or other animals
- Characteristics of the shrimp
    - Two compound eyes, eleven pairs of legs, can range between 1/4 of an inch to 3/4 of an inch long, visible to the naked eye
    - Females have tapered pear-shaped brooding pouch
    - Have dart-like movements to obtain oxygen
- Mating
    - Semelparous breeding--male attaches to female for up to several days, copulation only takes a few minutes, male dies when successful breeding takes place, female carries her 10-150 eggs for several days until she drops them at the bottom of the pool, she then also dies
- Cysts (Eggs)
    - Have a high survival rate, can withstand desiccation, can be viable after 15 years, can withstand temperatures as high as 99 degrees Celsius and as low as -190 degrees Celsius
    - High rate of survival helps them be dispersed by animals that can get stuck on, can be passed through in feces
    - Two types of eggs
        - summer eggs--which are thin shelled and hatch the same season as they are laid, laid when there is a shortage of males, hatch sooner to help repopulate males in the pool
        - winter eggs--can last several seasons or whenever water returns
- Life cycle
    - Only lasts a few weeks
    - Not all mating pairs mate simultaneously, mate in the window of time where there is water in the pool
- Habitat
    - Require flat grassland vernal pools, unplowed hard clay pan, soil is young, rich in basalt and sandstone, high alkalinity, pH may vary, requires swales, no more than a meter depth of water, water lasts between 60-65 days
- Ephemeral Life
    - Not known to live anywhere else, as far as I know, no research has been done to see if they can live anywhere else

    - We shouldn’t take a chance on their remaining habitat
- What about our pools
    - *B. lynchi* is confined to the vernal pools of the Central Valley, from Shasta to Tulare, Solano, San Benito, Soda Lake, Santa Barbara, Santa Rosa, and Riverside
    - 75% of the Central Valley’s pools are gone, due to urban sprawl, agriculture, heavy grazing, water runoff, pollution, non-native grasses can create thatch, which sucks up all the water and alters the life-cycle of the shrimp and changes the pH
- What has been done
    - 1994 - *B. lynchi* finally federally listed
    - 2008 - Protected under the Clean Water Act
    - In the case of UC Merced, land was set aside by the Nature Conservancy
- What we need to do
    - Preserve what we have, manage with appropriate grazing, strive to conserve plant communities with species within them (not just individuals),all connected

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ENH 160 Project Part 1

Kathyrn Stein

Vernal Pools Snail

Fossaria sonomaensis

A. Background and Justification

- It is extremely important to conserve and protect the Vernal Pools Snail in the Sacramento valley area. The Vernal Pools Snail is an important part of the trophic cascade of the vernal pools and is an indicator of overall pool health, function and quality of habitat. For example, snails require a certain pH and level of dissolved oxygen, so the presence of snails can indicate proper water chemistry. The snail interacts with many other organisms such as predators, aquatic plants, algae and parasites found in the pool and contributes to the complex ecology of the vernal pools. Snails influence the amount of algae in the pool. Also if snails are sparse in pools they can affect the trophic cascades of the pool by reducing the amount of food for their predators such as amphibians and waterfowl, and those species might have a reduced presence in the pool as a result.
- If the Vernal Pool Snail is conserved and protected, it will continue to be a valuable player in vernal pool ecology. These snails are important indicators of pool health. Presence of snail in Central Valley vernal pools indicates that the pools are inundated the proper number of days out of the year (at least 80) in order to support many other species with similar inundation and water chemistry needs. Snail size is also an

important indicator of habitat (influenced by amount and extent of microtopography in pool) and food quality (abundance of algae, plants and detritus) in pools, as well as proper pool pH and alkalinity, as the snail's shell is composed of Calcium Carbonate, and would be dissolved by improper hydrological conditions (ie: extreme acidiy or alkalinity, high and low temperature extremes). Snail abundance, fecundity and lifespan indicate that pool conditions are ideal for other creatures in the pool because nutrient availability and temperature influence abundance, fecundity and lifespan. Furthermore, the Vernal Pool Snail manages the amount of detritus and algae present in the pool and plays an imperative role in reducing algae blooms and keeping the pools clean. Presence of snails also attracts migratory birds and waterfowl to the pools, providing an important source of protein for these birds.

- Currently Vernal Pool Snails are considered special status invertebrates and are in danger of declining in pools that are influenced by runoff from agriculture and roads, which could alter pH to dangerous levels, trampling by humans and livestock, which could kill snails during aestivation, and draining of pools by invasive exotic plants, which could reduce the inundation period required for their lifecycle. They are in danger also simply because vast amounts of vernal pool land has been destroyed for the purposes of agriculture and development. Additionally, not much is known about these creatures and how the threat of global warming may negatively affect their life histories and survival. Likely it will have a negative affect, as climate change has the potential to change the length of inundation of vernal pools, as well as the temperature in vernal pools. These snails require at least 80 days of inundation to survive and they are very sensitive to even slight changes in temperature, though I could not find a specific temperature that they require in my research. Vernal Pool Snails are permanent residents of vernal pools and their life cycle depends on a wet season in which feeding, growing and reproduction occurs followed by a dry period, during which they burrow in the sediments and remain dormant. Global warming could also affect the depth of pools, and though an exact depth required by vernal pools snails was not found in my research, one study (Ghallager, 1993) concluded that when snails were moved to pools of various depths, they adapted to the new pool. Thus, snails must be able to tolerate a range of depths, so changes in depths of pools caused by global warming would most likely not be detrimental. Threats posed to the Vernal Pools Snail by parasitism by Flukes (Flatworms) in vernal pools could also be amplified in the future if Fluke populations are not controlled.

- Naturally occurring vernal pools are disappearing rapidly due to development and conversion of land to agriculture. The Vernal Pools Snail only occurs in vernal pools, so once vernal pools are gone, so is the Vernal Pools Snail. Thus, the Vernal Pools Snail faces the potential loss of its habitat and potential extinction. Pools created artificially due to mitigation often are not topographically and hydrologically constructed in such a way that supports the needs of the Vernal Pools Snail. The pools are often too deep, so that the water does not evaporate fully, the pH is not neutral, and/or the surface of the pool floor is unsuitable, that is, lacking in microtopography required for snail feeding, reproducing and nesting habitat.
- Since these snails are considered special status invertebrates, it could be somewhat easy to obtain the funding and support for a protection plan to be developed for them. It may be difficult to find public support for investing in its protection since they are not very well known or glamorous. Public support could be sought from duck clubs, hunters

and bird watchers, since the Vernal Pools Snail is a major food source for waterfowl and birds in the Central Valley.

B. Literature Review

- Vernal Pools Snails are permanent, year round residents of vernal pools. Once the pools dry up, they bury themselves in the mud and become dormant. They over winter there, staying alive but with highly reduced metabolic rates. Once flooding begins again during the wet season, the snails emerge to complete their life cycle. They feed, grow, and reproduce. Depending on water temperature, food and nutrient availability, and microhabitat presence, mature snails may die at the end of the season or they may repeat the aestivation process and emerge again the following season and can live up to three years. Snails are hermaphroditic, so they mate with other snails but also tend to self-fertilize. Some eggs can develop without fertilization. Snails lay their eggs in a gelatinous mass on the surface of the pool floor in little crevices caused by pool microtopography or on plants throughout the wet season, sometimes multiple times during one season.
- Dispersal between pools is somewhat limited for these snails. They cannot disperse on their own. They depend on other organisms to shuttle them between pools. Their main mode of transportation is on the feathers, feet or in the digestive tracts of waterfowl such as ducks. Snails' predators in vernal pools are ducks, other birds, aquatic insects, and salamander larvae. They are also parasitized by Flukes (Flatworms) and Scymozid fly larvae. Parasitism by Flukes is especially harmful to snail populations and can decrease individual growth, reproduction rate, change behavior and reduce size.

- Snails in vernal pools are grazers. They have a tooth-like structure with which they scrape algae and films of bacteria and fungi from surfaces. They also eat plants, detritus and decomposing animals. They sometimes hang upside down on the surface of the water and eat whatever they come across, including pollen and mosquito larvae.
- Snails have soft bodies that are protected by a shell, which is composed of mainly calcium carbonate. They have a muscular foot for transportation. Snails breath air even under water. Their blood contains oxygen-holding proteins that allow them to do this. Due to the delicate nature of their calcium carbonate shell, snails cannot live in water that is acidic, which can dissolve their shell. Thus, snails are good indicators of some aspects of water quality in vernal pools.
- In order to survive in vernal pools, snails need a highly seasonal flooding and dry period cycle to complete their life history strategy. If a pool is too deep or too shallow, it could be flooded for too long of a period or too short of a period. As long as a pool stays inundated for at least 80 days, the depth of the pool is not extremely important for the vernal pools snail. They can tolerate flexible depths. Snails also need an abundance of surfaces such as pebbles, plants and a clear pool floor on which to feed off of collected algae, bacteria and fungus and on which to lay their eggs. Pool water must also be well buffered, as in pools over limestone or other calcareous bedrock.
- The Vernal Pools Snail would most likely respond negatively to inputs to the pool from highway runoff and agricultural runoff as it could change the pH of the water and add other harmful chemicals such as nitrogen, which could cause algae blooms that the snails cannot keep up with, clouding the water and preventing sunlight

penetration. The snail would also likely respond negatively to mixed land use during the dry period such as grazing and other trampling while it is dormant beneath the ground because inactive snails could be crushed and killed. Introduction of invasive species such as bullfrogs, due to mixed use of the pools could also be potentially damaging to the snail, by consuming snails and their eggs and competing for their resources. Invasive plants species such as Perennial pepperweed and Mediterranean barley, surprisingly enough, could be the most damaging because they tend to uptake large amounts of water from the pools, which can reduce the inundation period of the pools.

- Very little focus has been put on the Vernal Pools Snail in previous vernal pool restoration efforts. Therefore, the Vernal Pool Snails' interactions with other organisms, restoration needs and recovery success have not been studied or documented. Furthermore, not much is known about its microhabitat or use of niches in its habitat, so habitat restoration will be difficult for this snail. Specific water temperature needs are unknown, as is specific depth preferred, though it has been observed that depth is flexible. Exact data for pH and dissolved Oxygen ions are not know, though it is known that these snails require a neutral pH and a high level of dissolved oxygen. Measurements of water chemistry should be measured in pools that support successful populations of vernal pools snail and this data should be considered in a restoration plan. The best strategy will be to study accounts of its behavior, life histories, feeding, etc and make educated guesses as to the best restoration plan for the snail.

Part 2: Management

Goals:

- Determine which pools contain successful populations of the vernal pools snail and which ones will require improvement to their conditions as well as inoculation. Determine which pools will not sustain snail populations.
- Permanently remove invasive species in and around pools that negatively affect nail populations within 5 years.
- Increase overall biodiversity of each snail population between pools and within pools by 30% within 20 years
- Increase population by 40% over the next 30 years

Restoration Plan:

- Population/ biodiversity: Each pool on Grasslands Park will be sampled to determine snail abundance. The pools with the most successful snail populations will be further sampled to determine pH, dissolved oxygen levels, temperature and length of inundation. During the dry season the pools will be observed and microtopogrphy of the pool floor and depth will be recorded. Pools in other areas of California that have successful snail populations will also be sampled for the same things. This data will be used to determine ideal conditions for our snail. Pools with ideal conditions will be inoculated with snails. For the inoculation, snails will be collected from pools with proper conditions from many pools throughout the area around Sacramento and Yolo county to ensure maximum biodiversity. As shown in Ghallager's study, snails can move from different pools of different depths and easily adapt to the new pool depth, so it should be possible to collect from many different pools. 50 specimens will be collected from 20 different pools in the Yolo and Sacramento county areas. Snails will only be collected from pools with enough abundance of snails.

- Invasive species: Invasive species will be as close to eradicated as possible within 5 years. To eradicate invasive plants perennial pepperweed and Mediterranean barley, cow calf grazing between the months of February though April could be very effective, as long as the animals are not allowed into the pools because that could negatively impact snails due to compaction, disturbance and crushing. Controlled burning would probably have the least negative impact on snail populations. Vegetation should be burned once a year for 5 years during the months of Feb through April. It will most likely take 3 to 5 years to eradicate the seed banks of most invasive plant species. After 5 years, controlled burns can be done as needed. Little is known about how to remove invasive amphibians such as bullfrogs. One possible way would be to introduce a native predator who would eat the bullfrog. The only possible problem with that is that the predator could begin to feed on the snail or just throw off the overall trophic relationships within the pool.

- Long-term management: After inoculation of snails to pools, pool conditions will be monitored for stability and quality every year by a team of biologists. If conditions have changed, they will determine the source and do what they can to fix it. Snail population abundance and average individual size will be sampled every three years, since most snails live a maximum of three years. The goal is for populations to increase. If they are decreasing there may be a problem with pool conditions. This problem must be assessed and corrected. Invasive species will also be monitored to make sure they are decreasing. For plants, grazing or burning must be implemented if their numbers reach a threatening level. During monitoring, biologists should make sure that the snail is on track for a 30% population increase in 20 years. After 20 years, if the populations have grown significantly, monitoring will be decreased to every 6 years.
- Construction of new pools: The abundance of the snail in the existing created pool should be sampled. If it is low, like I imagine it is, due to the

lack of microtopography, we should figure out why and use this data to construct at least one new created pool. This new created pool should be shallower, larger and less “bowl” shaped. It should incorporate microtopography features, proper pH, dissolved oxygen and water temperature. It should also be constructed on the same soils that other successful snail pools are currently on. These pools should be monitored once a year for 10 years. Biologists will monitor pools chemistry and snail population. After 10 years, if pool is successful, monitoring can be reduced to once every 5 years.

- Research: In order to successfully restore vernal pools with these snails in mind, much more research must be done about the snail and its ideal habitat and conditions, ie: exact water temperature, exact pH, how deep it burrows underground, required water depth, etc. This restoration project should be treated as a research experiment about these unknowns because this is the first restoration plan with the vernal pools snail as its focal species. Clear and detailed data must be kept and conclusions must be drawn. This information should be made available to the public and to other restoration groups.

Part 3

- The vernal pools snail is most likely to be successful in pools 9a and 9b at Grasslands park because these pools are inundated at least 100 days out of the year and the snails require pools with at least 80 days of inundation. All of the other pools have inundation periods that do not meet the snails' needs consistently every year. The conservancy fairy shrimp and the vernal pools fairy shrimp also have the most potential for success within pool 9a and 9b and though the two cannot coexist in pools together, both can coexist with the vernal pools snail because the vernal pools snail is a bottom and surface feeder and the fairy shrimps feed in mid depths in the pools. One of the pools should be inoculated with both the vernal pools snail and the conservancy fairy shrimp and one of the pools should be inoculated with the snail and the vernal pools shrimp. Fortunately, restoration of any of the other special status plants or invertebrates in the park will not interfere with restoration of the snail. Removal of all of the invasive plants and invertebrates found in the park will be to the benefit of the snail. It is particularly important to focus invasive plant removal on the large pools 9a and 9b since the special status invertebrates are found there and they need the length of inundation to remain.

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Vernal Pool Snail Fact Sheet

Fossaria Sonomaensis

About Fossaria:

- Year round residents in Vernal Pools
- Range from 0.005 g to 0.2 g after aestivation
- Minimum size at reproduction is 0.035 g
- Live up to 3 years (3 reproductive seasons)
- Variation in snail population within pool is a result of the pool's characteristics
- Shell composed of Calcium Carbonate, which can be dissolved or damaged at a high pH
- Feed on algae, fungus, detritus, aquatic plants and pollen
- Keep pool clean

Why Restore?

- Keeps pool clean, controls algae
- Important part of food chain
- Snails presence indicates pool health, length of inundation, temperature, pH, etc

They are the only snail in vernal pools, add to diversity

Snail Needs:

- Pools flooded at least 80 days
- Flooded between November and May
- Length of inundation affects snail ability to survive the summer

Drying early, young do not grow large enough

- Clay soils with hardpan and a clay, silt and cobble surface

Ideal pool hydrology:

- Conductivity: 55 to 110 micro ohms/cm
- Dissolved oxygen: 4 to 10 ppm (snails breath through their skin under water
- pH: 7.5 to 8.5
- Dissolved Ca+: 11 to 16 ppm
- Moderate temperatures (?)

Change in optimum temperature of 5 degrees can be damaging

Possible Constraints to Restoration:

- Difficult to keep water at proper temperature
- With climate change, length of flooding may decrease, water temperature may change
- Difficult to determine the proper pool depth

Other animals

Nick Stromberg

ENH 160: Eviner

June 3, 2010

Oligolectic andrenid bees in Yolo County's Grasslands Park vernal pool complex

Part I

Andrenidae is the family of solitary, burrowing bees found throughout the world. California's entomophilous (insect-pollinated) vernal pool flowers, such as *Blennosperma*, *Downingia*, *Lasthenia*, and *Limnanthes*, are pollinated by oligolectic andrenids; oligolecty is the exclusive reliance of bees on pollen from one or a few closely related flower species (Thorp 1990). Although most of these flowers are also visited by generalist pollinators, andrenids are the most abundant, diverse, and important pollinators of the abovementioned vernal pool flowers (Thorp 1998). Of the four abovementioned genera of flowers, *Lasthenia* and *Limnanthes* have the greatest diversity of pollinators, with *Lasthenia* having the greatest number of oligolectic andrenids and *Limnanthes* having the greatest number of generalist pollinators. *Blennosperma* specimen in vernal pools have meager numbers of oligolectic pollinators and no generalist pollinators because they bloom in February or March during the rainy season when there are few active pollinators. Although *Downingia* blooms the latest of the 4 genera, it has relatively few oligolectic or generalist pollinators because of its highly specialized flower morphology (Thorp 1998). The oligolege of *Blennosperma* is *Andrena (Diandrena) blennospermatis*; the oligolege of *Downingia* is *Panurginus atriceps*; the oligoleges of *Limnanthes* is *A. (Hesperandrena) limnanthis* and *Panurginus occidentalis*; and the oligoleges of *Lasthenia* include two species of *A. (Diandrena)*, namely *A. (D.) submoesta*, three species of *A. (Hesperandrena)*, and several undescribed species. All of the abovementioned flowers have a wide distribution throughout the northern portion of California's Central Valley; the oligoleges, however, are limited to the central range of their pollen-host's distribution (Thorp 1998).

All vernal pool andrenids build burrowing nests in dry upland habitats in the vicinity of their pollen-host(s). Most andrenids nest upland up to 100m from their pollen hosts, but some andrenids nest at the margins of pools in the middle of their host plant populations; there is an undescribed oligolege of *Downingia spp.* in the genus *Panurginus* that nests in soil fissures at the bottom of evaporated pools (Thorp 2007). Andrenids have evolved close ecological relationships with their pollen hosts, as evidenced by their highly synchronous annual life cycles. The majority of the andrenid life cycle is spent in upland underground nests, as they are only active for 4 to 6 weeks in spring when their pollen-hosts are in bloom. Andrenid nests are 10 to 30 cm deep and are excavated by females after they mate shortly after emergence from the previous year's overwintering nest. From bird's-eye view the nest resembles the spokes of a wheel, with the excavated vertical shaft branching off into individual lateral brood cell chambers for each individual offspring. Andrenids are considered solitary because they nest in an isolated fashion rather than gregariously. Andrenids are k-selected organisms that produce only one generation of offspring per year, with each female giving rise to 30 or less progeny; as such, andrenids invest heavily in provisioning for each offspring. Each lateral brood cell is lined with a waterproof secretion and provisioned with a pollen ball made from a particular host-flower's pollen and nectar; a single egg is then laid atop the completed pollen ball and the lateral tunnel is plugged with soil excavated from the next lateral brood cell. The larva hatches from its egg in spring and feeds on the pollen ball; after consuming the pollen ball the larva defecates and then remains quiescent throughout summer. In genus *Andrena* the post-defecating larva pupates in fall, spends winter in a natal cell as a diapausing adult, and emerges in early spring synchronously with its specific flowering vernal pool pollen-host; species the genus *Panurginus* typically overwinter as post-defecating larvae and pupate shortly before emergence in late spring (Thorp 2007). Andrenids are only active when their pollen-hosts are in bloom, which has led experts to believe that these vernal pool flowers have the same or similar cues for emergence as their oligolectic pollinators. In the spring of 1978 at a vernal pool complex in Dozier (near Davis), *Andrena (Hesperandrena) limnanthis*, oligolege of *Limnanthes douglasii* var. *rosea*, was observed emerging synchronously with their pollen-hosts following sufficient precipitation that ended a two year drought. In the two previous years of drought, very few *A. (H.) limnanthis* were observed and none of their obligate pollen-hosts were observed. During the same period of drought at the same pools, *Andrena (Diandrena)* and *A. (Hesperandrena)* oligoleges of *Lasthenia* and their *Lasthenia* host flowers were present each year, suggesting that different pairs of vernal pool flowers and their oligoleges have different cues for emergence (Thorp 1990).

As vernal pool habitat has been lost or degraded via urbanization or conversion to agricultural land, there has been a decrease in the diversity and abundance of endemic vernal pool flowers and thus a decrease in andrenid pollinators that rely exclusively on these dwindling populations of flowers. According to King (1998) 50-85% of California's pre-settlement Central Valley vernal pools have been lost; at best vernal pool vegetation is subject to the same rate of degradation or destruction because not only does the vegetation need pool habitat to exist, but altered pools may not be able to support endemic flowers. Diminishing numbers of andrenids further contribute to the loss of vernal pool flower populations, creating a positive feedback loop that could lead to the extirpation or extinction of endemic vernal pool flowers and their oligoleges.

The nature of vernal pool andrenid behavior has strongly influenced the distribution of their pollen-hosts and the composition of their associated communities. Foraging andrenids usually return to the same flower patches during successive foraging trips and tend to forage over restricted areas, typically visiting a close neighbor of the previously visited flower, resulting in restricted gene flow of outcrossing flowers via restricted pollen dispersal. A prime example of andrenid mediated gene-flow of outcrossing vernal pool flowers is the leptokurtic nature of *Limnanthes* pollen dispersal by *A. (Hesperandrena) limnanthis*. Leptokurtic gene flow means that most flowers are pollinated by other flowers in close proximity and few flowers are pollinated by flowers further away (Thorp 1990).

Beyond being the principle pollinators of endemic vernal pool flowers, andrenids also serve as an indicator species for the floral composition of vernal pools and link pool complexes with upland habitat. Both oligolectic andrenids and their pollen-hosts are reliant on the presence of the other to reproduce; the presence or absence of andrenids dictates what flowers are currently present at the pool and what flowers may be reintroduced (Thorp 1995). It is unclear as to how much upland habitat is sufficient for andrenid nesting sites, but it is generally thought that larger the upland habitat the more beneficial for nest construction (Black et al. 2009). Although andrenids can excavate a variety of soils, ranging from sandy to loess to clayey, they prefer bare or sparsely vegetated sandy or loose substrates (Lyon n.d. & Weiss 2002). Most of the upland habitats surrounding California's Central Valley vernal pools are dominated by exotic annual grasses. Based on pertinent literature regarding andrenids and a conversation with Carol Witham, I am confident that the extensive invasive grass ground cover inhibits the ability of andrenids to build nests (Thorp 2007). Grazing upland areas will improve nesting habitat by removing vegetative cover and providing more bare land. Conversely, overgrazing, especially in winter, may compact soil and make nest excavation more difficult. Burning upland grasslands to eradicate exotic annual grasses is a viable alternative or addition to grazing because low intensity ground fires will eradicate vegetation without negatively effecting overwintering andrenids; low intensity burns are not likely to significantly raise the temperature of soil at a depth of 10 to 30 cm and thus will not negatively affect diapausing andrenids. Over the course of a three year study at four sites, including the Jepson Prairie vernal pool complex, Marty (2007) affirmed that prescribed burns in combination with grazing usually only successfully eradicate invasives for one year; at Jepson Prairie, however, prescribed burns aided in exotic annual suppression for up to three years. Marty (2007) revealed that while exotic annual grasses decreased on average by 35% one year after burning, exotic annual forb cover nearly doubled at every site the year following the burn. According the Marty, on average, burning had no significant effect on total exotic species cover, except at Jepson Prairie. Moreover, burning had a dramatic, positive effect on native species cover and richness at Jepson for up to three years following the prescribed burn. Marty's Jepson Prairie findings suggest that well-timed fires in combination with low-intensity grazing can significantly reduce exotic annual cover and thatch, while increasing the cover and diversity of native annuals at vernal pools. Unfortunately, adding prescribed burns to management plans is an administrative nightmare due to air quality and fire liability issues related to site's relatively close proximity to uran areas (Marty 2007).

When constructing new vernal pools in existing pool complexes restoration managers must ensure that the artificial pool is not replacing key upland habitat. It is equally important to make certain that such an artificial pool is in close enough proximity to existing natural pools and adjacent upland habitat to allow for the natural introduction of desirable flora and associated fauna (Thorp 1995). *Additionally, it is possible to transplant andrenids into restored or created vernal pools in order to aid in the propagation of their pollen-hosts. In a transplantation experiment executed at Jepson Prairie Preserve Thorp (1998) collected 21 foraging andrenids* *and placed them in cold storage; after 1 week 66.7% of the bees were alive; after 2 weeks 43% survived. Thorp found the maximum length of survival in cold storage was 26 days. Thorp also performed a mark-release transplantation experiment at Jepson Prairie, in which collected bees were marked with acrylic paint spots and released the following day at a location with a vigorous bloom of Lasthenia close to the original collection site. Unfortunately Thorp's (1998) mark-recapture studies had limited success, as very few of the marked bees were observed foraging at the release site or the collection site. I believe that the limited success of the mark-release study is partially due to the fact that the foraging bees had already excavated nests and therefore would have to construct a new nest at the release site before foraging. Subsequent studies should focus on methods to collect freshly emerged female and male andrenids prior to mating or the methods to excavate nests containing post-defecating larvae in summer or diapausing adults in fall or winter. T*ransplanting progeny in soil nests proved successful for the solitary, but highly gregarious alkali bee, *Nomia melanderi* (Thorp 1998). *Although transplanting freshly emerged adults or excavated brood cells would likely yield a higher rate of colonization success these two collection processes are much more difficult than collecting foraging female andrenids (Thorp 1998).*

There are many more deficits in knowledge regarding andrenids beyond how to collect and transplant them. Andrena (Diandrena) is the only subgenus of California's vernal pool oligoleges with comprehensive systematics. In fact there are several species of A. (Hesperandrena) and Panurginus that are yet to be described and named. Additional gaps in knowledge include information regarding dispersal, nesting habitat requirements, and distributions relative to host plants (Thorp 1998). Though there is an immense lack of *information regarding vernal pool oligoleges, there are potential funding opportunities for further research on andrenids and the conservation of their vernal pool habitat.*

Firstly, andrenids pollinate several federal and state-listed endangered species of flowers, such as *Lasthenia conjugens*, *L. burkei*, *Limnanthes floccosa* ssp. *californica, L. vinculans, and Blennosperma bakeri*. The US Fish and Wildlife Service administers the Federal Endangered Species Act while the CA Department of Fish and Game administers the California Endangered Species Act. The presence of a listed species at a vernal pool complex necessitates additional funding and special management practices both to provide suitable habitat and to avoid incidental or intentional taking of the organism. Although the Pollinator Protection Act, which was introduced to congress in 2007, has not yet become a law and emphasizes research on colony collapse disorder in honey bees, if passed this bill will provide several million dollars in research funding for biology of native pollinators (GovTrack.us 2007). The Pollinator Partnership, a non-profit organization, established the North American Pollinator Protection Campaign in 1999, which provides funding for biological and ecological pollinator research (The Coevolution Institute 2005).

Whether conserving, restoring, or creating vernal pools bees in family Andrenidae are requisite for the propagation of showy vernal pool flora. As is the case with most restoration efforts, attempts to increase the number of oligoleges at any vernal pool complex will be highly experimental. Moreover, current and impending climate change will likely change the interactions between andrenids and their coevolved pollen-hosts, further complicating monitoring and restoration efforts (Rice 2003).

Part II

The primary goal of the following restoration plan is to increase the population and diversity of andrenid bees and their obligate pollen hosts at Yolo County's Grasslands Park. According to the 2005 Grasslands park management guide the only andrenid-pollinated flowers at Grasslands are *Lasthenia fremontii* and *Downingia insignis*; based on the known distributions of various species of *Blennosperma*, *Downingia*, *Lasthenia*, and *Limnanthes*, I believe that the vernal pools at Grasslands could provide habitat for a much more diverse assortment of showy vernal pool flowers and their oligoleges (Thorp 1998). Additionally, on May 21st I observed several flowering *Limanthes douglasii* specimen at the edge of pool 9A & 9B, which reveals that the 2005 Grasslands management guide did not comprehensively catalog native vernal pool flowers at the site. An increase in the abundance and diversity of either obligate pollen-hosts or oligoleges requires an increase in the abundance and diversity of the other. In order to accommodate more vernal pool flowers and their obligate pollinators the vernal pool complex must retain the current extent of pools and adjacent upland habitat. Instead of constructing pools on upland habitat, artificial pools should be constructed near existing pools; beyond limiting the amount of potential andrenid nesting habitat constructed pools would destroy, locating artificial pools near existing pools increases the likelihood that organisms will naturally migrate to these pools. Improving the suitability of pool and upland habitat for species of concern is another key restoration goal. Making pool and upland sites more suitable for species of concern will necessitate intensive suppression of European annual grasses. Exotic annual grasses dominate Grasslands Park's upland habitat as well as the fringes of the pools; beyond outcompeting native flora of concern, these grasses cover an extensive area of upland habitat making it difficult for andrenids to excavate nests. After being introduced, colonization of the vernal pool complex by desirable flora and fauna will take several years. Assessing how successful restoration efforts have been will likely take five or more years of monitoring before becoming apparent. Five years is the approximate amount of time it will take to establish enduring annual exotic suppression followed by early succession of native vernal pool flora; andrenids populations should expand following the improved proliferation of native vernal pool flora. The initial steps for this restoration plan revolve around monitoring the presence of vernal pool flowers and andrenid bees and the eradication of exotic annual grasses.

In order to maintain the existing populations of *Lasthenia fremontii*, *Downingia insignis*, and *Limnanthes douglasii* their respective oligoleges, which are likely *Andrena (Diandrena) submoesta*, *Panurginus atriceps*, and *A. (Hesperandrena) limnanthis*, measures must be taken to ensure that monitoring of flowers and andrenids is as unobtrusive as possible (Thorp 1990). Depending on the most recent pattern of precipitation monitoring of *Lasthenia* and *Limnanthes* will begin once the pools are no longer inundated, which should be between March and June; for example, due to this year's heavy spring rains it is likely that monitoring should begin in late May or June. *Downingia* tends to bloom later in the season so we should begin monitoring it two to four weeks after we begin monitoring *Lasthenia*. Monitoring of *Lasthenia* should cease with as we begin to monitor *Downingia*, but we should continue to monitor *Limnanthes* because it has a broader potential flowering time. The monitoring regime will consist of population transect sampling to assess both the abundance of *Lasthenia*, *Limnanthes*, or *Downingia* per meter squared at varying distances from the pool edge. The transect sampling should take into account the other associated vegetative components of the communities sampled. I predict that the samples will indicate that invasive annual grasses near the edge of vernal pools are inhibiting the potential population sizes of the flowers of concern through both direct competition for resources (space, light, water, nutrients, etc.) and alterations in vernal pool hydrology.

In an attempt to avoid taking the already limited number of andrenid bees at the site, I suggest that the initial monitoring of the oligoleges revolve around dusting blooming flowers with a fluorescent powder that will be picked up by pollinators and provide insight into the behaviors of different oligolectic and generalist pollinators; this dusting method was performed by Thorp (1990) and revealed the pollination habits of andrenids at Jepson Prairie. We could also employ a simpler method for assessing andrenid populations by monitoring blooming flowers with a camera or field technician to observe and record pollination events, paying close attention to which insects are pollinating flowers of concern as well as non-obligate pollen-hosts. If viable populations of andrenids are observed in two to three consecutive years then I suggest that we begin capturing andrenids, marking them with acrylic paint, and tracking their pollination patterns, as Thorp has done at a variety of Central Valley vernal pool complexes (1990 and 1998). Tracking pollination patterns will provide insight into andrenid behavior that will aid in future conservation and restoration efforts, particularly with transplantation. My suggestion of waiting two or more years before capturing andrenids is based on the tendency for population sizes of various vernal pool flower species and their oligoleges to fluctuate annually based on seasonal temperatures and precipitation; waiting until we observe consecutive prolific years before capturing andrenids lowers the likelihood of these takes having a harmful effect on andrenid populations. Despite being eager to assess the potential for transplantation to lead to successful colonization of restored and created pools by andrenids, I believe that such studies must be postponed until there is sufficient evidence of ample numbers of andrenids inhabiting the uplands of Grasslands Park; I predict that it will take at least five years of monitoring to determine the abundance of andrenids.

Although the restoration plan necessitates the monitoring species of concern in order to determine subsequent restoration goals and actions, I believe that eradicating the exotic annual grasses that dominate the upland and pool habitats via grazing or burning will have the most immediate positive impact on our initial restoration goals. In a conversation with Carol Witham, she suggested a grazing regime centered around the passive rotation of twelve cow-calf pairs beginning in November and ending in spring when the pools are no longer inundated. Though Carol is clearly more of an expert than I, my suggestion is to closely monitor the cattle during the wet season to make sure that they are not encroaching on pools or compacting and eroding soil. When I mentioned my reluctance to advise winter cattle grazing for Grasslands Park, Carol pointed out that a dozen cow-calf pairs is too meager a number to cause significant compaction, even on saturated soils. Cow-calf pairs can be passively rotated throughout the park by moving water and food sources on a weekly basis. Continual, low-intensity grazing will reduce the overall grass coverage throughout the park; this low-intensity grazing strategy does not, however, target especially detrimental invasive species when they are most vulnerable. For example, many of the exotic annual grasses and forbs at Grasslands have robust resprouting capabilities. Though we can attempt to target thoroughly invaded edges of pools when exotic annuals are most susceptible (usually just before they set seed and have dwindled carbohydrate reserves), having such a low stocking rate limits the area the grazers can cover during this brief window of opportunity. I suggest supplementing the grazing regime described above with prescribed burns in the spring, after vernal pool flora of special concern have set seed. In a several year study at Jepson Prairie and three other sites, Marty (2007) revealed that prescribed burns can dramatically lower the coverage of invasive annuals and support the proliferation of native annuals in the short term. Though Marty (2007) asserts that after one year the exotic annuals tend to rebound to their original coverage, well-timed spring burns in consecutive years could positively transform vernal pools and their associated uplands over the course of a few years. The timing of prescribed burns should be mainly based on seasonal precipitation and temperature, which will dictate the development of vegetation. Unfortunately, due to Grasslands Park's relative proximity to urban areas, prescribed burns will likely be excluded from the management plan because of air quality and fire liability issues (Marty 2007). Another supplement to the abovementioned grazing regime is hand-pulling at the margins of pools. In order to minimize the potential negative effects of poolside grazing, such as contaminating inundated pools with heavy loads of manure, cattle should be kept at least 10 m away from pool edges via electric fencing. Exotic eradication efforts at pool margins should avoid herbicide applications and instead revolve around hand-pulling. I am unsure as to which combination of grazing and burning will prove itself the superior eradication strategy. In an attempt to discern which eradication effort is most suitable I suggest establishing several 100 x 100 meter experimental plots in the upland area; one control plot will be left untouched; one ungrazed plot will be burned in late spring after the vernal pool flower vegetation of concern has set seed; another plot will be grazed from November to early spring, once the pools are no longer inundated; the fourth plot will have the grazing regime of the third plot and the fire regime of the second plot. These treatments will continue for three consecutive years; triannual monitoring of vegetation coverage and diversity will occur in late October, prior to the initiation of grazing, early spring, shortly after grazing ceases, and in late spring before the prescribed burns. If after a year or two a particular regime yields palpable positive changes in vegetation succession, then we will tentatively employ that regime at the most heavily invaded upland sites. Furthermore, we will begin new experiments on additional upland plots in an attempt to discover the best timings for grazing and/or burning to occur. Restoration managers will assess the success of fire and grazing regimes by monitoring changes in the abundance and composition of upland vegetation.

As earlier suggested, I believe the most positively impactful restoration effort to be employed as soon as possible is the eradication of invasive annual grasses from pools and upland sites in order to provide more habitat for flower species of interest and nesting sites for andrenids. Hopefully improving the landscape's suitability for vernal pool flowers and their oligoleges will yield an increase in the abundance and diversity of species of interest. If these habitat alterations produce a positive impact, then further studies can be pursued in order to better comprehend the ecological and biological interactions between oligoleges and pollen-hosts at Grasslands Park. If after five or more years of monitoring we observe thriving populations of andrenids we can begin experimental studies to improve our understanding of andrenid behavior to further efforts to conserve and restore vernal pool complexes by preserving and transplanting andrenid populations. There are a myriad of uncertainties associated with andrenids; improving our understanding of andrenid biology and behavior requires extractive experiments and, in my opinion, we should only pursue intrusive studies after we are certain that our inquiries will not have a detrimental impact on these already dwindling endemic pollinators.

Part III

Grasslands Park contains several listed species as well as dwindling populations of unlisted endemic species of flora and fauna. Although the species of concern have different biological and ecological requirements, for the most part the needs of each species are relatively complimentary. At the risk of sounding andrenid-centric, I assert that the Grasslands Park restoration effort should emphasize the eradication of exotic annuals, particularly European annual grasses. Aside from reducing andrenid nesting habitat, the prevalence of exotic annual grasses reduces habitat for listed native flora, such as Crampton's Tuctoria, Colusa grass, and Alkali-milk vetch, by directly out competing the native vegetation and by altering pool hydrology to reduce the seasonal period of inundation. The extensiveness of exotic annual grasses in upland habitats also limits suitable habitat for Swaison's hawks and western burrowing owls. Restoration efforts should also include attempts to suppress exotic annual forbs, such as yellow star thistle and perennial pepper weed, at pool margins because they also compete with species of concern and negatively alter pool hydrology; eradication efforts should revolve around mechanical removal of undesirable vegetation rather than herbicide applications that can have deleterious effects on listed invertebrate species, such as the vernal pool fairy shrimp and the conservancy fairy shrimp.

Fact Sheet

- Vernal pool andrenid bees are oligolectic (host specific for pollen at genus or species level)
- Main vernal pool annual flower genera of concern are *Blennosperma*, *Downingia*,*Lasthenia*, and *Limnanthes* (*Lasthenia fremontii* and *Downingia insignis* present at Grasslands site)
- Oligolectic andrenid genera for the abovementioned genera are *Andrena* (*Diandrena*), *A.* (*Hesperandrena*), and *Panurginus* (not respectively)
- Andrenids are the most abundant and important pollinators of outcrossing populations of many vernal pool flowers
- Oligolectic andrenids have evolved close ecological relationship with their pollen hosts
- Life cycles of andrenids are highly synchronized with the flowering period of their pollen host(s)

- Andrenids build underground nests (10 – 30 cm deep) in upland area as far as 100 m from pollen-host population and thus link vernal pools with adjacent upland habitat
- Preferred nesting habitat is sparsely vegetated with sandy or loose substrate
- Majority of annual life cycle spent underground as diapausing adult until emergence in spring followed by 4 to 6 weeks of flight activity while flowers are in bloom
- Similar to the seeds of their pollen-hosts, andrenids can overwinter for one or more drought years until cued to emerge by a sufficient amount of precipitation in a winter
- Exact cues and thresholds for andrenid emergence are unknown
- Different pairs of vernal pool flowers and their oligolectic andrenids have different cues for germination and different emergence timings
- Some oligolectic andrenids exhibit behavioral adaptations to specialized flower morphologies (eg the exserted androecial columns of *Downingia*)
- Andrenids restrict foraging patterns to a single pool or over a limited area of a large pool
- Andrenid-mediated pollen flow is leptokurtic (most pollen going to nearest-neighbor flowers)
- Vernal pools exhibit high floral diversity between pools and low floral diversity within pools
- Andrenids occur within the central range but not the entire range of their pollen-hosts
- Sufficient knowledge of the specificity and seasonal synchrony of oligolectic andrenid bees and their vernal pool pollen host-plant taxa and their annual life cycles
- Insufficient knowledge of complete systematics (except for *Andrena (Diandrena.)*), dispersal, nesting habitat requirements, and distributions relative to their host plants
- Andrenids are obligate pollinators of several endangered species of vernal pool flowers throughout California, including *Lasthenia conjugens, L. burkei, Limnanthes floccosa* ssp. *californica*, *L. vinculans, and Blennosperma bakeri*

- Foraging female andrenids that had already established nests have been successfully transplanted to restored vernal pool sites
- Higher colonization success for transplantation likely to occur if experts devise a procedure to collect and introduce freshly emerged female and male adult andrenids or overwintering diapausing adults or post-defecating larvae via soil coring
- Without developing an improved procedure to transplant andrenids, created vernal pools must be located approximately 100m from existing pools in order for them to support showy vernal pool flower species
- Potential non-profit funding sources: Pollinator Partnership's North American Pollinator Protection Campaign
- Potential legislative/governmental funding sources: Federal and CA Endangered Species Act (USFWS and CADFG), Pollinator Protection Act
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ENH 160

Western Spadefoot Toad Vernal Pool Restoration Plan

Basics:

-Toad sized about 1.5 to 2.5 inches that feeds on invertebrates and is consumed by birds and amphibians during its larval phase.

Target Goal:

-Design man-made vernal pools with an inundation period that supports the Spadefoot toad but not other invasive amphibians.

-Place enough pools near each other (all within 368 meters of one another) so proper population dynamics can occur like genetic drift and variability.

-Allow toads to disperse without being killed by agricultural machinery or motor vehicles.

-Overall allow for a thriving sustainable population of vernal pool toads to that can feed higher animal orders in the season wetlands.

Difficulties:

-Funding to restore damaged habitats and improve upon vernal pools. Sacrament area still expands and developers would rather build up the land than see habitat expansion.

-Protecting existing lands. Even though the Western Spadefoot toad coexists with endangered species, its ecosystem keeps getting destroyed.

-Higher water temperatures with climate change allows for fungus to flourish more readily on the toad's eggs, significantly increasing the eggs' mortality.

-Invasive species such as the American Bullfrog and the African Clawed frog place considerable pressure on the Spadefoot's population.

-They are very response to noise caused by human influences which will increase as more development and roads are built through areas like Sacramento, Santa Barbara and Las Angeles.

Justification:

-This toad is still being studied for its rare ability to adjust to a quickly drying pool. Metamorphosis can be accelerated in response to its environment at a moderate cost of fitness. Amphibian researchers want to learn the specifics in this adaptation process.

-The toad is needed to feed certain migratory birds and the endangered tiger salamander larvae.

-A key part of this fragile and special ecosystem in California

Design and Management:

-Pools that have inundation periods that will allow native species to thrive without supporting the American Bullfrog and African Clawed Toad. Spea Hammondii can survive with as few as 30 days of inundation unlike its invaders, 45 days would be the maximum inundation time if you wanted to push out invaders.

-Opportunity for livestock grazing (preferably a smaller sheep over the soil disturbing cow)

-Allow the frogs to disperse, burrow and mate in the same managed region since they rarely travel farther than 300 meters in a season.

-Prevent over-population of predators such as tiger salamander, every pool the salamander's larvae lives in will significantly lower the population of the Spea Hammondii tadpoles.

-No nearby pollution sources such as agriculture or large human populations.

-When considering habitat placement, avoid freeways as they will prevent dispersal of the toad to the other side, and fast moving water since eggs and tadpoles need slow moving or still water to thrive.

I. BACKGROUND

The project goal is an approach to halt ecosystem degradation and induce restoration of the Western Spadefoot Toad's (Spea Hammondii) Vernal Pool habitat. Developers have built urban and agricultural constructs on much of the toad's ecosystem throughout the state (Morey 1998). It is estimated about eighty percent of their environment in Southern California has been destroyed, along with thirty percent of their habitat in Central and Northern California, notably Fresno, Bakersfield and Sacramento areas (Jennings and Hayes 1994). Introduction of exotic species such as mosquito fish, American Bullfrogs and African Claw Toads has threatened the native populations. The population of the Western Spadefoot Toad is decreasing and its status remains a threatened species (IUCN Red List). Wetlands continue to be developed in the Sacramento Area, impacting the Spadefoot's habitat lands.

II. JUSTIFICATION FOR CONSERVATION

The tadpoles are able to complete metamorphosis faster if they detect drying pools; this mechanism is of an interest and still being actively studied (Morey 1998; Boorse and Denver 2004). Any other possible questions and knowledge this metamorphosis would reveal will become increasingly harder to study as Spadefoot populations decline.

The larvae of the endangered California Tiger Salamander feeds on the Western Spadefoot Toad, since the toad is an important food source, conservation of the toad and its habitat will increase the survivability of the endangered salamander (Feaver 1971). Dabbling ducks and other migratory birds feed on the larvae of the toad and depend on this feeding for their seasonal cycle (Stebbens 1985, Morey 2010).

III. ACTS PROTECTING SPECIES

-Endangered Species Act (since Spadefoot is food source of Endangered Tiger Salamander)

-Clean Air Act (reduction of air pollution on the toads and mitigates the damaging effects of global warming on the toad's eggs)

-Clean Water Act (reduces the amount of discharged pollutants that will reach into the toad's wetland habitat)

- National Wildlife Refuge System Administration Act of 1966 (help manage the land the Western Spadefoot toad lives on)

IV. POSSIBLE FUNDING ORGANIZATIONS

-National Fish & Wildlife Foundation (funding for wildlife and habitat conservation)

-Wildlife Forever Challenge Grant (can be used to address invasive species, which could be used to control the Toad's competitors)

- Wildlife Habitat Incentive Program (can benefit at risk species, such as the toad)

- US Fish & Wildlife Service (provide grants for protection of wildlife)

-Conservation Grants Center (links to many conservation grants)

-Nature Conservancy (a group that provides conservation grants)

-CalFed (group that has contributed to restoration projects)

V. SOCIO-ECONOMIC LIMITATIONS

Preserving these wetlands directly interferes with more urban development on wetlands such as the expanding Sacramento Area. Anther limitation of conservation is the lands cannot be used for growing crops or intensive cattle grazing if they are preserved properly. Since the species is not on the IUCN's list as endangered, merely threatened, so the cost trade-off versus 'more endangered amphibians' may be seen as economically unfavorable.

- DESCRIPTION

The toad measures from 1 1/2 to 2 /12 inches (~37-62 milimeters). The toad's coloration runs from green to green-gray or green brown, also having uneven stripes on its back, and a lighter than body coloration on its belly. The name of the spadefoot comes from the characteristic spades shape on each hind foot, useful for digging. (Santa Ana Water Association 2008). The toads have been known for releasing irritant: a roasted-almost smelling secretion that deters predators from eating them. The poison deters to a level that toads have been found eaten but their poisoned skin were left behind (Stebbins 1985).

It is reported that "virtually no data" exists for demographic values, long-term population dynamics, survival rates, reproductive success and dispersal rates (USFWS). What is understood is that metapopulations must be connected via corridors. The general distribution of adults to juveniles is 7:3 (Morey and Guinn 1992).

VII. RANGE

They span historically from Redding down to Baja California (Jennings and Hayes 1994). The toad is mainly seen in areas such as the Great Central Valley and its foothills, along with the cosast ranges of Monetery Bay to northern Baja Califoria (Stebbins 2003).

VIII. HABITAT

The Western Spadefoot Toad thrives in areas of open and or low vegetation. (Yolo Natural Heritage Plan 2009) They need areas with sand or gravel-like soil so they can burrow into the ground during the off years. Some of the uplands they spend most of their dormant life cycle are often found in the grasslands of valleys and foothills, chaparral and pine-oak woodlands (Stebbins 2003). The toad needs the uplands because its soil is diggable, allowing the toad to burrow during the dry season, and prevent desiccation. The temporary rain pools in the environment must not have exotic predators or it risks unsuccessful reproduction (Jennings and Hayes 1994). Exotic predators easily eat many toad larvae preventing much of the young from surviving until maturity.

Toads and their larvae have been seen in rivers, creeks, pools in short lived streams, watering holes for cows and temporary rain pools (California Natural Diversity Database 2000). The species has shows tolerance with the variety of habitats it can thrive in.

The toads depend on a temporary pools that are inundated for more than three weeks for successful egg laying and tadpole metamorphosis between nine and thirty degrees celsius. The toads need an uplands habitat within 300 meters to disperse to so they can burrow and hibernate for the dry season. Lower water temperatures are more ideal since fungus which plays a high death tole on the eggs above 21 degrees Celsius (Storer 1925).

IX. LIFESPAN

Male Spea Hammondii will form clusters on top of water that has been present for three weeks and call out for mates. Females lay a total of three-hundred to five-hundred eggs, which she lays in patches of ten to forty on protruding objects in the water such as plant stems or debris (Storer 1925). Breeding generally occurs between January and March, but depends on rainfall patterns, since they need the moisture to prevent desiccation (Jennings and Hayes 1994). The eggs can hatch and release larvae between fifteen hours and six days after being laid (Yolo Conservation Plan 2009). Anywhere from three to eleven weeks after the tadpoles are born, they will complete metamorphosis and be viable on land (Feavor 1971). The adults toads will migrate and return to the uplands after their breeding period in the vernal pools of one to two weeks (Stebbins 2003). Adult toads will live about six to seven years throughout their entire life, spending eighty percent of this time burrowed about one meter bellow the ground (Animia Daily 2008).

X. FOOD WEB

The Western Spadefoot Toads feed on invertebrates such as insects, worms, crickets, grasshoppers, true bugs, and beetles (Yolo Natural Heritage Plan 2009). Their larvae feed on algae, planktonic organisms and will feed on other larvae from their and other species.

Native predators such as the Dabbling Duck and Tiger Salamander Larvae along with non-native mosquito fish, crayfish and bullfrog toads feed on the Spadefoot's larvae. Adult toads will be predated by snakes, raccoons and heron (Yolo Natural Heritage Plan 2009).

Amphibians pose an important part of the trophic cascade since their tadpoles feed insects which feed higher organisms, but also their adult populations feed on insects, thus the absence of the Spadefoot would incur diversity losses (Reylea 2005).

XI. ENVIRONMENTAL CONSIDERATIONS

The Western Spadefood Toad is susceptible to tractor tilling since most of their adult life is less than one meter underground. The toads dispersing across roads risk being run over by cars. Low frequency non-natural noises resemble rain drops, which is when the toads can leave the burrow and risk desiccation. Pesticides like Roundup and Malathion harm toad eggs and adult populations, being very toxic at concentrations of 7.7 mg/Liter (Yolo Natural Heritage Plan 2009, Westman 2009). Since the toad is so vulnerable to these human influences, care needs to be taken to offer about 134 acres of protected and isolated areas for the toad where no roads, housing or agriculture will exist near.

With these considerations, an ecosystem placed away from agriculture and a road would be ideal, with many populations placed within 368 meters of one another. In addition to large protected plots, locations with pools that remain saturated with water for more than 35 days will give most of the larvae enough time to go through metamorphosis; beneficial for the future adult population (Morey 1998).

Invasive introduced species such as the American Bullfrog or the African Claw Toad lower Spadefoot Toad populations (Morey and Guinn 1992). The invasive species do this by feeding on the Spadefoot larvae that reside in the Vernal Pool, events like this greatly pressure their populations.

If climate change occurs because of rising greenhouse gasses, environmental strain will be put on the Spadefoot Toad and its habitat. A drop in precipitation levels and a rise in temperature would increase evaporation rates and would offer shorter inundation periods for the pool's biota. The difficulty lies in reducing anthropogenic emissions that influence all ecosystems, which requires the cooperation of most of the world's countries.

XII. PAST RESTORATION

The United States Fish and Wildlife Service created man made vernal pools in the Sacramento area in 1980s (Thomme 2001). At first the vernal pools did not allow dabbling ducks to migrate because the bank slope was too steep. Another problem with the pools was that they held water longer than natural pools, but after modifications by biologists they were able to amend these differences. Ultimately, "Vernal pool ecosystems within Placer, Sacramento, and Butte Counties have shown significant recovery as a result of the USFWS' restoration efforts," which helps to increase the Spadefoot Population (Thomme 2001). After about six years in vernal pools installed in Santa Barbara area in 1986 native populations were increasing and stabilizing in the pools (Ferren 1998). With past restoration projects successful for the vernal pools, aiding the S. Hammondii population is a matter of preserving healthy ecosystems and rebuilding damaged ones. A healthy ecosystem will ultimately include clean water and air, no human disturbances near the uplands or vernal pools, and enough land for the species to properly disperse after maturation. Past successes are useful as templates for future restoration projects like in Santa Barbara County and Sacramento, and a tool for working with local and regional planners in this direction.

Management and Monitoring Plan for Spea Hammondii

A. GOALS

Long Term: To conserve existing habitats by lowering stressors from human and invasive causes. Stresses like pesticides, cars and American Bullfrogs will help populations if cut back. Conservation includes monitoring water quality into the system and preventing pesticide levels at or below 0.7 mg/ liter through regulation or law changes in the local towns and cities (Relyea 2005). Preventing offloading from disturbing pools and the separation of vernal pool sites from their nearby uplands regions. Construction of new vernal pools with nearby uplands to bring the population of the toad back to the Sacramento wetlands, and the foothills and valley of Central and Southern California.

Short Term: Firstly restore seasonal wetlands habitat for the species by building new manmade vernal pools. Find locations with suitable sandy uplands to form new aestivation habitat for the toads (Stebbins 2003). It would be helpful to pay special attention to any rare genetic diversity that remains important for habitat adaptation. Increase the ability for the Spadefoot Toads to disperse, which will include placing 350 acre two or three 350 acre habitats next to each other. Placement of multiple pools connecting to each other is needed to conserve metapopulations (USFWS).

B. Restoration Plan

Conservation of Existing Land: Fences or gates need to be used to prevent off-road vehicles from accessing the vernal pools. Regulatory agencies need to monitor water quality in the vernal pools and prevent insecticides like Roundup at low enough levels (0.7 mg/ liter) to prevent damage to the eggs of the Western Spadefoot Toad

(Relyea 2005). Pathways under major roads can be formed so the Toads can disperse under the road safely.

Restoration and the Creation of New Habitat:

Short Term: Measures need to be taken to push out the invading species which requires manmade pools to inundate shortly thus preventing the African Claw Toad and the American Bullfrog from establishing in the pool environment. Given the two invasive species' metamorphosis period of a month and a half to two months, an inundation period of 30-35 days will let the Spadefoot still mature without letting its competitors (Casper and Hendricks 2005, Jennings and Hayes 1994). This data can be extrapolated from the Spadefoot matures in as little as 21 days, while its competitors matures as little as 42 days. Also if the inundation period stays at about 30-35 days, then it will more likely stay within the 21-42 days that allows the Spadefoot larvae to survive but not the invasive frogs. Since the Toad shows little selectiveness as far as depth, already functional dimensions for the pool can be used (California Natural Diversity Database 2000). A successful pool design includes a maximum depth of 4 to 6 inches (De Weese 1998). When constructing the habitat you want to find a large uplands area with a high water table within a meter or so of the ground. The uplands area needs to be a consistent habitat at least 130 acres in size, preferably with other uplands habitat nearby for dispersal (Yolo National Heritage Plan 2009). If invasives enter some of the pools, measure needs to be taken to separate the pools so they don't exchange surface water, thus isolating each habitat.

Using a pool that has already been populated naturally that needs introduction of the Spadefoot Toad will allow the larvae to feed on such invertebrates as the Fairy Shrimp. For introduction, toads should be taken from breeding pools in other habitats in January, right after the end of their previous hibernation period and transplanted to the manmade new habitat to lay eggs in this location. To preserve natural adaptations, Spadefoot Toads from multiple sites with the most similar uplands to the manmade site for restoration.

Long Term: Sites need to be monitored over the next seven to eight years to decide if the construction was sound, similar to Santa Barbara's restoration (Ferren 1998). Research could be done to learn about the Toad's population dynamics by recording toad genealogy, toad population sizes. Inundation period and invasive populations should be monitored yearly to prevent their colonization.

If the inundation period goes above 45 days with the expose of adult Bullfrogs or African Claw Frogs, then a large population decline in Spea Hammondii can be seen. With this inundation period a population of African Claw or Bullfrogs can start reproducing and perpetuating its lineage in the vernal pool . If invasive species like the Bullfrog or Claw Toad start moving in for more than a single wet year, then the inundation period of the pond needs to be lowered with less grazing allowing for more water loss. The evapotranspiration will contribute to the amount of water lost to air, helping to dry up the pool.

The habitat with the Vernal Pools will require some upkeep for the toads. Any manmade pools will have hardpans that need to be adjusted for inundation times, like the ten year restoration plan in Santa Barbara (Ferren 1998). Climate change will increase water temperature and thus the amount of surviving eggs laid by the Spadefoot, weakening the restoration effort (Stebbins 1925). Downsides of this plan involve invasive species and the difficulty in pressuring them with little enough day so they cannot reproduce. Another difficulty is how to arrange the frog populations near each other in the vernal pool system, since metapopulations depend on corridors, but other genetic and population information is not known (USFWS). Finding new land to develop manmade pools in would require wetlands areas that will not be developed for agriculture or residential possibilities.

Spea Hammondii Restoration in Relation to Other Vernal Pool Species

Main management factors for the Western Spadefoot Toad include shorter inundation periods to resist invasive species, connections of pools for metapopulation stabilization, and preservation of uplands and a route to disperse to that location. One concern is that many native plant species need longer inundation periods to obtain a foothold in the vernal pool against invasive species, so managing for a shorter period would contradict native plants and some native animals such as the vernal pool snail. To manage for this inundation concern you could create or use a site with vernal pools with multiple inundation times, some short at about 30-35 days and some with upwards of 80+ days for the vernal pool snail. This time variation should encourage higher genetic and biodiversity within a wetlands habitat. As far as connecting the pools, other species that need populations distributed over many vernal pools for strong strong genetic variation would benefit by managing the many pools to include pathways connecting populations. Uplands are good locations to protect since other species also use the uplands for habitat during the dry months in addition to the Spadefoot Toad. By managing for Spadefoot Toads, you increase their population size in the pools, thus harming populations of vernal pool shrimp. Since the pool shrimp are also being preserved by our restoration plan, dramatically increasing the breeding of the Spadefoot Toad would produce many tadpoles lowering the populations of invertebrates such as the vernal pool shrimp. As long as predators such as the dabbling duck or tiger salamander larvae (can be introduced) control the tadpole population of the Spadefoot Toad, then the toads will be controlled and the pool shrimp should not be over-predated.

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Dabbling Ducks and Vernal Pools

Andrew Rice

Part I: Project Background and Justification

The genus Anas is made up of the dabbling ducks. These species feed mainly at the surface rather than diving. There are many species of dabbling ducks within this genus with Mallards and Teals being the most populous. Dabbling ducks are a migratory group that depends each year on ephemeral wetlands such as vernal pools for habitat on their journey. With severe decline in the amount of vernal pools still in existence, efforts should be made in order to conserve existing habitat and in the restoration of areas that have been devastated.

Dabbling ducks are migratory waterfowl that use wetlands in the winter and as nesting habitats in the spring. Due to urbanization, agriculture, and other factors, only a small portion of these areas are in existence today. Recent estimates suggest that only about 5% of historic wetland habitat still exists (Bogiatto 2006). Dabbling ducks depend on vernal pools for habitat that only vernal pools can provide (Bogiatto 2006).

Vernal pools are represented by a myriad of different sizes and shapes that occur in different densities and periods of water inundation throughout the California Central Valley. They are dependent solely on rainfall for their source of water. Vernal pools exist due to a hardpan layer of clay type soils that keep the water table high because it does not allow it to leach out. Because of this, the hydration period of vernal pools is always changing because of its dependency on rainfall. Late winter and early spring are usually the times when vernal pools are flooded, and are followed by dry times until rainfall is received the following wet season. The California climate and wet-dry pattern of vernal pools provides habitat not only for migrating waterfowl but for other species, many being endemic. (Silveira 1998)

Vernal pools are generally small, isolated wetlands that provide habitat for small numbers of dabbling ducks. Most never exceed 150 feet in width or 3 feet deep, with many being just a few yards across (Roble 2010). Because of their small size, vernal pools usually are seen with only a few numbers of ducks in them, with the larger pools supporting more waterfowl (Silveira 1998). According to Silveira, use of vernal pools by dabbling ducks and other avian species has previously been underestimated for three reasons: 1.) Vernal pools are ephemeral (short-lived) in their inundation of water and therefore do not provide much time for birds or other invertebrates to exist. 2.) Vernal pools usually occur in small basins in isolated areas which leads to observation trouble. And, 3.) Social structure of birds makes it hard to track because of their different uses in winter and spring. In spring dabbling ducks have usually paired off for mating and are not found in large flocks as they are in early winter at the beginning of the migration phase. These ephemeral wetlands do play a significant role for these ducks however in spring and will be further discussed.

`Many vernal pools in the central valley of California are located on government owned land as well as some on private land. Much research has been done in these areas on endemic invertebrates and plant life. Endemic crustacean species such as tadpole shrimp and fairy shrimp are large areas of conservation effort for these pools (Bogiatto 2006). However these and many other invertebrate species play a key role in the survival of migrating waterfowl due to their seasonal availability.

Birds have adapted to their environments drastically and do so throughout their lifetime. In their life histories, dabbling ducks have different resource requirements at different times; those being: reproduction, molt, migration, and maintenance (Silveira 1998). Energy requirements are different for different species and in these different stages of life. Silveira states that after fall migration (August-September), dabbling ducks are in poor conditions. They replenish their reserves however in the early winter months at ephemeral wetland sites like vernal pools. This is followed by a decline in body condition in the cold winter months, and again rebuilt in the early spring months. Vernal pools are essential to dabbling ducks for their replenishment. A study by the California Department of Fish and Game reported many species that were eaten by dabbling ducks were shown to be from vernal pools although some were from larger wetland areas (Bogiatto 2006). Reproduction, molt, and migration require high amounts of energy (Silveira 1998). It takes a mallard three to eight days to replenish the fat reserves that are lost in an eight hour flight period (Silveira 1998). Vernal pools provide food and rest for these migrating species during the months of migration and also provide these and nesting habitat during mating (Bogiatto 2006).

Dabbling ducks obtain nutrient reserves in spring that are essential for reproduction (Silveira 1998). In the spring time, ducks shift their diet from one dominated by seeds to a diet that includes invertebrates to increase their protein intake (Taylor 1978). This is done in order to maximize egg production. Invertebrates such as crustaceans, snails, and analids were found by Silveira to make up a major part of dabbling ducks' diets. Other animal foods found in vernal pools were tadpole and fairy shrimp, cladocera, copepods, and beetles. These, he stated, contained all the essential amino acids and calcium that was necessary for production of eggs. The study by Silveira did not say that all these species were found to be eaten by dabbling ducks, but it did state that they were definitely possible food sources that were thought to be consumed.

A study was conducted by the California Department of Fish and Game in the Sacramento Valley on the types of food that comprised migratory ducks' diets and the results are supportive (Bogiatto 2006). In the study, DFG collected 21 dabbling ducks comprised of 7 Mallards, 11 American Widgeon, and 3 Green-winged Teal. The study found plant material in all species of ducks. The plant material was mainly comprised of grasses and forbs with the highest occurrence of one species being Spikerush seeds. Vernal pool snails and immature stages of aquatic insects were found to be in the diets of dabbling ducks. The ratio of animal to plant matter was relatively low in dabbling ducks but in one female mallard's esophageal sample, over 300 snails were found. Other seeds found in the ducks were willow smartweed and watergrass. One of the biggest finds that resulted in the study was that dabbling ducks were observed to use vernal pools diurnally. (Diurnally meaning in the daytime). The dabbling ducks were found to retreat from the vernal pool sites back to larger bodies of water such as state reserves at night. The study's results helped enforce the idea that dabbling ducks use of the vernal pools is primarily for the enhancement of nutrition and replenishment of reserves. (Bogiatto 2006).

Some species of ducks utilize vernal pools in the spring time as areas of shelter for reproduction. Species like mallard and cinnamon teal seek small isolated areas such as those provided by vernal pools to pair off at in their typical breeding grounds (Silveira 1998). During these times, the ducks construct nests in these areas and make vernal pools temporary homes as opposed to their diurnal use during migration. From November to April vernal pools are a crucial part of dabbling duck feeding grounds. Although the DFG study showed that most dabbling duck species used vernal pools diurnally during migration, it is also thought that some species most likely use the pools at night as well. Whether they are used as a resting place to replenish or a breeding ground, vernal pools are key to their survival. These small areas of water are habitat not only to dabbling ducks but to other species, many endemic, as well. With the constant disappearance of these areas, habitat for dabbling ducks and vernal pool endemic species is swiftly dwindling.

Dabbling ducks also have some affects on other vernal pool species. In a study by Green *et. al.* (2001), dabbling ducks play a key role in the dispersal of vernal pool species. This can be done by the attachment to the external part of ducks such as the head, beak, feet, or feathers, or internally through the digestive system. Very little research has been done on the dispersal effects of migrating waterfowl, but however the study above did show that dispersal of certain seeds did occur. The variation of dispersal varies greatly. The study showed that different seeds were eaten during the late fall and early winter migration months than late winter and spring months of mating. It can be inferred that due to this many seeds that are eaten along the migration pathway are more likely to be dispersed further along that path. Likewise seeds that are eaten during the late winter and spring months are more likely to be dispersed in the areas that mating actually occurs in due to the relative lack of geographical movement by the ducks. (Green *et al.* 2001)

Dabbling ducks also may have negative effects on some species. Many species of fairy shrimp are endemic to vernal pools and are listed for protection. One listed species, the Western Spadefoot, has numbers that are dwindling. Dabbling ducks are considered to have a diet of seeds, grasses, and invertebrates. In vernal pools, the tadpoles and eggs of the W. Spadefoot are probably one of many species that are vulnerable to dabbling ducks. Because it would be impossible to kill all of the dabbling ducks to save the Western Spadefoot, if restoration were to commence, it would be wise to take in consideration species of concern like the Spadefoot and introduce other species along with it so there would be higher diversity in the vernal pools so that dabbling ducks did not consume a large amount of listed species. (Morey, 2010)

Restoration and conservation of vernal pools in the Great Central Valley of California is a major area that should be being focused on for the continuation of a variety of species. These areas already are home to many species that are endangered and only found in these types of habitat. Vernal pools, however, do not get the amount of effort and attention needed. As shown in this paper, one group of species' dependency on vernal pools for all cycles of its life and energy requirements is staggering. Dabbling ducks use vernal pools as a major role in its habitat. If urbanization, agriculture, and other factors depleting vernal pool sites such as grazing continue, we will see more species become endangered and possibly extinct.

The goal we should have is at least to not lose any more sites of vernal pools. In the event of restoration of vernal pools it would be different from site to site. The needs of dabbling ducks are fairly simple. They need food to replenish and a place to rest. Seeds such spikerush and native grasses should be planted along with introductions of invertebrates that are key to the life cycle of vernal pools and dabbling ducks. There are many considerations that play in a restoration attempt. Obviously dabbling ducks are not the only species that depend on vernal pools for survival. Many ephemeral invertebrates and endemic plant species have adapted to these areas specifically. Because vernal pools are not all alike, size should remain small to medium in size. With this size, it will provide dabbling ducks with the type of habitat that it uses vernal pools for most: nesting. As reported by the study conducted by DFG, dabbling ducks have the opportunity to retreat to larger bodies of water at night or during possible disturbances like those at refuges, but small vernal pools are used for specific replenishing and nesting.

Possible funding for this goal will most likely not be provided by the state at this economic point in time. Thus, funding should be looked for in the private sector such as waterfowl conservation efforts. Organizations such as the California Waterfowl Association and Ducks Unlimited both are privately funded and each year contributes large amounts of money to ensure conservation and restoration of wetlands for migratory waterfowl.

The need for wetlands such as vernal pools by dabbling ducks is undoubtedly present. Conservation of the few areas that currently exist should be the main goal at this point in time. Looking to the future, restoration of historical vernal pool sites should be examined and planned through carefully and thoroughly. A wide variety of species depend and these areas and it would be foolish to create an area in hopes of the preservation of one species. With proper planning and execution, restoration of vernal pool sites could be accomplished. It is obvious that the parameters of each site would play a major role in the process of restoration. Each site, historical or current, has characteristics that may be found over many sites or just at that one. This is important in the restoration process in order to find what commonalities between sites exist and the frequency they appear in, in order to establish what components are absolutely essential in the creation, restoration, or conservation of a vernal pool site.

Part II - Goals and Management Plans

Goals

1.) Assess the current potential for the site relative to habitat for dabbling ducks
2.) Identify and protect what habitat is already occurring naturally
3.) Remove invasive vegetation
4.) Introduce or foster vegetation suitable for nesting habitat
5.) Introduce or foster vegetation and invertebrate food sources
6.) Implement Management Phase

- Goal One: It is imperative before any work be done on the site that it is evaluated for the potential benefit that it may offer dabbling ducks. Knowing to what extent the land area's degradated is a good start. Soil quality and hydrology are key factors to examine. If the soil has been degraded heavily, it is more vulnerable to invasive species. Also, vernal pools depend on a clay-pan layer relatively shallow in the soil for periodic inundation to occur so a soil survey should be conducted to establish possible needs in the site to ensure proper dabbling duck habitat species may grow. Dabbling ducks feed from the surface, not by diving. Shallow pool depth of less than 30 centimeters is necessary for their feeding and should be evaluated accordingly.

- Goal Two: In California today, minimal natural habitat in its historical state still exists. If at all present it is an extreme priority to protect and foster what natural vegetation/habitat is still in existence which will benefit dabbling ducks. If a site has the potential for management rather than complete restoration, it would benefit not only economically, but for the natural sustainability of the existing vegetation itself.
- Goal Three: This is obviously going to be part of any restoration project, especially in vernal pools. Invasive species have a severe effect on native plant and animal species because adaptations to these species take very long periods of time. Because dabbling ducks are migratory, they are more accustomed to variable sources of habitat and food. However, removal of invasive species will allow for optimal areas of habitat and to foster species that are needed by dabbling ducks.
- Goal Four: The introduction or fostering of species of vegetation for nesting habitat is self explanatory. Native grasses and forbs should be at the top of the list for fostering or planting, especially native grasses. These provide enough shelter that would give adequate building materials and cover for nesting.
- Goal Five: Fostering and/or introducing vegetative and invertebrate species as food sources is necessary. Species like vernal pool snails, various fairy shrimp species, along with plants like spikerush, minimal watergrass species (due to takeover of vernal pools), and native grasses are major food sources.
- Goal Six: Implementation of a management phase is crucial to the continual benefits that were introduced with the previous goals. Keeping invasive species from the vernal pool site should be a major priority. Also, keeping disturbance of the pools to minimal levels is crucial. Some physical disturbance allows for diversity of species but disturbances such as grazing during nesting and mating phases of dabbling ducks will alter their natural life cycle. During these phases, disturbance to the area should be kept minimal as possible in order to foster dabbling duck habitat.

Restoration:

The restoration plan for any site is considerably variable depending on spatial scale, budget, and a myriad of other factors that dictate what goals can be achieved. For the sake of this project we will continue forward with the mindset that all goals presented are as equal as another and will be accomplished.

After assessing what the characteristics of the site are, determine if the site can be further developed or if it is in need of restoration. If the site needs to be fostered, further discussion in the paper will address this. If restoration is needed, you need to pick a place to start. If a soil survey shows that the clay-pan layer is shallow enough for vernal pool existence, then this is a good jumping point. If there is not adequate clay-pan layer or depth of it is wrong for periodic inundation, one will have to be created before any further restoration occurs.

Once proper hydrology of the soil is addressed, it will be necessary to create, if not already present, swales that will bound the vernal pools in the site. These swales are border-like mounds that encase the vernal pools. Different heights are necessary in swales in order for connectivity of the pools to exist. The swales need to be high enough to encase the vernal pool(s) in dryer times, but low enough in height that periodic flooding may overflow their boundaries. This will allow for dabbling duck nesting sites to be available in spring. From the top of the swales, the pool depth should be in the range of 15-30cm for dabbling ducks. The edges of the pool should not be vertical, but sloped as they would be in natural locations. Sloped edges of the pool and minor sloping of the pool itself allows for inundation periods to differ throughout the entire pool depending on height and water amount. This difference in inundation results in different species habitat. Different species can handle inundation in different lengths. Species on the outer edge can survive shorter inundation periods and species closer to the inner part of the pools can handle longer periods of inundation, naturally.

After topography of the site is completed, introduction of vegetation and invertebrate species should be your goal. Vegetation as a food source and as shelter for dabbling ducks is the important goal here. It takes a dabbling duck many days to replenish the reserves it lost in an eight hour flight period so shelter and food species in the vernal pool are top priority. There should be a variety of natural grasses that are planted around the edges of the pools for habitat and some food. Because dabbling ducks are migratory birds, they can work with a variety of species. Colusa grass is an example of native grass that could be planted as good nesting material. The logical percent cover that the grasses should be planted as should be around 50%. Other plants such as spike rush and native forbs should be planted on about 30% cover rate. Leaving some area of the pool edges open should be done in order to allow for expansions of species. This may leave room for invasive species which is why monitoring of the site should be conducted. Transplanting would most likely give the species the best chance of survival, if the seeds have been grown in site-like conditions with comparable soil quality, pH, and soil salinity. If seedlings of wanted species are not available, seeding will have to be accomplished by some other mechanism of planting. Because seed sources vary, it is important that the source of the seeds picked to be planted in the vernal pool site come from like areas. This will ensure that they are suited for the habitat they are planted into. Transplants are another way of accomplishing this goal. If the transplants are, as before, from like areas of habitat, and are harvested sustainably.

Introduction of native invertebrates to the pools will also be a major goal. Species like fairy shrimp, vernal pool snails, and native insects should be top species for restoration. Many species are distributed naturally, so key species, like those listed should be introduced to further their numbers. It is a problem however on the allocation of these species. Because some species are endangered, their source should be selected very carefully. If at all possible choose sources that are sustainable and possibly implement farmed species, but only if those said species are farmed in environments such as those in the site. Otherwise, the species will not be able to adapt to the new conditions and will not survive.

It is possible that certain problems will occur with the restoration. Events such as complete failure of establishing a species or low survival rate of a species may happen. In these events, a team should be assembled to assess the root of the problem for establishment. There may be problems such as soil quality or nutrition availability. In either event, the assessing team should determine what the problem may be and develop a plan to correct it. Within that plan, parameters of other species should be considered. I.E. if multiple species will be harmed in order to establish one species it may be necessary to step back and address if restoration of that species is imperative. There will be no utopian solution for all species. But if all possible try and accomplish through further attempts to encourage and foster the restoration that has already occurred.

Monitoring of the site should be a major part of the restoration plan. Immediately after restoration constant monitoring of the site will be necessary. In the first initial months following restoration, monitoring of 1-5 times per month will be needed to ensure that proper species establishment is occurring. If establishment is not going well refer to the information above as possible re-introductions of species may be necessary. If establishment succeeds an initial period of six months, monitoring may slow down to possibly once a month for up to one to two years. At this point, the vernal pool should be well established and monitoring should continue at rates of a few times a year in order to assess disturbances that may start occurring to the site. If disturbances do occur, address them by taking similar actions as above: assess, plan, implement.

At this current moment, there is very little research on the actual intricacies of dabbling ducks and their use of vernal pools. Much research is pointed towards wetlands and the ducks use their. Further vernal pool research should surely encompass dabbling ducks and their use of vernal pools and the minor details that may coincide with it. With greater knowledge of preferred habitats and food sources, restoration of vernal pools will be more factual instead of trial and error procedures. It is most likely that during restoration, problems will arise, regarding dabbling ducks, or any other species that may be the key species for restoration. When this happens, it is very important to step back from the situation and address the problem. Assess the cause or causes that occur, plan accordingly, and implement a plan of attack that will be most likely succeed for multiple species, not just one.

Part III: Synthesis of Goal with Class Scope in Mind

Dabbling ducks, because they are migratory, are able to adapt to variable conditions more so than some other species. Species such as endemic fairy shrimp have specific needs of pools in temperature, pH, salinity, etc. Dabbling ducks do utilize vernal pools as vital stops during migration to replenish and also in spring time as nesting habitat. Native plant species restoration goals coincide with dabbling duck needs because of their ability to cohabitate. Dabbling ducks use these species as shelter and nesting material, and in the case of some species, food, and in return help in their distribution. Dabbling ducks may be harmful to some invertebrate species which may be listed but in most cases, eradication of endemic species hardly occurs and will eventually plateau in a predator-prey relationship. The goals outlined in this case were determined prior with other species in mind. To ensure a successful restoration, multiple species need to be thought of, and the goals outlined in this paper should encompass a majority of species in a positive manner.

Dabbling Ducks and Vernal Pools Fact Sheet

1.) What Are Dabbling Ducks?

- AKA Pond Ducks
- Feed at the Surface, not by diving
- 50- 60 species in 8 different Genera
    - Mallard, Teal, Widgeon, etc

2.) Dabbling Duck Needs

- Different times in life cycle = different needs
- Migration, Molt, Maintenance
- Different species

3.) What Dabbling Ducks Use Vernal Pools For

- Fall Migration
    - Resting place
    - Replenish Reserves
    - Day use
- Spring
    - Food
    - Shelter
    - Reproduction

4.) Energy Needs

- Usually eat seeds and grasses

-Willow smartweed, Spikerush, Watergrass

- But in spring switch to diet with invertebrates included

-Such as snails, crustaceans, analids

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Special Status Native Plants

Amy Brasch

ENH 160

3 June 2010

Solano Grass

Background & Justification

Solano grass, also referred to as Crampton's tuctoria and *Tuctoria mucronata*, has been considered an endangered species since the late 1970s. It is listed in both the Federal and the State endangered species list. Most of the original Solano grass sites have been destroyed by farmland creation and the construction of the Monticello Dam in Napa County (U.S. Fish and Wildlife, 2009). In the past decade, it has only been spotted in three locations (although some reports say different), all of which are located in Yolo and Solano County.

Having only been spotted in the northern California Central Valley, this endangered species main habitat is the Yolo Bypass Wildlife Area and Jepson Prairie; both of which are within only twenty minutes from Davis. Creating favorable vernal pool conditions for Solano grass will also help other endangered species found in northern California vernal pools, such as Colusa grass and alkali milk-vetch (Yolo Conservation, 2009). Another interesting fact about Solano grass is that it can only thrive in alkaline vernal pools with presence of salt. Solano grass exhibits a single-cell C_4 synthesis that is unique amongst grass; it is found in only .003% of all C_4 plant species (U.S. Fish and Wildlife, 2009).

Solano grass has been listed on the Federal endangered species list since 1978 and on the State endangered list since 1979 (California Department, 2008). The state listed it as having a population of less than 1,000. It is now limited to only two counties: Yolo and Solano. My target goal is to increase the overall population by protecting and creating more alkaline vernal pools. It is critical that we focus on improving the growth rate if this species is to avoid extinction.

Solano grass' habitat was once abundant in areas throughout Yolo, Solano, and Napa County. The fairly recent construction of the Monticello Dam and increasing farmlands have already destroyed several of the remaining sites, making it unlikely that Solano grass will ever re-establish there again .

Listed under the endangered species act (ESA), any modifications made to the Solano grass habitat are drastically limited to the conditions and regulations specified in the ESA. The state forbids, by law, the removal of any endangered species without special permission.

Funding

CalFed gave Yolo County a generous grant in 2002 to conduct research about management, restoration, and recovery plans. Yolo County also received funding from the Bureau of Reclamation (BOR) to specifically create addition alkali vernal pools in the area. The California Department of Fish and Game invested millions into the creation of the Yolo Bypass Wildlife Area. I believe the predominant potential funding is provided by the State. The amount of research and habitat construction can be extremely costly.

Goals and Management Plans

There are several impeding threats that exist which constrain the Solano grass's survival. The combination of habitat loss, invasive species, and agricultural runoff deposit accumulate to create an immense amount of stress on the endangered Solano grass. I devised three management plans to help decrease and/or diminish the immediate threats on this species. With proper management plans set in place, the chances of Solano grass being restored will become exponentially higher.

Goal 1: Create Vernal Pools/Protect Current Vernal Pools

Solano grass prefers vernal pool swales because, being a C_4 organism, it has the ability to withstand dry periods for longer (California Department, 2008). However, Solano grass also has the "potential to occur on the pool bottoms, which are otherwise typically sparsely vegetated" once the vernal pool dries out (California Department, 2008). Furthermore, Solano grass also needs alkali conditions to survive. To put it simply, Solano grass requires a very unique habitat with specific soil composition and hydrology patterns. Protecting the basin part of the pool (after inundation) and the swales (during inundation) becomes a key part of this goal. Furthermore, designing more vernal pool and swales could potentially provide additional habitat to Solano grass. The created vernal pools would have to be fairly large, probably no smaller than 500 square meters, and isolated. I estimate 500 square meters because Solano grass generally congregates in larger and deeper pools (Robins and Vollmar, 2002). Considering how Solano grass prefers sparsely vegetated areas, a large portion of funding and attention would have to be directed towards habitat maintenance. Habitat maintenance entails keeping non-native/invasive species out and regular water quality testing to make sure hydrology conditions are stable. However, even if conditions are ideal, the Solano grass population may fluctuate annually. Solano grass has the ability to avoid growth and reproduction when conditions are unfavorable, because it can withstand long dry periods. For example, approximately twenty thousand Solano grass plants were observed in the Yolo Grasslands Park in 2004; however, zero reproductive plants were observed at the same site in 2007 (Yolo Conservation, 2006). This long-term goal of creating/protecting vernal pools comes with a tradeoff requiring a significant amount of time, funding, land, and labor.

Goal 2: Eradicate Non-Native and Invasive Species

Swamp Timothy and perennial Pepperweed are amongst the two top competitors with Solano grass. Both species are highly invasive and reproduce at a fairly rapid pace. However, Swamp Timothy and perennial Pepperweed populations could be drastically reduced with the introduction of two biological controls, waterfowl and cattle. Studies show that by introducing Waterfowl, the overall population and reproduction rate of Swamp Timothy drastically declines (Yolo Conservation, 2009). Additionally, cattle like to feed on Swamp Timothy and Pepperweed. Another perk to using waterfowl and cattle is that they will not consume the Solano grass, because Solano grass produces "sticky pungent exudates that coat the leaves and stems" that deters the waterfowl and cattle from eating it (Robins and Vollmar, 2002). Since Solano grass germinates so late, usually after other plants have died, the pollination and reproduction are minimally affected (Robins and Vollmar, 2002). If limited grazing is performed in early spring, before the Solano grass germinates, then this goal may be an effective method to improving the Solano grass's condition. Allowing grazing strictly before the Solano grass germinates is crucial because it avoids trampling and over-grazing the seedlings. Although Solano grass has the mechanics to avoid herbivores, it still has the possibility of being consumed. Other non-target species may get consumed in the process as well. This goal is small-scale and short-term, but it has immediate effects.

Goal 3: Reduce the Amount of Local Agricultural Runoff

Surrounding the majority of the Solano grass sites are productive agriculture fields. The herbicides, pesticides, and fertilizers used on the crops become surface runoff, which eventually makes its way to the vernal pools. Thus, lowering the overall pollutants in the water and soil becomes a primary goal for Solano grass management. Targeting agricultural runoff is a difficult task, because this type of runoff is a non-point source. Limiting the amount of herbicides the farmers can use is one solution. However, that is a relatively small-scale and long-term goal that will create a lot of opposition with farmers. Increasing the amount of constructed wetlands surrounding the agriculture fields can also be effective, because it takes up a large portion of the pollutants before they even reach the vernal pools. However, the constructed wetlands would have to be positioned far enough away so that they do not take away water from the vernal pool. I would estimate the wetlands should be located at least few miles away from the vernal pool.

Restoration Plan

Considering the extent of how limited the Solano grass distribution and population is it comes as no surprise that this restoration plan would have to be small scale. However, if successful, this restoration plan could spread to a larger scale project by incorporating other potential Solano grass sites. A prime spot to apply this small-scale restoration project would be at the Grasslands Regional Park. When looking at the vernal pool distribution, we see that there is a current population of Solano grass present in Pool 9a and 9b. These pools are ideal habitats for Solano grass because they have a deep depth, pescadero soil, long inundation and dry periods, and a complex topography of vernal pool swales and basin. Another potential site in the same area would be Pool R4. However, Solano grass favors long dry periods and Pool R4 has a relatively short average dry period. Since Solano grass requires such a complex habitat, introducing a restoration plan to the created pools would be the best option. Creating a vernal pool has its advantages because it gives us the freedom to build a customized habitat for the Solano grass. The following is a basic guideline for a restoration plan for Solano grass. It is meant to be a foundation for a specific restoration plan; it should be manipulated to meet the environmental criteria of the particular restoration site. Each individual site needs its own restoration plan devised, because every detail of the restoration process is crucial; there is little room for error when such a small population exists. One mistake could potentially wipe out the entire species.

Methods

Before starting the restoration, a perimeter must be created around the designated site to keep out disturbances (i.e. vehicles) and non-target species. Within the perimeter, there needs to be the vernal pool and a buffer zone, because Solano grass is known to inhabit swales and pool basins. The buffer zone must be large enough to incorporate any potential suitable habitats near the vernal pool. As a rough estimation, I would recommend being extra precautious and place the fence at about 40 meters away from the vernal pool, even though “most regulations require a 32.7 year (30 m) buffer zone around the pool basin” (Manomet Center).

It is important that the Solano grass be grown directly in the habitat. Due to the specific soil composition and hydrology patterns, transplanting a Solano grass seedling could be dangerous. Transplanting should occur only after the plant has developed a strong root system. When transplanted, the energy in the plant relocates from above-ground growth to repairing the root system. The plant must focus on getting the roots established in the new environment before it can focus on further growth. Thus, I suggest transplanting the Solano grass a little bit before the plant reaches maturity.

The Solano grass needs to be planted in small patches with little to no competition. When Crampton discovered the Solano grass in 1958, it was growing in “3 to 8-meter diameter patches” (Yolo Conservation, 2009). Solano grass also prefers sparse vegetation, so the grass should not be planted near other plant species. As a rough estimation, the amount of Solano grass plants in a group should range between 5-10; although, more research should be dedicated to finding the exact size of patches that Solano grass thrives.

Light to moderate manipulated disturbances should occur within the site. These disturbances will be caused from grazing, researchers, waterfowl, and other natural occurrences (i.e. floods, droughts, or fires). Slight disturbance is ideal because it will reduce the amount of competition for the Solano grass. Since the Solano grass has such a late germination period (usually after most other vernal pool species have matured), it will be minimally effected if the timing of the disturbance occurs in the early spring.

Monitoring

The potential site should be monitored for no less than three years before the restoration process is set in place, because we want to take into account the variation between year to year. Water quality needs to be tested at different times of the day and different days of the year. The likelihood of drought, length of inundation, saline level, etc. should all be known prior to the restoration. In addition, the vegetation characteristics and behavior should be known as well. When the other plants flower/germinate, types of species, possibility of invasive species, etc. should all be documented. As a rough estimation, I would suggest gathering at least 15 days of observation during each season. We want to be able to establish a general life cycle of species within the area and note the changes in environmental conditions throughout the year. Recordings should be taken several times a day to get a more specific daily pattern of the area, such as amount of sunlight received and changes in water levels. Ideally, pre-monitoring testing and observing would have equal intensity. However, a heavier focus during the later summer months (during Solano grass germination and growth period) could provide the most crucial information.

Heavy monitoring should be continued into the first five years of re-establishment. A minimum of five years is required, because Solano grass populations are known to fluctuate yearly. If the population does not persist after five years and the population is still declining, then we need to figure out if there is an external factor limiting the Solano grass's growth. We can perform a comparative analysis between other Solano grass populations to determine any differences in nutrient levels, water pH, amount sunlight, temperature average, etc. Another option would be using the pre-monitoring data from the site prior to reestablishment to see if we can locate a particular stressor. Once the problem is targeted we can move on to fixing it. If the problem is too massive (i.e. soil composition is not compatible), then we must find a different site for reestablishment. If the worst case scenario was true and the restoration is considered a "failure", it is still important that the site be periodically monitored, in case a Solano grass seed decides to germinate at a much later time. It must be clearly determined that there are no chances of germination before we can fully declare the restoration project a failure, which is difficult to determine with germination patterns like Solano grass. Solano grass needs ideal conditions and a long period time to establish itself before a steady population can occur regularly, making this a long-term management plan. Once the population reaches a steady yearly increase from the initial amount introduced, mostly likely over the span of a few decades, we can slowly ease off the heavy monitoring into periodical monitoring.

Potential Problems

The spread of invasive species, mainly Swamp Timothy and Pepperweed, is the primary problem we may face. If the population of invasive species is small enough, we can remove by the plant hand, thus ensuring the roots are removed as well. If populations are larger, then we must turn to grazing or potential herbicides. However, the effects of herbicides on Solano grass must be researched before implementing.

Agriculture runoff is another potential problem that may alter the habitat conditions. Monitoring amount and time when herbicides are used in the neighboring fields becomes crucial in the pre-monitoring phase of this restoration. Ways to deal with runoff should be embedded within the management plan from the beginning. However, if sudden and extreme changes occur in the water quality, we may need to plant certain wetland species, compatible with Solano grass, to take up some of the pollutants and toxins. Although, we have to be sure that the constructed wetlands do not alter the vernal pool's water availability.

Risks and Uncertainties

There is no guarantee for success, even in the ideal habitat. Vernal pool characteristics tend to change annually. Thus, a strong population must be established to withstand these unexpected changes, such as droughts or floods. This restoration calls for investing an immense amount of time, funding, and energy to one species that may not even take to the habitat. The distinct habitat required by Solano grass is extremely hard to replicate.

Questions and Understanding

Prior to the restoration, we need to understand the reasons why other Solano grass restoration projects failed. We need to be aware of stressors and competitors, so we can sense the threats before they become a major problem to the site.

In any case, this restoration project can tells us an immense amount of information, even if it is not successful. After completing the project, we can answer questions such as: what worked with our restoration plan? What did not work? What led to failures and/or successes? How were stressors avoided or dealt with? What made this habitat layout more or less suitable?

Potential for Multiple Goals

Solano grass grows at the bottom and swales of clay-pan vernal pools with saline conditions, a habitat which is unfavorable to most plant species. When researching Solano grass, I found a few research studies that mentioned finding Colusa grass in the same area as Solano grass. When discussing our species in class, I found that Colusa grass not only shares the same habitat conditions, but it faces the same threats as well: invasive species (Swamp Timothy and Pepperweed), overgrazing, and possibility of extinction. Seeing as they are both from the same family (Poaceae family), it comes as no surprise that they may be compatible with each other. When creating habitats for Solano grass, as recommended in my management plan, it would be wise to incorporate Colusa grass as well. Maintenance of the two species will be simple since they share the same threat of invasive species. By doing integrating the two species into the restoration project, we provide a habitat for two endangered/threatened species for the price of one, creating a win-win situation. Alkali Milk-Vetch, which is in the Fabaceae family, also shared similar habitat requirements. However, Alkali Milk-Vetch faces different threats and disturbance patterns than Solano grass. It also has a completely different flower and inflorescence characteristics compared to Solano grass. The Alkali Milk-Vetch is listed as a species of concern, so it wouldn't hurt to run a trial and see if it is compatible with the habitat. To accompany Colusa grass and Alkali Milk-Vetch into my management plan, the restoration would need more space because we do not want the species competing against each other for resources. Additional funding would be required to supply the extra labor of transporting, planting, and monitoring the extra plants. The cost of these additional needs would be relatively inexpensive, compared to funding a completely separate restoration project.

Amy Brasch

Fact Sheet

Species Name: Crampton's tuctoria

Common Name: Solano Grass

Genus: Orcuttia

Family: Poaceae

Status: Endangered (State and Federal)

Species Characteristics

- Discovered in 1958 in Solano County by Beecher Crampton
- Characterized as a small, annual plant in grass family
- Height ranges between 1-5 inches
- Contains yellowish-green leaves covered with a sticky, fowl-tasting fluid that wards off herbivores. The fluid dries as the plant matures and turns brown.
- Grows on the bottom of drying alkaline vernal pools, preferably areas with notable amounts of sodium and boron salt
- Solano grass tends to grow late in the summer, April - September, which is later than most other vernal pool plant species
- Holds the potential to germinate in dry conditions because of its C_4 composition, which photosynthesizes more CO_2 with less energy
- Distribution limited to the northern Central Valley in California, primarily Jepson Prairie Preserve and Yolo Bypass Wildlife Area

Justification and Purpose

- 1 of 15 species endangered species that require similar alkaline vernal pool habitat, including Colusa grass and Alkali Milk-Vetch
- Feasible recovery due to the vast amount of information & research available on this species
- Exhibits a single-cell C_4 synthesis that is unique amongst grass, found in only .003% of C_4 plant species
- It has been listed since 1979 under California Native Plant Society's list 1B, placing it under the highest endangerment rating possible

- The fairly recent construction of the Monticello Dam and increasing farmlands have already destroyed several of the remaining sites, making it unlikely that Solano grass will ever re-establish there, thus conserving the current inhabited areas is crucial

Constraints

1. *Highly Specific Habitat:* Crampton's tuctoria requires concise habitats with little room for variation. This species occurs on vernal swales during inundation period and occurs on bottom of vernal pools after inundation. The ideal habitat for Crampton's tuctoria consists of: fined grained clay-pan soils, alluvial soils, high salinity, turbid surface water, limited nitrogen, and limited sunlight.

2. *Timing of Germination:* With the effects of global climate change, vernal pools are drying up earlier, significantly decreasing the window of opportunity Solano grass has to germinate.

3. *Invasive Species*: Swamp Timothy and perennial Pepperweed, both highly invasive species, are taking over primary habitats

4. *Agriculture:* Nearby farms create pesticide and fertilizer runoff into the nearby waterways, which eventually seep into the vernal pool water system. Additionally, the habitat destruction caused by creating agriculture fields has decreased the available area.

Current Management Efforts

- In 1990, the Nature Conservancy reduced the amount of invasive species in Jepson Prairie Preserve using herbicides & mechanical removal
- In 2007, Yolo County launched a Swamp Timothy eradication program
- Reintroducing more waterfowl into the critical habitat areas proved to be a successful biological control method for invasive species
- Research conducted by Dr. Jaymee Marty provides information on grazing in vernal pools and inundation periods in the Central Valley region, however, grazing practices have not been formally implemented into the management plans for Crampton's tuctoria (U.S. Fish, 2009)

Literature Review

Key Species Characteristics:

- "Crampton's tuctoria (*Tuctoria mucronata*) are small, annual plants in the grass (Poaceae) family" (California Department, 2008).

- "Leaves are yellow-green and covered by a sticky aromatic fluid that dries as the plant matures" (Yolo Conservation, 2009).

- "Solano grass (*Tuctoria mucronata*), also commonly known as Crampton's tuctoria, is an annual grass ranging from 2 to 12 cm (1 to 5 inches) tall" (Yolo Conservation, 2009).

- Solano grass has the ability to withstand dry periods for longer; in other words, it germinates a few months after most other vernal pool vegetation germinates (California Department, 2008).

Key Habitat Requirements:

Hydrology and soil plays major role:

- *"…* have the potential to occur on the pool bottoms, which are otherwise typically sparsely vegetated. Vernal swales, because they hold water for relatively short periods of time, typically contain a mix of species found in both vernal pools and annual grasslands" (California Department, 2008).

- "It is restricted to areas within alkaline vernal pools that have sodium and boron salt affected soils and to similar salt affected areas in alkaline playas" (Yolo Conservation, 2009).

- "Williamson et al. (2005) and Rains et al. (2008) summarized the situation well with regard to parent material: 'The vernal pools on clay-rich soils formed on alluvium derived from sedimentary and metasedimentary rocks of marine origin. The soils that developed on these sediments are fine grained, saline, and sodic. These soils support vernal pools that are perched surface water systems, have relatively saline, sodic, and turbid surface water, and may be nitrogen and light limited.' Other studies have confirmed the nitrogen and light limitations (Barclay and Knight 1981)" (Yolo Conservation, 2009).

Broad Distribution Patterns:

- "When Crampton discovered the Solano County population in 1958 it was only growing in three 3 to 8-meter diameter patches in areas with cracked soil that were covered by a brownish film and was not growing on the smooth white areas that covered most of Olcott Lake" (Yolo Conservation, 2009).

Interactions with Other Species:

- "Developing a refined grazing plan for the vernal pool areas throughout the Tule Ranch is a high priority for future management and will most certainly focus on the management of the nonnative Italian ryegrass" (California Department, 2008).

- Immediate threats to Solano grass in Yolo County are primarily due to the invasion of its habitat by swamp timothy (*Crypsis schoenoides*) and perennial pepperweed (*Lepidium latifolium*) (Environmental Science Associates 2005). There are no known effective management tools for reducing the impacts of swamp timothy but in 2007 Yolo County began a long term perennial pepperweed eradication program that has proved to be effective" (Yolo Conservation, 2009).

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Ella Ver

4/22/10

ENH160

Part 1

Colusa Grass, *Neostapfia colusana*

Goal: To conserve existing populations and increase number of individuals of Collusa grass.

A. Background and Justification for Goal: Populations of *Neostapfia colusana* should be maintained for the following reasons.

1. **Status:** *Neostapfia colusana* has been federally listed as threatened since 1997. It has been listed as endangered by the California Department of Fish and Game since 1978. Additionally, the California Native Plant Society placed it under category 1B which means it is rare or endangered throughout its range (US Fish and Wildlife Service, 2008).

2. **Limited Range:** Colusa grass has a naturally very limited range. From 1898 to the 1950's this species has been sighted only in Merced and Stanislaus counties. As of 2009, critical habitat for Colusa grass lies in counties: Solano, Yolo, Merced, Meriposa, Stanislaus, and Tuolomne. However, the critical habitat is concentrated in Merced and Stanislaus counties (US Fish and Wildlife Service, 2008).

3. **Uniqueness:** Colusa grass is a member of the *Poeceae* (grass) family and is the only member of the *Neostapfia* genus. It is in the Orcuttieae tribe which consists of genera: *Neostapfia, Orcuttia,* and *Tuctoria.* All members of this tribe are endemic to California vernal pools. Members of this tribe share characteristics that are different from those of most other grasses, however, the overall appearance of *Neostapfia colusana* is unique and thus, easy to distinguish from other grasses.

4. Reasons for Decline: Currently, the biggest threat to populations of this species is conversion of vernal pool land to agricultural land. The second biggest threat is conversion of vernal pool habitat to urban land. Many sites are also damaged by water contamination. For example, occurrences in Yolo county have been damaged by herbicide application and ground water contamination by industrial chemicals (FWS, 2003).

Changes in natural hydrology are also among the factors leading to species decline because they change periods of inundation. These changes include draining pools, creating reservoirs, and preventing site flooding.

Livestock grazing is another reason for Colusa grass decline. Increased grazing intensity and summer grazing can threaten Colusa grass, however, moderate spring grazing has not posed a problem. Sheep grazing is compatible with Colusa grass, but only if sheep are removed before the grass starts growing. Sheep trampling of seedlings is detrimental to the Colusa grass populations. Herbivorey by grasshoppers has been observed on Colusa grass, however, the extent of its damage is unknown (FWS, 2003).

Additionally, several exotic invasive species are competing with Colusa grass. These species are swamp timothy, perennial pepperweed, and Lippa. These are swamp species that compete with Colusa grass for habitat. More research needs to be done to fully understand how to eradicate these species and the exact effect they have on Colusa grass (Yolo national heritage program, 2009).

Some other factors leading to the decline of this species are loss of habitat and fragmentation of habitat due to: Changes in hydrology caused by drainage of ponds and runoff from surrounding land uses. Lack of regulation and maintenance can lead to invasive species taking over. Exclusion of grazing where it is needed and over grazing can lead to loss of natives and compaction of soils. Contamination by poultry feces can add harmful bacteria to the vernal pool ecosystem (Fish and Wildlife Service, 2004).

5. Recovery Plan and 5 Year Review: The US Fish and Wildlife Service lists *Neostapfia colusana* as Recovery Priority category 2C. The highest Priority category is 1 while the lowest priority is 18. The rating for Colusa Grass indicates that is is a high priority species with high degree of threat, high recovery potential, and recovery needed of full species. The recovery plan recommends that 90 percent of occurrences of the species in its natural area be protected, however, acreage of suitable or protected area within species native range has not yet been estimated. Therefore, percentage of native habitat protected cannot be calculated. However, as of 2008, 43 occurrences of this species within its range have been recorded and only 5 of these are in protected areas.

The recovery plan recommends reintroduction of Colusa Grass into areas in the counties of San Joaquin, Colusa (where the species is apparently completely eradicated), and appropriate sites in the Fermington area. Colusa grass has not been reintroduced to any of these areas (US Fish and Wildlife Service, 2008).

6. Population Growth Trends: According to the US Fish and Wildlife Service, species numbers have been decreasing since discovery in 1898. During the 1980's many new populations were discovered due to extensive surveying. In 1989, 40 occurrences were extant and 11 were extirpated. In 2002, 48 occurrences were believed to be extant. In 2008, 43 occurrences were believed to be extant (US Fish and Wildlife Service, 2008).

Laws and Policies that are Protecting the Goal:

1. The California Endangered Species Act (CESA): All native plants and animals and their habitats, which are threatened with extinction or in danger of declining in their native habitat shall be protected or preserved. Collusa grass is listed as threatened, so it should be covered by this law.

2. California Environmental Quality Act (CEQA): Requires local public agencies to identify the environmental impacts of a proposed project, to determine if they will be significant, and to propose alternatives and mitigation that will lessen the damage. Requires agencies to take Collusa grass into consideration when constructing a new project.

3. Endangered Species Act (EPA): The federal government is required to protect threatened and endangered species and their critical habitat. This includes national and international species.

4. National Environmental Protection Act (NEPA): This act requires federal agencies to incorporate environmental quality and protection into their policy making. The act also requires federal agencies to prepare Environmental Impact Statements.

5. Clean Water Act (CWA): This act aims to restore and maintain the biological, physical, and chemical integrity of the nation's waters by preventing point and nonpoint pollution sources. This act may help maintain Collusa grass habitat by protecting vernal pools and their water sources.

7. Native Plant Protection act: Its purpose is to protect, preserve, and enhance native plants of California. Collusa grass is a native plant to California, so it is protected under this act.

8. Lake and Stream-bed Alteration Program: Determines whether an agreement is needed for an activity that will modify lake or stream-bed areas. The agreement includes conditions necessary to protect these resources. It must comply with CEQA .

Possible Funding Opportunities:

1. The California Society of Ecological Restoration (SERCAL): A non profit organization dedicated to bringing about the recovery of damaged California ecosystems (SERCAL, 2009).

2. California Ecosystem Restoration Program, CALFED Bay Delta program. Implemented by California Department of Fish and Game, US Fish and Wildlife Service, NOAA'S National Marine Fisheries Service (California Department of Fish and Game, 2009).

3. The Doris Duke Charitable Foundation: The mission of the environmental branch of this Foundation is to preserve native wildlife in the United States. This includes both flora and fauna. The foundation aims to accelerate the protection of essential wildlife habitat by working with federal and local governments (Global Restoration Network, 2009).

4. Wildlife Forever: The mission of this foundation is to conserve wildlife through conservation education, preservation of habitat, and management of fish and wildlife (Global Restoration Network, 2009).

B. Literature Review:

Plant Characteristics of Orcuttieae tribe: Colusa grass is a member of the Orcutt grass tribe. Members of this tribe share characteristics that are different from most other grasses. For instance, most other grasses have hollow stems, however members of the Orcuttieae tribe have pith filled stems. Members of this tribe also produce two or three different types of leaves during their lifespan, while most other grasses produce only one type. The juvenile leaves of the members of this tribe form under water and have a cylindrical basal rosette. After the pool dries, terrestrial leaves form. These are flat and grow along the stem. Members of this tribe also lack a ligule, which is a leaf appendage found on most grasses. Additionally, all members produce an aromatic exudate which most likely repels herbivores (Sacramento Fish and Wildlife Service, 2009).

Range: All members of the Orcuttieae tribe, including Colusa grass, are annuals, endemic to vernal pools, and pollinated by the wind. Locally, seeds are carried by water and long distance dispersal is unlikely. It is not known how long the seeds of these plants can remain dormant, but the time frame is no less than 3-4 years. After their dormancy, the seeds germinate under water. Members of this tribe flower during the summertime. Their seedbank is estimated to be at least 50 times larger than the existing population at a particular time. In general, years of increased rainfall promote larger populations of these species. Many years of monitoring are required to determine if populations are in tact because numbers of individuals change greatly from year to year and sometimes no mature individuals are present (Fish and Wildlife Service, 2004).

Neostapfia colusana Appearance: Some characteristics of Colusa grass show fewer adaptations to the aquatic habitat and indicate a more primitive evolutionary position than other members of the Orcuttieae tribe. The appearance and inflorescence of Colussa grass are unique and easily distinguishable from most other grasses.

The aquatic stage of this plant has only one or two juvenile leaves while the terrestrial stage has multiple stems arising from a single root system. According to Gerlach and contrary to other sources, the young plants produce a long floating basal leaf when submerged in shallow water. Stem length ranges from 10 to 30cm and stems are zigzaged. Lower portions of the stems lie on the ground while the upper portions of the stems are vertical and terminate in spike-like inflorescences that resemble corn ears. Young plant color is blue green, but the plant produces exudate that hardens as the plant matures. The exudate makes the plant color more brown as it matures. Leaf length is 5-10 cm.

Inflorescences are 2-8cm long and are produced by each stem (Sacramento Fish and Wildlife Service, 2009). These are dense and cylindrical. Within each inflorescence, spikelets are packed in a spiral fashion. The grains are typically 2.5mm long and are coated with exudate (FWS, 2003).

Neostapfia colusana Life History: Seeds of Colusa grass take approximately 3 months to germinate after inundation and are expected to germinate in late spring. Plants flower 3-4 weeks later in early summer. The plants are self compatible and can produce seed without cross pollination (SCWA). Reproductive and survival rates of this species have not been monitored, but population size varies wildly from year to year (Fish and Wildlife Service, 2004).

This species is wind pollinated, but seeds are not likely carried a very long distance. Locally, the seeds are dispersed by water, which breaks apart the inflorescences. Although long distance dispersal is uncommon, occasionally seeds may have been carried by water fowl, tule elk, or pronghorn. (FWS, 2003)

Colusa grass possesses C_4 photosynthetic biochemical pathway which is adapted to low carbon dioxide levels in vernal pool water. However, O_2 and CO_2 concentrations are constant in turbid vernal pools. The most likely explanation to the C_4 pathway is that it is an adaptation to water and salt stress these plants experience while growing in saline heavy clay soils (Garlach, 2009).

***Neostapfia colusana* Range:** This species occurs on the rims of alkaline basins in San Joaquin and Sacramento valleys. It also occurs in acidic soils of alluvial fans and stream terraces of San Joaquin valley and nearby foothills. Elevations of known population sites range from 18ft to 350 ft. Populations have been found in Northern Claypan and Northern Hardpan vernal pools surrounded by rolling grasslands. Colusa grass grows in pools ranging from .02 acres to 617.5 acres in size. It also grows in intermittent streams and artificial ponds. It typically grows in the deepest portion of the pool, but can also occur in the margins. Deeper pools may be more hospitable habitats for this species because it needs a longer inundation time.

Neostapfia colusana grows in several different types of soils including: clay, silty clay, and silty clay loam (Fish and Wildlife Service, 2004).

Usually, Colusa grass grows in single species strands. Associated species with Colusa grass are species that grow in nearby strands at the same time as Colusa grass. In acidic soils associated strands include ***Eryngium*** spp., ***Eremocarpus setigerus***, and *Plagiobothrys stipitatus.* In saline or alkaline soils associated strands include *Frankenia salina* and *Distichlis spicata* (Fish and Wildlife Service, 2004).

Gaps in Knowledge: Environmental triggers that allow the species to respond to yearly climate variations need to be studied more in detail, particularly for understanding germination and reproduction. This would be helpful to know in cases or reseeding areas or germination in labs. Additional information that would help in management of this species includes seedling survival rates, impact of swamp timothy, factors controlling seed production and dispersal (Yolo national heritage program, 2009).

Management Goals Part II, Colusa Grass

Colusa grass (*Neostapfia colusana)* is one of the two plant species in Grassland Park that is federally listed as threatened. Listed are several goals aimed at the upkeep and possible increase of the Colusa grass population in Grasslands park.

Part I

Main Goals (method will be explained in part II)

- Protect Colusa grass populations in Grasslands Park.
  - Currently populations have been found in pools 9A and R4. They must be protected because according to the US Fish and Wildlife service, populations have been in decline since the species was discovered in 1989.
- Enhance Colusa grass population in Grasslands Park through management practices and preventative measures.
- Ensure long term stability in Colusa grass populations.
  - Many specifics about species internal cues and habitat needs are still unknown. To protect Colusa grass populations, we must determine what they need.

Part II Colusa Grass management plan

1. Controlling weed populations:

- Species such as perennial pepperweed and swamp timothy compete with Colusa grass. Controlling them will open up new patches for Colusa grass.

IX. Short term goal: conduct weeding in and around vernal pools preferably before weeds set seed.

X. Long term goals: drastically reduce weed populations sizes by weeding, grazing, and limited herbicide application.

   A. According to ENH 160 lab, pepperweed was not mentioned as one of the threats to pools R4 and R9a. However, weeding must be conducted in other pools which have this problem, as a preventative measure.

XI. Indicator of success: reduced numbers of weeds in and around vernal pools, with numbers decreasing ever year.

XII. Herbicide application

A. Colusa grass is sensitive to changes in water quality, so avoid using herbicides in or around vernal pools where it may exist.

B. In the past experiments have been conducted on reducing perennial pepperweed populations. One study found that cutting the stems and then painting Rodeo on them lowered their numbers (Yolo Country, 2005).

1. Particularly effective at reducing density of flowering stems, however it was not effective at reducing density of rosettes.

2. Further research needs to be done using this experiment to see how this herbicide application effects native species and water quality before it is applied to vernal pools with Colusa grass.

XIII. Grazing

A. Sheep grazing has been compatible with Colusa grass, but only if done before new plants sprout in late spring.

B. Moderately graze vernal pool areas in spring, preferably with sheep, before pepperweed sets seed, and before Colusa grass seedlings sprout.

C. Avoid grazing during the summer.

XIV. Hand Weeding

A. Use this method in vernal pools, especially in pools R4 and R9a, where current populations exist.

2. Conduct annual monitoring of populations

- To gain further understanding of population trends, of species habitat cues and triggers, and to measure how management practices are effecting the species.

X. Short term goal: Monitor population sizes each year

    A. Mapping their location with GIS and GPS devices

    B. Counting number of individuals

    C. Collecting tissue samples from both populations

        1. Must be proportional to population size to prevent over harvesting.

XI. Long term goal: Monitor population size each year for at least 15 years because population sizes vary widely each year.

    A. Graph population trends over time.

3. Collect seed samples from populations

B. Collect seeds in late summer, before rains begin.

C. Collect seeds in proportion to population size to prevent over harvesting.

D. Use some of the seeds for research.

E. Store some seed as insurance in case a population dies out.

4. Monitor vernal pool physical characteristics

C. Measure hydrological mechanisms each year in pools 9A and R4.

    A. This includes pool size, pool shape, inundation periods, connectivity between pools, monthly timing of these aspects.

    B. Frequency of each measurement depends on the specific data.

D. Measure climate each year

E. Measure water chemistry.

    A. pH, conductivity, salinity, dissolved oxygen levels, etc

5. Establish a population in created vernal pools.

- This will help to establish and refine guidelines for future created vernal pools.

- It will determine if population exists in created pools
- Indicator of success: stable numbers of individuals in created vernal pools
    - As pools dry, count individuals
    - If individuals do exist:
        - Monitor their numbers as in pools 9A and R4.
        - Note they exist and what aspects of created vernal pools were successful.
        - This will help in construction of future vernal pools.
    - If individuals do not exist:
        - Further research is needed to figure out exact reasons.
        - Note particular aspects that were not successful to avoid in future restoration projects.
        - Fix problem and re-seed.

6. Use data collected on population size and data collected on vernal pool characteristics to look for environmental cues.

VIII. Use collected vernal pool characteristic data in conjunction with population trends to figure out environmental ques.

A. Some data is still missing in regards to environmental cues of Colusa grass, by observing the species growing in this habitat and monitoring them, we may be able to discover some more of its needs.

- graph and analyze information to look for trends and correspondence between climate, pool characteristics, and population sizes.

6. Protect and enhance vernal pool hydrology.

- Colusa grass needs 3 months of inundation, any changes leading to shorter inundation periods threatens the species.

B. Avoid walking or driving on inundated vernal pools.

C. Avoid construction in or around vernal pools.

- Protect connections between pool 9A and 9B by fencing connection off.
- Protect connections between pool R4 and R3.
- Research water sources for pool R4, runoff from nearby road and farmland could be a major contributing water sources, however, they may also be major polluting sources.
    - It is worth it to re-grade the site in order to prevent runoff from these facilities from coming into vernal pools?
    - Or, will it harm individuals by shortening the inundation period of the pool?
    - Is there a way to filter runoff before it reaches the vernal pools with the endangered species in them?
        - further research needed for all these questions.

7. Use adaptive management

- Long term goal: use data collected from experimentation and monitoring on site to direct future management of species.
- There are many unknowns in this management plan, it relays on research and monitoring for improvement.
    - Change management practices as we learn from research.

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Colusa Grass (*Neostapfia colusana*)- Fact Sheet

Colusa grass small annual grass (Poaceae family) found in vernal pools around the Central Valley. It is federally listed as threatened. It is a member of the Orcuttieae tribe.

Orcuttieae tribe: (Colusa grass is one member of this tribe)

- All are annuals, endemic to vernal pools of California, and pollinated by the wind.
- Locally, seeds are carried by water and long distance dispersal is unlikely.
- It is unknown how long seeds can remain dormant, but the time frame is no less than

3-4 years.

- Seeds germinate under water and plants bloom during the summertime.
- The Seedbank is estimated to be at least 50 times larger than the existing populations.
- Most other grasses have hollow stems, but Orcutt grasses have pith filled stems.
- They produce two or three different types of leaves during their lifespan.
- **The juvenile leaves of this plant form under water and have a cylindrical basal rosette. After the pool dries, terrestrial leaves form. These are flat and grow along the stem.**
- All members produce an aromatic exudate which most likely repels herbivores.

Specific Characteristics:

- Seeds take approximately 3 months to germinate after inundation and plants flower 3-4 weeks later, in early summer.
- Individuals can self pollinate.
- Aquatic stage has one or two juvenile leaves, while the terrestrial stage has multiple stems arising from a single root system.

Habitat:

- Species occurs on the rims of alkaline basins in San Joaquin and Sacramento valleys. It also occurs in acidic soils of alluvial fans and stream terraces of San Joaquin valley and nearby foothills.
- Populations have been found in Northern Claypan and Northern Hardpan vernal pools.
- It typically grows in the deepest portion of the pool, but can also occur in the margins.
- Usually, Colusa grass grows in single species strands.

Threats:

- Habitat loss due to conversion of vernal pool land to agricultural urban land.
- Water contamination by herbicide application, industrial chemicals, feces, etc.
- Changes in hydrology alter inundation periods.
  - These changes include draining pools, creating reservoirs, and preventing site flooding.
- Grazing can be compatible with species if done moderately and during the spring. Before seedlings emerge in early summer.
- Competition from exotic species such as swamp Timothy.

Opportunities for Conservation and Restoration:

- Protecting more areas in which populations exist.
- Finding and applying compatible grazing regimes.
- Little is known about environmental cues and needs of this species.
  - Further research on germination and reproduction environmental cues, dispersal, and seed production is necessary.

My Sources:

Yolo Couny Planning and Public Works Department, ESA. "CALFED At-Risk Plant Species, Habitat Restoration and Recovery, and Non-Native Species Management ERP-02-P46: Final Restoration plan."October 2005.

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Alkali Milk-Vetch

Laura Forlin
ENH 160
Spring 2010

The goal of this project is to establish viable populations of Alkali Milk-Vetch (*Astragalus tener* var. *tener*) at our restoration site at Yolo County Grasslands Park Vernal Pool Complex. Alkali Milk-Vetch, an herbaceous annual, was found to be widely distributed throughout the San Joaquin and Sacramento Valleys and the San Francisco Bay Area 100 years ago (Barneby, 1964). As of 2005, Alkali Milk-Vetch was observed in only 5 of the 13 counties it had previously been observed in (Yolo Natural Heritage Program, 2009). Alkali milk-vetch is a species of federal concern and is listed by the California Native Plant Society as rare or endangered in California and elsewhere (CALFED, 2005). We hope to restore the Yolo County Grasslands Park Vernal Pool Complex to support Alkali Milk-Vetch (as well as other endangered species) to the point that it is able to sustain stable populations with minimal human intervention.

Literature Review

Life History

Alkali Milk-Vetch, also known as Slender Rattle-Weed, is in the Fabaceae family (the pea family). As many plants in the Fabaceae family, they are nitrogen fixers, which may lead to increased nitrogen levels in the surrounding soils. It is an herbaceous annual that generally grows 2 to 16 inches tall. It has been differentiated from a closely related species, *Astragalus tener* var. *Ferrisiae* based on differences in leaf and fruit morphology (US Fish and Wildlife Service, 2005). Flowering occurs from March to June (Skinner and Pavlik, 1994). They have been found to be self-compatible, however in crossing studies done by Liston (1992) there appeared to be high levels of out-crossing and it is thought that butterflies may be the insect pollinator involved. The exact pollinator is not known, so the specificity or generality of the pollinator cannot be determined at this time.

There is limited data on germination requirements for Alkali Milk-Vetch. In a study by Witham (1990) there was an observed increase in population size after an area was disturbed for a pipeline installation at Jepson Prairie Preserve. At another site near Albrae, an artificial vernal pool was constructed and Alkali Milk-Vetch was observed there after the construction – prior to that it had not seen there since 1923 (Yolo County Natural Heritage program Draft Species Accounts, 2009). It is not clear if the more recent observations were a result of a long-lived seed-bank that was able to germinate after the disturbance or if the seeds were introduced from soil that came from another site. These findings suggest disturbance, and perhaps open soil, may be important source for recruitment efforts in the future.

Species Distribution

According to CALFED (2005), Alkali Milk-Vetch had historically been found in 13 counties in California, but as of 2005 it was found in 5 only counties: Central Coast, Livermore, Solano-Colusa, Lake-Napa and Santa Rosa Vernal Pool Region. The populations of each colony range in size from a few scattered plants to several hundred plants. There appears to be wide variation from year to year in population numbers. In a survey conducted by CNPS botanists in 2002 at a site in Davis, found no Alkali Milk-Vetch. In a follow up study at the same site in 2004 and 2005, a "vigorous" population of Alkali Milk-Vetch was found (CALFED, 2005). Additionally, more recent observations of actively growing populations at sites where Alkali Milk-Vetch was thought to be extinct suggests a long-lived seed bank may be responsible (Yolo Natural Heritage Program, 2009).

Community Associations and Habitat Requirements

Alkali Milk-Vetch tends to grow in swales and on higher mesic grasslands surrounding vernal pools (Barbour et al., 2007; CA Natural Diversity Data Base, 2001). These mesic flatlands can occasionally be inundated for brief periods of time during the rainy season (Barbour et al., 2007). According to Sawyer and Keeler-Wolf (1995), the types of vernal pools they are associated with include: Northern Hardpan, Northern Basalt Flow, Northern Volcanic Ash Flow, and Northern Claypan. Alkali Milk-Vetch associates with vernal pools that have an average depth of 27cm and area of 32,500m2 (Barbour et al., 2007). Alkali Milk-Vetch is generally associated with Colusa grass (*Neostapfie colusiana*), Solano grass (*Tuctoria mucronata*), *Sidalcea hirsuta, Phlaris lemmonii, Scirpus mucronatus, Lasthenia glabrata, Lolium multiflorum, Pogogyne zizyphoroides, Downingia insignis* and *Hestperevax caulescens* (Ca Natural Diversity Division, 2007; Environmental Science Associates, 2005 Hickman, 1993). In Solano-Colusa and San Joaquin Valley Vernal Pool Regions it is associated with *Lupinus bicolor* and occasionally *Eryngium aristulatum* (Barbour et al., 2007). The soil in the sites where Alkali Milk-Vetch typically grows is moderately alkaline. The elevation range is between 5 and 290 feet (US Fish and Wildlife Service, 2005).

Threats to survival

The primary threat to Alkali Milk-Vetch, like other vernal pool species, is the loss of habitat. Habitat loss has occurred because of changing land use, primarily for agricultural purposes, urbanization and mining. The degradation that has occurred as a result of the change in land use has led to disturbances in hydrological flow, local climatic changes, erosion, an increase in contamination of water, changes in grazing patterns and an increase in exotic plant species.

Hydrological flow has been greatly altered, leading to changes in inundation patterns in vernal pool habitats. Levees have been constructed to manage water flow in Alkali Milk-Vetch's native habitat, greatly altering the flow patterns. It is also thought that Alkali Milk-Vetch may be negatively effected by wetland areas that are maintained for water fowl (US Fish and Wildlife Services, 2005).

Invasive species also appears to be playing a significant role in the decline of Alkali Milk-Vetch. According to the US Fish and Wildlife Service (2005) there are several plant competitors threatening Alkali milk-vetch: *Salsola* sp. (Russian Thistle), *Lepidium latifolium, Melilotus indica* (Sweet Clover) and *Lolium mulltiflorum.*

The high potential for water contamination from agricultural fields is another threat to Alkali Milk-Vetch. Run-off of fertilizers, herbicides and pesticides from agricultural fields can pollute the water flowing into vernal pools. Additionally, pollutants from urban areas can contribute to water contamination. It is thought that the fertilizers may also promote the growth of exotic species, leading to competition issues (USFWS, 1997).

An additional threat for Alkali Milk-Vetch may be habitat fragmentation and loss of habitat that support pollinators associated with Alkali Milk-Vetch (USFWS, 2005). This could lead to a decline in pollinators that associate with Alkali Milk-Vetch.

There is conflicting information about the effect of grazing on Alkali Milk-Vetch. It has been mentioned as a possible threat to survival, however on some sites, where regular cattle grazing has occurred the populations are rated as "good" (Ca Natural Diversity Data Base, 2007). It is thought that grazing may control populations of invasive species, leading to a decrease in competition.

Key Questions

There are multiple key gaps in our knowledge about Alkali Milk-Vetch. There is minimal to no data on germination requirements, role of disturbance and specific pollinator. Lastly, while there is some evidence suggestive of a long-lived seed bank, there is little data to support this. All of these gaps in our knowledge may potentially limit our ability to effectively restore Alkali Milk-Vetch.

Alkali milk-vetch Part 2

Restoration Goals

Our general restoration goal for Alkali Milk-Vetch in Yolo County Grasslands Park Vernal Pool Complex is to maintain the existing populations and establish additional self-sustaining populations of Alkali Milk-Vetch to ensure long-term species conservation.

Overall Objectives to meet our Restoration Goals

Promote the Yolo County Grasslands Park Vernal Pool Complex natural ecosystems functions and processes by conserving and protecting the site. Loss of habitat is a primary threat to Alkali Milk-Vetch, so we hope to begin our restoration process by establishing a protected site and providing habitat requirements necessary for its survival. Second, we aim to remove or minimize threats by invasive species in addition to ensuring adequate populations of associated species, such as Colusa Grass and Solano Grass. Lastly, we aim to maintain the colonies of Alkali Milk-Vetch currently on the site and to establish new colonies of Alkali Milk-Vetch within the mesic grasslands of the Vernal Pool Complex. The colonies we are aware of in existence today range in population size from a few plants to several hundred. Because have no data on effects of population density on the species, we would begin with a conservative goal of 10 new colonies, each with populations of 50 or greater within 10 years.

Management Strategies

Land management

Because habitat loss is the primary threat to Alkali Milk-Vetch, conserving and protecting the Vernal Pool Complex is imperative in its survival. Preservation of the Vernal Pool Complex would benefit not only Alkali Milk-Vetch, but also other associated vernal pool species, such as Colusa Grass, threatened by extinction because of fragmentation and habitat loss. For the existing natural vernal pools on the site, vernal pool hydrology should be maintained as they currently are by creating buffer zones around these pools. Further research is needed to determine appropriate areas for buffer zones.

For the created pools at the Vernal Pool Complex, further work may be needed to improve their hydrology. The created pools are deep and bowl shaped with uniform topography, unlike the natural vernal pools, which generally are shallower with variable topography. Additionally, because of the disturbance during construction of the created pools, there are many more exotic invasive species at these sites as compared to the existing natural sites, which will need to be addressed before Alkali Milk-Vetch can establish there. Also, if additional pools are created as part of the site restoration, the additional constructed pools should more closely resemble the natural pools at the site, which tend to have complex topography and mixed depth to hardpans (unpublished lab data, 2010).

Another important aspect in land management at the Vernal Pool Complex is minimizing pollutants from nearby agricultural areas. It is thought that run-off from nearby agriculture may be high in nitrogen, which may improve exotic invasive species competitive ability. Further research is needed to determine the amount of “tolerable runoff”, the amount that the system can handle without serious regime shifts. Given there is little data on this, it would be prudent to minimize the amount of runoff from local agriculture and monitor annually for pollutants in each vernal pool as well as growth of exotic invasive species. The land within the Vernal Pool Complex will be managed using an adaptive management plan and will be in compliance with state and federal regulations.

Establishment of Alkali Milk-Vetch Colonies

Alkali Milk-Vetch is currently found growing in the upper grassland region near pools 9A and 9B within the park. Both pools are large in size and have complex topographies. Pool 9A is a pescadero and marvin soil, and pool 9B is pescadero and capay. Alkali Milk-Vetch is found to be growing along with Colusa Grass, one of it’s associated plant species, at 9A. We know very little about Alkali Milk-Vetch germination requirements. We do know Alkali milk-vetch flowers from March to June and then sets seed and appears to have a long-lived seed bank. We also know there is little genetic variation between populations. In previous studies, there was an increase in population size after a disturbance, indicating that disturbance may be beneficial in germination. Though we have no data about establishment of new colonies and success of propagating new colonies using the seed bank, we would attempt to harvest seed from the seed bank at pool 9A and 9B and introduce seeds in the grasslands surrounding pools RA4, R3, R4 and R6. Pools RA4 and R4 have pescadero soil; R3 has marvin and pescadero. RA4 has some complexity of topography R4 has Colusa grass growing nearby, a plant which associates with Alkali Milk-Vetch. All of these pools in the R series have complex connections with the other pools in this region.

Typically high numbers of seed are required to establish new plant colonies (in general, given losses due to predation, lack of germination, etc), however because our existing populations of Alkali Milk-Vetch at the Vernal Pool Complex are low and given we have no data on seed collection or germination, I would suggest being very cautious and only gathering 100 seeds each year for 10 years from the seed bank and introducing these in the areas outlined above. Given the different soil type and high number of invasive species at the created pools, as well as the limited data for the other natural pools, we would hold off introducing seeds in other areas until we see what kinds of success we have at RA4, R3, R4 and R6. However, in the future, if the invasive species can be reduced at the constructed pools, these may be good sites to introduce Alkali Milk-Vetch given it appears to do better with disturbance.

Population numbers in colonies of Alkali Milk-Vetch can vary widely from year to year, so adaptive management plans should include on site annual evaluations between March and June for the next 10 years to monitor population densities at the existing colonies and to determine germination success at the seeded pools, and if successful monitoring could be reduced to every other year thereafter, given the annual fluctuations. If we do not see successful germination at pools RA4, R3, R4 and R6 within 5 years, we would perform further research into the cause of failure – could it be herbivory, not enough disturbance, not enough seed, irrigation requirements, timing, pollinators, etc. If germination is occurring at the seeded sites, the population sizes of each colony should be tracked annually for 10 years, keeping in mind that current population sizes range from just a few plants to several hundred.

Minimizing Threats by Non-Native Species

Invasive species are thought to play a significant role in the decline of Alkali Milk-Vetch (US Fish and Wildlife, 2005). There are 2 non-native plant species thought to directly threaten Alkali Milk-Vetch: Perennial Pepperweed (*Lepidium latifolium*) and Russian Thistle (*Salsola tragus*). In addition to these non-natives, 2 others appear to be strong competitors and they are: Sweet Clover (*Melilotus indica*) and Italian Ryegrass (*Lolium multiflorum*). To deal with the invasive species, given the limited data we have, controlled grazing and mowing or cutting by hand are the best way to reduce numbers. Herbicide can be even more effective than mowing or cutting, however given the risk of pollution into the vernal pools this is not recommended. We recommend cattle grazing 1 time/year at low densities (2 cows/acre) in the mesic grasslands to the pool margins, early in the spring before Pepperweed and Russian Thistle set seed and before Alkali Milk-Vetch is flowering.

Future Research

There are many gaps in our understanding of Alkali Milk-Vetch. We are limited by our lack of data in the following areas: germination requirements, specific pollinator, role of disturbance – beneficial vs. not - and patterns of gene flow. Given our limitations our chance of success at this point is quite poor. Over the course of the next few years, funding needs to be allocated to address these questions and may increase our chances of success.

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ENH 160

5/6/2010

Alkali Milk-Vetch Fact Sheet

Life History

- Alkali Milk-Vetch (*Astragalus tener* var. *tener)* is an herbaceous annual in the Fabaceae family
- Flowering occurs from March to June
- They have been found to be self-compatible, however also demonstrate high levels of out-crossing, suggesting insect pollinators
- Specific pollinator is not known
- Germination requirements are not known

Distribution

- Extremely limited data available documenting the population trends
- Previously found in 13 counties within CA, as of 2005 only found in 5 counties: Alameda, Solano, Napa, Merced and Yolo Counties (CALFED, 2005)
- Alkali Milk-Vetch distribution range is varied – from colonies that contain only a few scattered plants to colonies that contain hundreds of plants
- There is wide variation in population size from year to year

Habitat Requirements

- Alkali Milk-Vetch is found near vernal pools with an average depth of 27cm and an average pool area of 32,500m2 (Barbour et al., 2007)
- It grows on swales and higher flats, in the mesic grasslands surrounding vernal pools. These areas may become seasonally inundated for short periods of time

- Types of vernal pools it has been associated with are: northern hardpan, northern basalt flow, northern volcanic ash flow and northern claypan.
- Alkali Milk-Vetch requires alkaline soil

Plant Associations

- In Solano-Colusa Vernal Pool Region and San Joaquin Valley Vernal Pool Region Alkali Milk-Vetch is associated with *Lupinus bicolor* and occasionally *Eryngium aristulatum*
- More generally it has been found to be associated with: *Sidalcea hirsuta, Phlaris lemmonii, Scirpus mucronatus, Lasthenia glabrata, Lolium multiflorum, Pogogyne zizyphoroides, Downingia insignis* and *Hestperevax caulescens* (Hickman, 1993; Ca Natural Diversity Division 2007)

Disturbance

- 1 study found an increase in population size after disturbance for a pipeline installation; at another site where an artificial vernal pool was constructed, Alkali milk-vetch was observed after the pool was constructed – previously it had not been at the site since 1923. Though this data is extremely limited, it suggests disturbance may be beneficial.
- Conflicting data is available on grazing. In 1 study it was mentioned as a possible threat, however in another study they found the locations where cattle grazing occurred regularly had populations that were rated at "good"

Threats

- Loss of habitat related to changes in land use, primarily for agriculture, but also related to mining and urbanization
- Changes in hydrological flow are thought to be another threat. According to the US Fish and Wildlife Services (2005) Alkali milk-vetch is thought to be negatively effected by wetlands maintained for water fowl
- Declines in pollinators because of habitat loss are a potential threat
- Threats by invasive species: *Salsola* sp. (Russian Thistle), *Lepidium latifolium*, *Melilotus indica* and *Lolium multiflorum*.
- Listed as a federal species of concern and is listed by the CNPS as a plant that is rare or endangered in California and elsewhere
- Currently has no legal status

Key Questions/Issues

- Germination requirements
- Role of the Seed bank
- Role of pollinators
- Role of disturbance
- More information about what is going on at the sites where population numbers are good

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Part 3: Synthesis of goal within class project

Based on the presentations and discussions of options for managing multiple goals at the Yolo County Vernal Pool Complex, I think the primary component of the management plan for Alkali Milk-Vetch that impacts other species is grazing. Grazing to reduce the numbers of exotic invasive species is an area where there may be both tradeoffs and win/win situations. Because grazing appears to be deleterious for some important species, such as Solano Grass and San Joaquin Spearscale, in these cases it may be considered a tradeoff. On the other hand, grazing is beneficial for many other species, such as *Psilocarus sp*. and *Plagiobothrys sp*. in addition to Alkali Milk-Vetch. In these situations, grazing is viewed as a win/win. Given there appear to be more species that benefit from grazing than those that are negatively affected (according to the fact sheet on Grazing), I would not change my original goals and management plan to accommodate other goals.

Tara S. Hanlon

Ecological Restoration

Instructor: Valerie Eviner

June 3, 2010

Gratiola spp., Hedge-hyssop

PART I

INTRODUCTION

PROJECT GOALS

The goal of Part I is to provide background information and justification to retain, in areas where is currently exists, and restore, in areas where it may have existed, species of special concern within the genus *Gratiola* (Hedge-hyssop). Through the vernal pool literature study I have conducted, the most common species of *Gratiola* mentioned was *G. heterosepala*, Bogg's Lake Hedge-hyssop. Bogg's Lake Hedge-hyssop has been known by only one scientific name since it was first named by Mason and Bacigalupi (1954) (U.S. F.W.S., 2004). Most of the information included in this paper will refer to the characteristics, environmental needs, etc. of *G. heterosepala*.

STATUS OF SPECIES

G. heterosepala has no federal listing status but is proposed for federal listing or federal concern (Barbour *et al*., 2007). It was listed endangered by California in 1978 and included in the California Native Plant Society's first list of rare and endangered plants, most recently placed on the 1B list. The United States Forest Service formerly considered it to be "sensitive" but has reclassified it as a "special interest plant" because it is more abundant than previously thought. The U.S. Bureau of Land Management classifies it as a "special status" species.

Belonging to the Scropulariaceae family, *Gratiola* includes some 25 species of annual and perennial erect or creeping, glaborous or glandular-pubescent herbs (Dictionary of Gardening, 449). Of the 25 species in this family, the species that grow in California are more relevant to learn about in regards to management issues. Some known species of *Gratiola* found in California include: *G. ebracteata*, Bractless Hedge-hyssop; *G. heterosepala*, Bogg's Lake Hedge-hyssop; *G. L.*, Hedge-hyssop; *G. neglecta*, Clammy Hedge-hyssop; and *G. repens* Sw., Creeping Waterhyssop (USDA Plants Database online, 2010).

GENERAL DESCRIPTION

Gratiola heterosepala is an annual that flowers form April to August (Barbour *et al*. 2007) with hollow stems 2 to 10 cm (0.8 to 3.9 in) tall with yellow and white flowers that appear yellow from a distance (U.S. F.W.S., 2004). The fruit of *G. heterosepala* is a small, dry, pear-shaped capsule and the tiny seeds are oblong with narrow lengthwise ridges (U.S. F.W.S., 2004).

© Carol Witham, 2004, http://calphotos.berkeley.edu/cgi/img_query?enlarge=0000+0000+0404+0179

BACKGROUND AND JUSTIFICATION

DISTRIBUTION

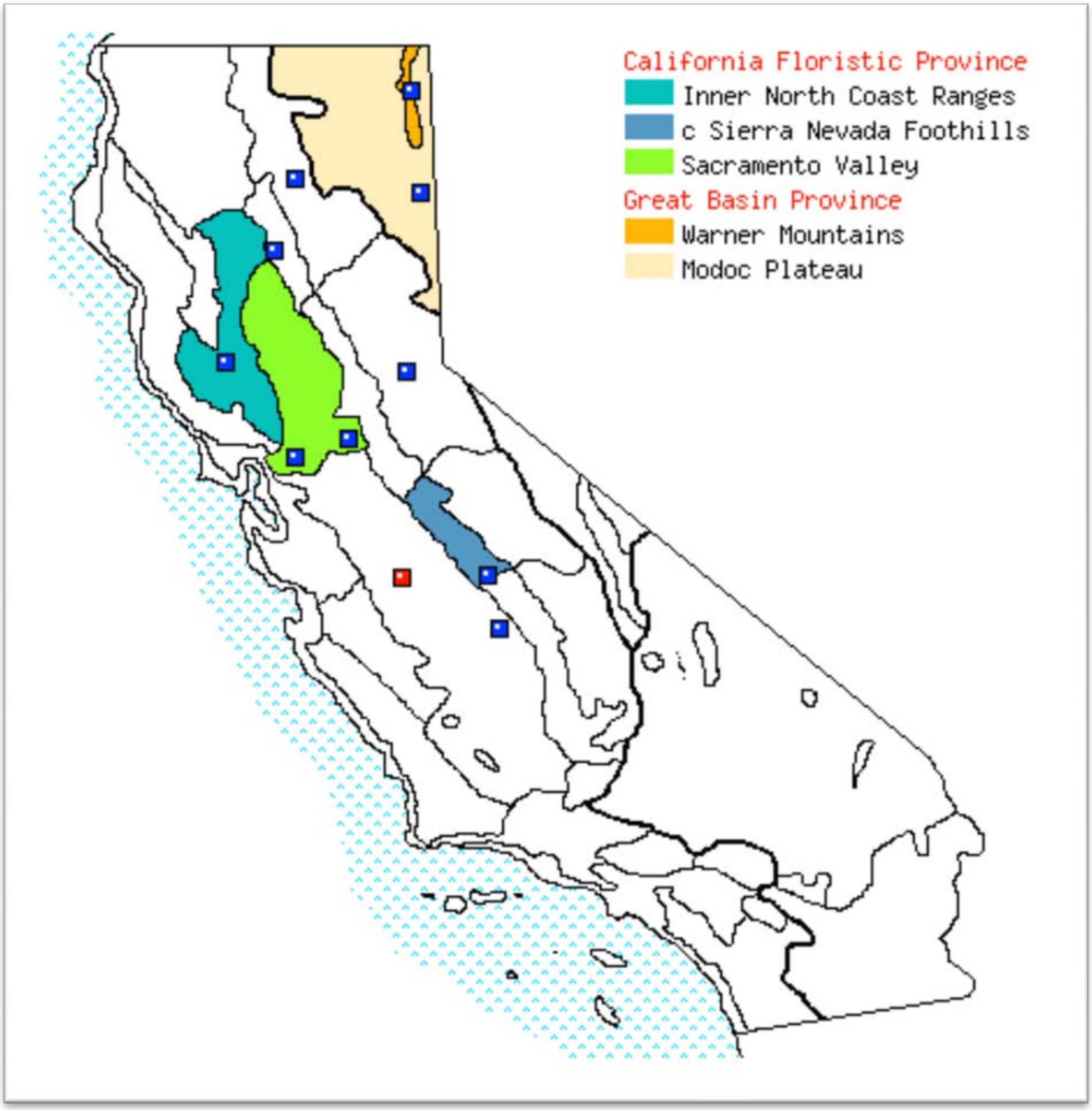
The California Natural Diversity Database describes the distribution of *Gratiola heterosepala* as:

— 39% in the Modoc Plateau Vernal Pool Region (32 occurrences)
— 20% in the Sacramento Valley Vernal Pool Region (17 occurrences)
— 20% in the Northeastern Sacramento Valley Vernal Pool Region (17 occurrences)
— 7% in the Southern Sierra Foothills Vernal Pool Region (6 occurrences)
— 6% in the Solano-Colusa Vernal Pool Region (5 occurrences)
— 4% in the Lake-Napa and Northwestern Sacramento Valley Vernal Pool Regions (3 occurrences), (U.S. F.W.S., 2004).

RANGE

Gratiola heterosepala has been found in more locations since it was first discovered. The first collection was in 1923 in Lake County, most likely at Boggs Lake (Mason and Bacigalupi, 1954). Before the 1980's, only two other sites were discovered, one in Madera County and one in Sacramento County (California Natural Diversity Data Base, 2001). During the 1980's, 20 more occurrences were discovered in California (California Department of Fish and Game, 1987). Thus, the historical range includes the Lake-Napa, Modoc Plateau, Southeastern Sacramento Valley, and Southern Sierra Foothills Vernal Pool Regions, and it is now known from the Northeastern and Northwestern Sacramento Valley and Solano-Colusa Vernal Pool Regions (Keeler-Wolf *et at*., 1998).

The map on the following page shows the regions where *Gratiola heterosepala* can be found throughout California. The colored bioregions represent the areas where the distribution of *G. heterosepala* is according to The Jepson Manual. The squares on the map represent the counties where the Consortium of California Herbaria specimen records of *G. heterosepala* were taken. *G. heterosepala* can occur in vernal pools at elevations of 10 meters to 2,375 meters in elevation (Barbour *et al*., 2007).



County and Bioregion Distribution Map, Consortium of California Herbaria

http://ucjeps.berkeley.edu/cgi-bin/get_county_map.pl?taxon_id=27295&hcode=0012100204

Since the 1980's, when most occurrences were located, there are few vernal pool systems containing *G. heterosepala* that have been destroyed. For a system that was destroyed in Sacramento

County, it was due to an increase in urbanization (U.S. F.W.S., 2004). No restoration projects concentrating on *Gratiola* spp. were found in the literature review.

SOURCES OF FUNDING

Potential funding for restoration of *Gratiola* spp. could come from:

— Bureau of Reclamation
— CALFED
— California Department of Fish and Game
— California Native Plant Society
— Caltrans
— California Wildlife Conservation Board
— Defenders of Wildlife
— National Fish and Wildlife Foundation
— Natural Resource Conservation Service
— The Nature Conservancy
— Sierra Club
— Solano County Water Agency
— Trust for Public Land
— United States Air Force
— United States Bureau of Land Management
— United States Fish and Wildlife Service
— United States Forest Service
— University of California Davis, Department of Land, Air, and Water Resources
— University of California Davis, Groundwater Cooperative Extension Program
— UC Davis, John Muir Institute of the Environment, Natural Reserve System
— Tuleyome Organization

LITERATURE REVIEW

G. heterosepala is self compatible and is believed to have a significant seed bank evidenced by greatly fluctuating populations (Barbour *et al*., 2007), but can be propagated by seeds, division, and cuttings in spring (Dictionary of Gardening, 449; Encyclopedia of Horticulture, 1535). This species has seeds that germinate and grow under water; however, it lacks the distinctly different aquatic juvenile foliage present in many other vernal pool species (Barbour *et al*., 2007). Flowers are present between April and August, with those at higher elevations flowering earlier (U.S. F.W.S., 2004). Each plant typically produces only one or two flowers, which mature into fruits within 1-2 weeks after flowering begins (U.S. F.W.S., 2004). In one study, a population in Oregon (Lake County) averaged about 150 seeds per fruit, but the umber of fruits per plant was not reported (U.S. F.W.S., 2004).

<u>CALIFORNIA POPULATIONS</u>

California populations range from only a few individuals to over 1 million and fluctuate greatly from year-to-year (U.S. F.W.S., 2004). The population at Boggs Lake (South of Clear Lake, CA) dropped from 1,000 individuals to zero within 8 years and remained at zero for another 8 years until 5 plants were found (U.S. F.W.S., 2004). There are five occurrences of *G. heterosepala* in Solano County and while some have been found to grow isolated from each other in some populations, others were found in densities of 67.4 plants/m^2 (6.3/ft^2) (U.S. F.W.S., 2004).

<u>HABITAT REQUIREMENTS</u>

Hedge-hyssop occurs naturally on moist rich soils by ponds, lakes, ditches, streams (Dictionary of Gardening, 449), vernal pools, marshy areas, and reservoirs, as well as man-made habitats such as borrow pits and cattle ponds (U.S. F.W.S., 2004). Seeds germinate with the autumn and winter rains and plants are budding or flowering by the time water levels recede to 5 cm (U.S. F.W.S., 2004). It was found to occur in the deepest and largest of studied vernal pools, which would be 40 cm or more in water depth and 50,000 meters square in area (Lazar, 2006). In the Barbour *et al*. study, releves that contained *G. heterosepala* had an average depth of 24 cm with a range of 5-70 cm and the average pool area across sites was about 69,5000 m^2 with the smallest pool sampled at 3,000 m^2 and the largest pool at 283,000 m^2.

An impermeable layer underlies most sites (U.S. F.W.S., 2004). Clay is the most frequently encountered underlying soil type in occupied habitats, although loam and loamy sand have also been noted (U.S. F.W.S., 2004). In general, there are relationships with the type of impervious soil horizon and/or the alkalinity/salinity of the soil, with a few rare taxa associated with volcanic mudflows: *Castilleja campestris* ssp. *Succulenta, Gratiola heterosepala*, and *Orcuttia tenuis* (Barbour *et al*., 2007).

VERNAL POOL ASSOCIATES

G. heterosepala was present in a wide range of communities indicating that it may be better able to adapt to different vernal pool environments than other vernal pool endemic species (Lazar, 2006). Certain rare vernal pool species were found to group together in areas that have similar environmental requirements with *Gratiola heterosepala*, including *Castellega campestris* ssp. *succulenta*, *Downingia pusilla*, and *Legenere limosa* (Lazar, 2006). The species with the greatest percent cover in releves with *G. heterosepala* were *Downingia bicornuta, Isoetes howellii,* and *Navarretia leucocephala* ssp. *Leucocephala* (Lazar, 2006).

CAUSE FOR CONCERN

According to the United States Fish and Wildlife Service's Draft Recovery Plan for Vernal Pool Species (pp. II-145-146) there are specific reasons for the decline of *G. heterosepala* and certain threats to its survival. Cattle trampling, excavation and damming, surface disturbances such as discing and grading, urban growth through residential development, shopping center construction, and landfill expansion, and threats from non-native species, such as *Taeniatherum caput-medusae*, are all reasons that populations of *G. heterosepala* have been extirpated or are in danger of extirpation.

PART II

The most commonly located and studied species of the genus *Gratiola* is *Gratiola heterosepala*, Boggs Lake hedge-hyssop. This species has been found at and around Jepson Prairie Preserve, Solano County, California, which is the closest extant site to Grasslands Regional Park. Six populations that range from a hundred to a million plants were found on and in the vicinity of Jepson Prairie Preserve

(Solano HCP, 2). Because of the similar climate, soil types, and geographic extent, the species at Jepson Prairie Preserve may help the restoration of *Gratiola heterosepala* in Grasslands Park to be successful.

GOALS

— Promote healthy population establishment by providing similar requirements needed for associated plant communities, which can also promote a more diversified vernal pool plant community.

— Restore populations of *Gratiola* spp. at Grasslands Regional Park in Davis, California by using propagation and planting techniques that have been used successfully in suitable habitats and by allowing regular vernal pool hydrologic patterns to occur.

— Protect *Gratiola* spp. growing in the vernal pools in Grasslands Park from natural, animal or human-induced disturbance while it is germinating, flowering or fruiting.

— Ensure long-term viability of *Gratiola* spp. in the park by monitoring restored populations beyond the time frame when it has been known to stay in dormancy due to environmental conditions, which would inhibit recurrence.

— Contribute knowledge to other restoration *Gratiola* spp. projects by conducting and distributing research findings of the *Gratiola* spp. restoration process at Grasslands Park.

RESTORATION PLAN

HABITAT REQUIREMENTS

Create suitable habitat for *Gratiola* spp. by using conditions known to be suitable for associated vernal pool plant communities.

— Since a lot of specific habitat requirements were not found in the literature study, the following associates' habitat requirements can be used for guidelines:

    - — *Castillega campestris* spp. *succulenta, Chamaesyce hooveri, Downingia bicornata, Eleocharis macrostachya, Legenere limosa, Myosurus minimus* spp. *apus, Navarretia leucocephala* spp. *plieantha, Plagiobothrys stipitatus, Orcuttia inaequalis, O. pilosa, O. tenuis, O. viscida,* and *Tuctoria greenei.*

- — There needs to be a shallow margin around the perimeter of the vernal pools that can provide a swampy environment for *Gratiola* spp. to grow and flower under inundated conditions.
- — Site locations should have an impermeable layer or hardpan below the surface soil layer.
- — Choose a site with a soil type that *Gratiola* spp. has been known to grow in.
    - — Clay soil is the most suitable soil for *Gratiola* spp. to grow in.
    - — Other site soils that can be used area loam and loamy sand.
- — Site should be chosen for a soil acidity that is slightly acidic to acidic.
    - — A soil pH of about 5 would be preferred.

<u>MAINTAINING INUNDATION</u>

Keep vernal pools inundated by allowing fall and winter rains to settle and stay in the vernal pools without draining off site.

- — Do not re-grade the topography in or around the vernal pools to ensure water retention on site.
- — If any construction is to occur near the restoration site that would cut through hardpan, it must maintain a distance far enough away to allow water to stay above the hardpan to stay seasonally in restored vernal pools.
    - — Construction protection distance would be determined from other successfully installed vernal pool restoration projects.

- The ponding of water will provide sufficient inundation time for seeds to germinate and grow under water. Time requirements for inundation was not found in the literature study, but *Gratiola* spp.'s inundation depth was:
    - The vernal pool water level must be higher than 5 centimeters for *Gratiola* spp., which is the water level that is known to be suitable for budding and flowering.

PROPOGATION

Establish *Gratiola* spp. by collecting mature fruits of some of the species found at Jepson Prairie Preserve and distribute them around the margins of restored vernal pools by scattering the seed.

- Collected fruit must still retain seed bank and be done in a way that is less intrusive or damaging, such as hand-picking ripe fruits.
- More fruit should be collected and distributed than the anticipated amount to be successfully propagated to ensure that at least a portion of the seed set will be able to grow in the restored area.
- Fruit should be allowed to dry and then use the seeds for spreading onto vernal pool restoration sites around the margins of the pools during the same time as other known *Gratiola* spp. populations.
    - Have a monitoring program set up at Jepson Prairie or other populated site to match the timing of seed release that occurs naturally.
- Spread seeds by scattering by hand or by using a method that does not create surface soil compaction or breaking of the hardpan.

DISTURBANCE LIMITATIONS

Protect flowers and mature fruits from getting destroyed from invasive plants, plowing, live-stock grazing and trampling, vehicles, construction, etc., by installing fencing to buffer the pools.

- Limit exposure of grazing animals within vernal pools to the seasons when *Gratiola* spp. is not in bloom. Fall and winter seasons are suitable for grazing.
    - No grazing should occur in the spring and summer seasons.
    - Timing of grazing must happen before plants germinate and after seeds are set.

MONITORING GUIDELINES

Monitoring of restored *Gratiola* spp. populations should be continued for at least twenty years, as my recommendation, to determine if establishment has been successful.

- Count the number of species found in populations and measure the spread of the population distribution within the vernal pools to determine the densities of each restored *Gratiola* spp. population.
- Monitor *Gratiola* spp. in the spring season and early summer when plants would be sprouting, flowering and fruiting.
- Monitor *Gratiola* spp. on a yearly basis for at least twenty years because they are able to stay dormant for many years at a time.
    - *Gratiola* spp. has been known to range from thousands of individuals to zero within eight years and stay at zero for another eight years before a handful of specimens were found at the same site.

FURTHER RESEARCH

Research should be conducted on *Gratiola* spp. by monitoring success rate based on amount of viable plants that grow in restored vernal pools of Grasslands Regional Park.

- Monitoring could help answer some of the questions that would be helpful to the success of future vernal pool restoration projects where *Gratiola* spp. and other sensitive species are considered:

— How long do the fruit need to be on the plant for seeds to mature to a fertile condition?

— How much water is needed for *Gratiola* spp. to be able to germinate, flower and produce fruit?

— What density and frequency is considered 'moderate' for livestock grazing regimes?

PART III

SYNTHESIS OF GOALS

Establishment and retention of *Gratiola* spp. in Grasslands Regional Park could be successful with the integration of management requirements of other vernal pool species. Restoration suggestions for *Gratiola* spp., as indicated in this report, have been found to be similar to the needs of many vernal pool sensitive species. Timing of grazing and disturbance regimes will need to be adjusted according to the needs of invasive species, to minimize the spread and negative effects that these species have on vernal pools. It is not recommended to allow grazing where vigorous invasive species have been found in vernal pools. These species should be removed within the vernal pools by hand (or by means that cause minimal disturbance to the vernal pool endemic species) before any grazing is allowed.

FACT SHEET

REPRODUCTION

— Autumn and winter rains allow seeds of *Gratiola heterosepala* to germinate.
— Plants are budding or flowering by the time water levels recede to 5cm (2in).
— Flowers present between April and August, with those at higher elevations flower earlier.
— Produces one or two flowers, which mature to fruits within 1-2 wks after flowering begins.
— Studied population averaged about 150 seeds/fruit.
— Genus is self-compatible and does not require insects for pollination.

DEMOGRAPHY

— Populations range from a few individuals to over 1 million & fluctuate greatly from yr to yr.

— The population at Boggs Lake (Lake Co.) dropped from 1,000 to zero within 8 years and remained at zero for another 8 years until 5 plants were found.
— *G. heterosepala* can grow isolated from each other in some populations and in others in densities of 67.4 plants/m^2 (6.3/ft^2).

HABITAT ASSOCIATIONS

— Occurs in margins of vernal pools, marshes, reservoirs, lakes, borrow pits & cattle ponds.
— An impermeable layer underlies most sites.
— Clay is usually the underlying soil in occupied habitats, loam and loamy sand suitable too.
— *G. heterosepala* grows on acidic soils with a pH ~5 & on some sites with slightly acidic soils.
— 5 occurrences of *G. heterosepala* in Solano Co. are in the Solano-Colusa Vernal Pool Region.
— Site elevations range from 8m (25 ft) to 1,576m (5,170 ft), from Solano Co. to Modoc Co.

COMMUNITY ASSOCIATIONS

— Associates: *Gratiola. ebracteata*. *Plagiobothrys stipitatus*, *Downingia bicornuta*, *Orcuttia tenuis*, and *Eleocharis macrostachya*.
— Rare, threatened, & endangered plants that co-occur: *O. tenuis, Tuctoria greenei, Castilleja campestris* ssp. *succulenta, O. pilosa, Chamaesyce hooveri, Legenere limosa, Myosurus minimus* ssp. *apus, Navarretia leucocephala* ssp. *plieantha, O. viscida,* and *O. inaequalis*.

CONSERVATION EFFORTS

— No Federal listing status.
— First listed endangered by CA in 1978 and currently included in the CNPS's list 1B.
— The U.S. Forest Service formerly considered it to be "sensitive" but has reclassified it as a "special interest plant" because it is more abundant than previously thought.
— The U. S. Bureau of Land Management classifies it as a "special status" species.

THREATS TO SURVIVAL

— Extirpation occurs from habitat conversion for urban growth (ie. residential development, shopping center construction, and landfill expansion).
— Disturbance occurs from cattle trampling, hydrological alterations (ie. excavation and damming), and surface disturbances (ie. discing and grading.)
— Competition from *Taeniatherum caput-medusae* is potentially threatening.

MANAGEMENT

— Trampling and herbivory can be detrimental if use is concentrated in a small area.
— Moderate grazing is believed to be compatible if it occurs after *G. heterosepala* sets seed.
— Directed research is necessary to establish appropriate use levels and seasons.

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San Joaquin Spearscale (*Atriplex Joaquiniana*)

Alexis Fuller

ENH 160

Dr. Eviner

April 22, 2010

Background

Atriplex joaquiniana is a rare species of vernal pool annual forbs native to California. Vernal pools are important diversity hotspots in California because they contain a wide range of species that have unique adaptive traits to different stresses. Vernal pools are important in grassland ecosystems because they act as buffer systems for flooding, retain metals detrimental to our water quality, and serve as corridors for various kinds of birds (Lazar, 2006). A diversity of annual forbs constitutes the plant communities in vernal pools that have adaptations for tolerating seasonal inundation (Silveira, 2000). Annuals are important species isince their life cycle allows them to disperse seeds every season that may be important forage for waterfowl or invertebrate species that thrive in this kind of ecosystem. Seasonal senescence contributes to the soil year after year. Studies estimate that vernal pools in California have been reduced by 60 to 95 percent, mostly due to reconstruction into agricultural lands (Lazar, 2006). Furthermore, the California Native Plant Society lists Atriplex joaquiniana as rare and endangered. Reduction in annual forbs could be detrimental to the seasonal trends that these ecosystems exhibit. Since many vernal pools plant communities naturally possess limited dispersal zones and are highly limited in range (Silveira, 2000), conserving unique species habitats for species like Atriplex joaquiniana is important for keeping the plant diversity of this ecosystem.

A. Nelson first discovered Atriplex joaquiniana in 1904 in either Tulare or San Joaquin County (CA High-Speed Rail, 2004). There is probable thought, according to the California Native Plant Society, that historical populations of A. joaquiniana covered a larger range of California compared to present locations, and that the counties where they were originally found no longer include A. Joaquiniana

(CNPS, 2010). No known plants exist in their founding sites, suggesting that Atriplex Joaquiniana must have gone through significant habitat reduction (CNPS, 2010). Furthermore, it is listed at the global level as rare, threatened, or endangered, and it is listen in California as fairly endangered (CNPS, 2010). Unfortunately, it has no federal or state status, and there is little documentation on the specific biology of the plant (HCP[1], 2006). A. Joaquiniana is limited to the Sacramento Valley, San Joaquin Valley, and Inner South Coast Ranges (Jepson, 1993) in reported sightings of less than twenty specimens for each county it is found in (Calflora, 2010). For Solano County there has been eight sightings documented in the 1990's in the California Natural Diversity Database ranging from 33-200 species across the county.

Atriplex joaquiniana grows with a variety of different plant communities. It can also persist in places overrun with non-natives like Italian Ryegrass and Mediterranean Barley (HCP, 2006). Atriplex joaquiniana can grow with most Valley grassland species and Foothill grassland species (CA High-Speed Rail, 2004). Plant communities associated with Atriplex joaquiniana include meadows dominated by Saltgrass and Chenopod Scrub communities. Native plants that are commonly associated with A. Joaquiniana include Atriplex depressa and Cordylanthus palmatus (HCP, 2006).

Like most Atiplex species, A. Joaquiniana persists in saline soils (Yolo Natural Heritage Program, 2009). The Contra-Costa Habitat Conservation Plan (2006) aimed to characterize soil requirements with that of Atriplex depressa, just to find out that A. joaquiniana is not limited to the Pescadero and Solano soils like Atriplex depressa. Although it is found on these soils, it seems to persist in a wider range of alkali and saline soils (Yolo Natural Heritage Program, 2009).

A. Joaquiniana's seed bank is small in size, but temporally lengthy according to the East Contra Costa Habitat Conservation Plan (2006). Atriplex Joaquiniana produces a dark brown seed up to 1.5 millimeters in length for every one fruit. Bracts surround the flowers and there are no sepals or petals. The male flowers are located at the end of the dense stems (Jepson, 1993). It has numerous but very condensed and corrugated leaves (Jepson, 1993) like many other Atriplex species designed to tolerate high temperatures (Osmond, 1980). It blooms from April to October (Calflora, 2010), suggesting that A.

[1] East Contra-Costa County Habitat Conservation Plan

Joaquiniana is not as dependent on seasonal timing of water flow out of it's vernal pool habitat compared with species occupying lower regions in the pool. A. Joaquiniana has trichomes, but only on the lower base of the plant, and becomes smooth towards the top (Jepson, 1993).

In Vacaville, California, Atriplex joaquiniana persists at an alkali wetland west of Lagoon Valley Lake that was unintentionally created by construction of a bypass channel (EIP Associates, 2004). Furthermore, it is know to germinate after a soil disturbance (Yolo Natural Heritage Program, 2009). This suggests that Atriplex joaquiniana may be an important successional species for disturbance of upland vernal pool sites. Although no grazing interactions with this species have been made, it seems as if even moderate grazing with cattle has a positive coorelation with most Atriplex species since the palatability of these plants is very low (Cibils, 1998). Furthermore, even sheep avoid most Atriplex species unless there is substantial drought (Cibils, 1998). Other species interactions might include seed dispersal by small mammals like the at-risk species Perognathus inornatus, the San Joaquin Pocketmouse. This small mammal has a range similar to A. joaquiniana and is known to have a diet consisting mainly of seeds from the genus Atriplex (Best, 1993). Other species interactions may include waterfowl, since the Yolo Natural Heritage Program (2009) lists waterfowl as a threat to existence.

Atriplex joaquiniana usually resides on the outer edges of clay bottom vernal pools, and can extend up into grassland communities (Yolo Natural Heritage Program, 2009). A. joaquiniana can also reside in basins and alluvial fans (HCP, 2006). According to the California Native Plant Society it ranges in elevation from 1-835 meters, but several resources indicate that it does not usually reach higher than 320 meters in elevation.

Goals and Management Plan for Atriplex Joaquiniana in Grasslands National Park

The foremost goal in this restoration plan would be conserving San Joaquin Spearscale populations that have already established. Conservation would include monitoring seed viability on a year-to-year basis. Recording the average number seeds that set on each bract after April 1st, the flowering date, would be important for understanding how many flowers actually produce seed. This could be carried out by weekly monitoring of the flower and seed number throughout April to October for each established plant. Weekly recording of plant establishment during the April to October of the subsequent year compared to the record of how many seeds set in each bract could give an idea of the germination percentage on the site. Since the seed dispersal range for Atriplex joaquiniana is not well understood, making data points of where Atriplex Joaquiniana establishes on a map of Grasslands National Park and comparing it to plant establishment of subsequent years could give researchers a better understanding of how the seeds are dispersed. This could also give insight to what kind of disturbance regime is required for germination, if grazing or other disturbances are mapped and recorded for each year. Since most Atriplex species do not seem to have seeds that are capable of long distance wind transport, it is probable that seeds germinate fairly close to the parent plant, in accordance with other Atriplex species (Osmond, 1980). Keeping track of the number of individuals would be important to denote any trends from year to year in population dynamics. Since Atriplex has been noted to have a long-lived seedbank, finding out just how long this seed bank is dormant for could be useful for understanding population dynamics.

Another goal would be collecting information on how Atriplex Joaquiniana reproduces. This could be done simultaneously with the record keeping of plant establishments. How close are the male/female parts on the plant? Is it monoecious or dioecious? How is the plant pollinated? Careful watch of the flowering period from April- October should be made with observations about what mammalian/insect/bird species come into contact with the plant and if they actually aid in pollination or seed dispersal. Do plants/animals spend time prying open a bract, or do they just migrate away? Which waterfowl/bird species like to eat its seeds? Record keeping on various days throughout April-October could be kept by watching sites with Atriplex Joaquiniana in them and keeping records for each visitation event. Record keeping of these events should be made throughout the day. Perhaps recording during a couple hours in the morning, afternoon, and dusk hours would give us an idea of the different species that visit the plant. Once trends in plant/animal visitations are established, if at all (since Atriplex joaquiniana might be entirely dependent on wind dispersal), monitoring on a monthly basis during the fall could give us an idea of Atriplex joaquiniana's dispersal mechanisms.

I would not recommend seeding sites with Atriplex joaquiniana seeds until germination requirements and soil profiles/salinities have been established. Experimental data on the extent of salinity and soil profiles that allow of A. Joaquiniana to persist would definitely come into use when implementing plans for seeding. Collecting seed samples from an extensive population, or making tissue cultures for propagation of different species in order to avoid disturbing any population dynamics, could be used for propagation of this species in a Greenhouse. Since the germination requirements are unknown, reproducing this species in medium with varying salinities and found on the site that reflects the soil series of the site would be important for classifying its range, and could give us a better idea of where to plant new species on the site. There are records from the CNPS and CA Department of Fish and Game that indicate species located near intersections on agricultural roads above Davis and below woodland that could be used to seed areas in the park (Calflora, 2010). Finding these data points and collecting seed samples from these populations, if they still exist, would be safer than collecting seeds from plant populations already established in Grasslands National Park since disrupting the seed dispersal on the site may be detrimental to population dynamic that have already been established. Relocating seeds to a more predictable and protected environment would ensure a greater probability of germination and establishment. Seeding Atriplex joaquiniana on the site would have to occur in areas where a significant disturbance occurs. Disturbances that might fit into the germination requirements include old burrowing owl habitats, road developments, and the concrete block removal that occurred near Pool R6.

Keeping the soils in the area saline would be another management strategy important for keeping Atriplex joaquiniana habitat requirements in Grasslands National Park. Recording salinities of each vernal pool would be critical for understanding if inundation and evaporation processes were successful at keeping high salinities. Perhaps significant declines in salinity based on year-to-year records could be attributed to invasions of non-natives and their thatch accumulation. This is why grazing would be a good management strategy.

Although overgrazing has been listed as a threat to existence (HCP, 2006), grazing may increase the detritivores on the site by providing more detritus. Grazing in the early spring and late fall may reduce the amount of Italian Ryegrass and Mediterranean Barley that compete with Atriplex joaquiniana. It may also provide significant soil disturbances that heighten the establishment of germinating seeds. Since most Atriplex Species are highly unpalatable and have been known to even increase the persistence of some Atriplex species, light grazing could be a strategic experiment.

As noted by Silveira (1996), the Snow Goose, Ross' Goose, Western Canada Goose, and Crackling Canada goose are examples of waterfowl that feed on seeds in upland areas of vernal pools. How many and of which species of geese visit the vernal pools should be noted and recorded, especially in the months following the blooming period. Watching for species interactions, again, would be needed in order to proceed with any management plan for waterfowl since there is no solid documentation involving species interactions .

Other challenges for restoration include providing knowledge about its special status to visitors of the park and setting up experiments to collect data on salinity, soil, and germination requirements. Atriplex joaquiniana does lack showy flowers and does not usually reside directly in the pools where all the inundation-dependent species are constantly being studied. It is going to be a challenge to spread knowledge about this species special status and its importance in vernal pools. Furthermore, can this plant be propagated? Could sampling alter the population dynamics? How many individuals exist on the site, and what kind of soil series do they exist on?

Although this species has many challenges, I would recommend implementing a five year plan or more for yearly monitoring of its seed dispersal zones, at least a couple experiments regarding the soil and salinity requirements, and removal of Italian Ryegrass and Mediterranean Barley by either grazing in the late fall/early spring, hand weeding, or herbicide use in areas farther from vernal pool habitat. I recommend more than a five-year plan if populations seem to be declining and/or management techniques do not favor its survival. This species has a lot of potential: restoring its habitat and seeding on appropriate sites may reduce non-natives, keep soils high in salinity, and provide forage for different mammals and waterfowl.

Considerations

Although this species requires a disturbance regime, other invasive species also germinate well in response to a disturbance like Mediterranean Barley and Russian Thistle. This can be mitigated by recording what spots disturbances occur on the site and making sure none of these weeds are present by hand pulling them. The grazing regime recommended in the late fall and early spring may disturb certain invertebrate species during the inundation period. It may also disturb the upland area habitat for solitary bees that pollinate vernal pool species. Aritificial disturbances may also be detrimental to invertebrates and solitary bees. Keeping vernal pools fenced from the cows may help protect the invertebrates, but may not protect the solitary bee habitat. Herbicide use in the upland area may disturb invertebrates and other sensitive vegetation communities. This can be mitigated by hand pulling.

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Fact Sheet - San Joaquin Spearscale (Atriplex Joaquiniana)

Family: Goosefoot (Chenopodaceae)

- # Of species in Atriplex genus = 111

General Characteristics: Annual Herb

- Dicot
- Endemic to California.

Blooming Period: April- Oct.

Dispersal: Wind, most likely

- Flowers= "bracts" that enclose 1 small seed

Important Facts

- Known to germinate after soil disturbance (EIP Associates, 2004)
- Known to persist in grasslands dominated with exotics [especially Italian Ryegrass and Mediterranean Barley] **(**YNHP, 2009)
- Atriplex species are commonly characterized as ruderal species (Cibils, 1998)

- Long-lived seed bank (exact length unknown) (YNHP, 2009)

Central Valley Habitat: Clay, Alkaline, saline soils in

- Chenopod Scrub plant communities.
- Outer edges of vernal pools < 320 meters above sea level

- Other known habitats: meadows, basins, alluvial fans, valley grasslands, creeks, and seeps.

Observations: 94 Species accounts, 7 of which were in Yolo County (YNHP, 2009).

Important Associations: Atriplex Depressa and Cordylanthus Palmatus (YNHP, 2009).

Proposed ecological functions:

- May be important in keeping soils saline since most saltbush species retain salts in their tissues (can recycle it back into soil).

- May be important for keeping invasive species from inhabiting upland areas, altering hydrological regime.

- Seeds could be forage for certain mammal species (like the san Joaquin pocket mouse) (Best, 1993)

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FLESHY OWL'S CLOVER

Castilleja campestris ssp. *succulenta*

Samuel Fahrner

FACT SHEET

Species name: *Castilleja campestris* ssp. *succulenta*

Common name: Fleshy Owl's Clover

Status

Federal: Threatened since 1997

State: 1) California Native Plant Society listed it as endangered in 1974, it is currently on their 1b list 2) California Department of Fish and Game listed it as endangered in 1979

Important characteristics

- This subspecies is only found in California vernal pools
- Reproduction: Annual plant
- Hemiparasitic (only after germination), though it is not imperative for survival. However, association with a host (via a root graft) increases its reproduction rates/success
- Typically will flower in April/May

Vernal pool preferences

- Found in two different types of vernal pools: Northern claypan and Northern hardpan
- Soil: Loam, which is a mix of sand, silt, and clay. Found in different compositions of these three constituents, however a central theme is the capacity for high H_2O retention
- Ideal pH levels are between 5 to 6.24
- Fleshy Owl's Clover is typically found at elevations between 24 to 700 meters
- Vernal pools housing Fleshy Owl's Clover range between 0.07 to 1.61 acres
- Typical pool depths range between 8cm and 42cm, with an average of 19cm (Lazar 2006)
- Grazing has been shown to decrease the impacts of nonnatives, however more research is needed in order to fully understand its implications for *C. campestris* ssp. *succulenta*

- Common sympatric plant species are as follows: Fremont's goldfields, Downingia, Three-colored monkey-flower, Vernal pool popcorn flower, Coyote-thistle (Vernal Pool Recovery Plan 2005)

Specific Threats

- UC Merced expansion, Burn's Reservoir, general increase in agricultural production, and development of adjacent cities
- Genetic diversity is a concern, as many of the populations of Fleshy Owl's Clover are fewer than 100 hundred individuals

INTRODUCTION TO FLESHY OWL'S CLOVER, *CASTILLEJA CAMPESTRIS* SSP. *SUCCULENTA*

Fleshy Owl's Clover *Castilleja campestris* ssp. *succulenta* is a subspecies of Castilleja campestris (Vernal Pool Recovery Plan 2005). It is a member of the Scrophulariaceae family and is an annual, dicotyledonous plant. It is also identified using the common name "Succulent Owl's Clover" (Vernal Pool Recovery Plan 2005). Throughout this report, *C. campestris* ssp. *succulenta* will be referred to as *C. campestris* and Fleshy Owl's Clover, unless stated otherwise. Fleshy Owl's Clover is found in vernal pools, usually at elevations between 50 and 750 meters (Lazar 2006) and typically flowers in April and May (Barbour et al 2007). The fact this species is already listed as a threatened and endangered species by Federal and California State Agencies, respectively (Lazar 2006), and is a vernal pool species [a habitat type that has been on the decline for years (Crampton 1976)], places this plant in a precarious ecological situation. This report will outline why conserving *C. campestris* is important as well as describe the necessary components for the establishment and success of this plant.

Status and Legal Protection

The survival of *C. campestris* is a concern because it is a native species to California (one of may locations under siege by invasive species) and is also specific to vernal pools. Vernal pools are "protected" (so one might argue that as a result, *C. campestris* is as well) under legislature such as the Federal Clean Water Act, The Endangered Species Act, and The Migratory Bird Treaty Act (Resource

Conservation District). However, these acts do not outline specific necessities or management protocol that pertain to any of the endangered species that reside in or utilize vernal pools.

Specific Threats

The expansion of UC Merced Campus, general housing/construction development plans throughout the central valley as well as the typical threats that challenge all vernal pool species, such as climate change and agriculture (Vernal Pool Recovery Plan 2005) are obstacles facing the conservation of Fleshy Owl's Clover. Increases in invasive species and frequency of grazing may also be a threat to *C. campestris* (Vernal Pool Recovery Plan 2005), as they will present competition pressures and compact the soil, respectively. Changes in the water regimes of vernal pools housing *C. campestris* could also prove problematic. Current concerns include the Merced County Stream Channel Project and the proposal to increase the volume of water in Burns Reservoir in Merced County (Vernal Pool Recovery Plan 2005). With less water available, some vernal pools may dry up before favorable germination conditions can be reached. The amount of water that these projects would extract is unknown at this time.

Soil contamination and mining offer further complications to already established populations of *C. campestris* (Vernal Pool Recovery Plan 2005). If pollutants from mining change the soil composition and affect the alkalinity, then it may be impossible for this annual plant to establish itself from year to year due to the harsher conditions. On top of all of these threats, many of the populations (10 of 24) of *C. campestris* are fewer than 100 plants (Vernal Pool Recovery Plan 2005), which renders them vulnerable to disturbances and population bottle necking. The numerous complications facing *C. campestris*, coupled with its status as a threatened and an endangered species, makes understanding this plant from the molecular to ecosystem level crucial to its conservation.

Distribution

Between the years 1937 through 1986, *C. campestris* was surveyed at 33 different sites and every one of these documentations was in the Southern Sierra Foothills Vernal Pool Region (Vernal Pool Recovery Plan 2005). This does not mean that *C. campestris* is not more widely distributed, since it was not the sole focus of these surveys but part of a broader scale operation. There is supporting evidence that Fleshy Owl's Clover has a broader distribution since there was a population surveyed in the SE Sacramento Valley Vernal Pool Region **(**Vernal Pool Recovery Plan 2005). However, the vast majority of *C. campestris* that have been documented have been located in Merced County, specifically northeast of the city of Merced (Vernal Pool Recovery Plan 2005).

Soil Characteristics

C. campestris populations in the Southern Sierra Foothills Vernal Pool Region are associated with numerous different types of soil series, all of which ranged from sandy loam to stony loam to loamy clay (Vernal Pool Recovery Plan 2005). In one study focusing on soil composition and *C. campestris* relations it was discovered that in the University of California-Merced campus and community area the vast majority (80%) were found on Redding gravelly loam and the fewest were found on Keyes gravelly clay loam and Pentz sandy loam (Vernal Pool Recovery Plan 2005). This shows that this Fleshy Owl's Clover prefers larger soil particles but still needs the soil to demonstrate high water retention. With this knowledge, it would not make sense to focus on restoring Fleshy Owl's Clover in an area where the proper, or at least comparable, soils are not present.

Pool Specifications

Pools containing *C. campestris* were typically bowl-shaped with some shaped as swales (long/narrow) (Vernal Pool Recovery Plan 2005). As far as the dimensions are concerned, some studies have shown that populations of *C. campestris* are associated with pools that have an average pool depth of 19cm, with a range of 8cm to 42cm (Lazar 2006) while others found that this species preferred pool depths of 30 to 38cm (Vernal Pool Recovery Plan 2005). These measurements show that, while there are ideal depths for the establishment of *C. campestris*, there is no consensus on pool depth, and further exploration may prove useful. It may also mean that *C. campestris* is capable of thriving in a variety of different pool morphologies.

In addition to the depth, the average pool area was measured, with average recordings of 3,900 m^2. The smallest pool that contained *C. campestris* was 200 m^2 and the largest was 24,500 m^2 (Lazar 2006), findings that highlight the diverse sizes of pools that these plants can exploit. The prevalence of vegetation was also measured in the vernal pools, with average herb cover recorded at 59% of the total area with the least amount of cover being 20% and the highest 97% (Lazar 2006). All documentations of Fleshy Owl's Clover were found with vegetation cover, demonstrating its importance, although it appears that a broad range of percent cover may be acceptable. Other data were recorded measuring pH of the soil, which ranged from 5 to 6.24 (Vernal Pool Recovery Plan 2005), another broad range showing that this species has the potential to fit into multiple vernal pool scenarios. The aforementioned data show that Fleshy Owl's Clover can establish populations in different vernal pools displaying a variety of characteristics.

Ecological Implications

The success of *C. campestris* in vernal pools is highly coupled with the ecological needs of the plant. One factor that is frequently mentioned throughout the primary literature is the species living sympatrically with *C. campestris* in vernal pools. It was found that, in order from most frequent to least, the following species were typically found in the same pools as Fleshy Owl's Clover: *L. fremontii*, *Eryngium* spp., and *Deschampsia danthonioides* (Lazar 2006). Understanding co-inhabitants may be even more important for *C. campestris* than other endangered plant species because it is a hemiparasite. This means that, in addition to producing its own food from photosynthesis, it also extracts water and nutrients from host plants by forming root grafts (Vernal Pool Recovery Plan 2005). Regarding such interactions, *Castilleja* species in general do not need a host to reproduce, however reproduction is increased in the presence of a host plant (Vernal Pool Recovery Plan 2005). It is not clear why *C. campestris* ssp. *succulenta* and these other plants were found sympatrically at such high occurrences, but if *C. campestris* is extracting nutrients from them then they could be fueling its successful reproduction; It would be beneficial to explore these relationships further. In addition, out of the total 67 plants associated with *C. campestris*, 12 of them were invasive (specific species not clarified) (Lazar 2006), meaning that it could have positive and/or negative relationships with these invasives, another topic worthy of further research. It is apparent that there are serious ecological effects that these plants have on each other and if a deeper understanding is gained, then it may increase the efficacy of conservation efforts as well as hinder the invasion of nonnative species.

Further Research

The general ecology of this particular species of plant is not well understood. The necessity of a pollinator is not quite clear. One study suggested that it is self-pollinating (Vernal Pool Recovery Plan 2005) where as another offered generalist bees as possible pollinators because they pollinate numerous related taxa of *Castilleja* (Vernal Pool Recovery Plan 2005). The inconclusive research on pollinations is an important factor, especially if a specific insect population needs to be established before *C. campestris* can reproduce. Populations can increase or decrease by an order of two magnitudes by year (Vernal Pool Recovery Plan 2005), however there were only a few populations monitored in this study. Understanding what fuels this fluctuation, along with elucidating the ideal conditions and timing of germination, could help in future restoration efforts. Also, grazing frequency may also affect vernal pool biodiversity, which is another unexplored topic surrounding *C. campestris.* It is apparent that there are a lot of ecological factors that govern the success of *C. campestris*, as with all organisms, and not all of them are completely or even sufficiently understood. Knowing the environmental demands of this plant will aide in its conservation and perhaps the success of vernal pool ecosystems.

Conclusion

Despite past efforts that have been made to conserve *Castilleja campestris* ssp. *succulenta* this species is still listed as federally threatened and as an endangered species. In continued efforts to conserve *C. campestris,* critical habitat for this species was designated in 2003 (Vernal Pool Recovery Plan 2005). Some of the populations of *C. campestris* are in reserves (governed by Sierra Foothill Conservancy, U.S. Bureau of Land Management, California Department of Fish and Game, California Department of Parks and Recreation, Bureau of Land Management, and U.S. Bureau of Reclamation or a collaboration between some of the aforementioned groups) (Vernal Pool Recovery Plan 2005). Others are located on private land, which offers some protection but does not guarantee benefits to any specific species, so it remains to be seen what will become of such populations (Vernal Pool Recovery Plan 2005). Despite these efforts, there is still a huge threat to *Castilleja campestris* ssp. *succulenta*, as the human population booms (which leads to further development and agricultural expansion), the climate changes, grazing increases due to higher demands for cattle, and the need for water supply increases on a yearly basis, it remains to be seen where this plant, and vernal pools in general, will be situated in years to come.

RESTORATION AND MANAGEMENT AT GRASSLANDS PARK

Introduction

In starting this restoration process, it is an encouraging fact that Fleshy Owl's Clover is found within Yolo County's Grasslands Park vernal pool complex. Though this area is outside of the Southern

Sierra Foothills Vernal Pool Region (the typical geographic range of this plant) many of the pools found in Grasslands Park appear to be suitable habitat for Fleshy Owl's Clover (details to follow). However, despite these similarities, there are still some significant differences between pools preferred by this plant and the pools found in Grasslands Park, which will make the restoration and maintenance of Fleshy Owl's Clover a difficult process. Successful establishment of a larger population of *C. campestris* will require multiple levels of planning, beginning with the collection of seeds for introduction followed by careful monitoring and management plans in subsequent years.

Overall Goals and Determining Failure

Since populations of *C. campestris* fluctuate from year to year (Vernal Pool Recovery Plan 2005) and it is an annual plant, we should give them three to five years to establish themselves (germinate and produce offspring) in a new vernal pool or solidify an existing population by increasing its population numbers to above 100 individuals. If proper germination conditions exist in Grasslands Park, then the seeds should experience it within this three to five year time frame. Information on which vernal pools are suitable for introduction and the method of introduction can be found later in this report.

If no populations are established in any of the pools attempted within 20 years and we have used different, i.e. from various pools in various location, source populations, then this project can be considered a failure. Since there is no research explaining how long seeds of *C. campestris* can lay dormant for, we can assume that after 20 years the seeds are not dormant, they are unable to germinate in the given conditions. Following is an outline of recommendations for introducing *C. campestris*, starting from initial introduction up through year to year monitoring suggestions accompanied with potential costs and benefits of such efforts.

Origin of Seeds

Since Fleshy Owl's Clover is not abundant in this vernal pool region, seeds should be extracted from a different region(s) and introduced. However, the environment of the source population should be considered, since local adaptations may have occurred that could hinder the success of *C. campestris* in Grasslands Park. Finding conditions most similar to Grasslands Park would be ideal, since those populations should be the best adjusted. Previous research has suggested that populations of *C. campestris* may benefit from grazing, however, caution should be taken when using grazing with populations of *C. campestris* that have not previously experienced such pressures (Vernal Pool Recovery Plan 2005). Since Grasslands Park is located in an area affected by grazing, it may be best to select seedlings from a population that has lived sympatrically with cattle or other livestock.

In addition to this, one of the problems facing *C. campestris* is the fact that many of the populations are small and genetic diversity may be threatened (Vernal Pool Recovery Plan 2005). Therefore, more than one population should be used when seedlings are being collected. This should increase the diversity and avoid harming one of the source populations by removing all of their offspring.

Another point of concern is the altitude. Since Fleshy Owl's Clover is typically found at elevations between 50 and 750 meters (Vernal Pool Recovery Plan 2005) then populations from the lower end of this spectrum may be more successful in Grasslands Park, since it is not much higher than sea level. In addition, though the research is limited on inundation periods for *C. campestris*, vernal pools with similar water retention behavior to that of Grasslands Park might offer the most successful specimen.

It is not likely that all of these conditions will be met by many or even one population, so extracting seeds from multiple that meet one of more these criteria may offer the best chance of establishing a population (higher genetic diversity as well). However, cross-pollinating some of these populations with the already established populations should be carried out. If we introduce genes into the already established population of Fleshy Owl's Clover and these genes lower its success, then we will not only have a foiled restoration attempt, but will have doomed the already existing population. If the present population at Grasslands Park is severely threatened and is declining, then we can forego this procedure, since introducing foreign populations may be the only chance of maintaining a population in this region.

Seed Numbers: Temporal and Spatial

Considering that many other populations are still continuing with around 100 individuals (Vernal Pool Recovery Plan 2005) and a restoration project with *C. campestris* has never been documented, smaller numbers may be introduced at first with new seeds planted in subsequent years. This will also help avoid a population bottleneck. A reasonable number may be around 200 seeds for the biggest pool since, considering they are being placed in new conditions, we cannot expect all to germinate. For the other pools, a "seed number" to "vernal pool area" ratio could be used, starting with the "200 seeds":"biggest pool area" as the point of comparison. Germination conditions is an area that needs more research, since populations typically fluctuate (Vernal Pool Recovery Plan 2005), suggesting that Fleshy Owl's Clover may need very specific conditions in order to germinate. Such information will be vital in this restoration effort.

Fleshy Owl's Clover is already found in Grasslands Park, so we may want to introduce it into as many vernal pools as possible. As far as when to introduce these seeds, it may be best to add in the source populations at 4 different points throughout the year, separated by three month intervals. We can then measure which ones, if any, are successful later in the year (details on monitoring to follow). If certain populations thrive while others do not, then it may suggest something about soil temperature or composition at that point in the year that was ideal for Fleshy Owl's Clover. Environmental conditions (air temperature, inundation, etc) as well as soil composition and temperature should be measured in concordance with the month of introduction so that we know what may be stressing or benefiting the plants. This will also erase any confusion between a beneficial time of year (weather patterns, outside temperature) and beneficial soil conditions.

Vernal Pool Specifications

The typical vernal pool size for this plant is as follows:

- Depth: 8 cm and 42 cm, with an average of 18cm (Lazar 2006)
- Area: .07 to 1.61 Acres (Lazar 2006)

According to these measurements, C. campestris appears as if it could thrive (at least in regard to vernal pool size) in any of the vernal pools (Created, 4a, 4, 6, 9a, and 9b), since all are within the preferred area and depth ranges. The depth at where seeds should be placed is not known. A reference site should be used in order to observe 1) The water height and 2) The plant's distance from the bottom of the pool, when they flower. Since the germination timing and conditions are still unclear (Vernal Pool Recovery Plan 2005), this will be a difficult part of the restoration process.

Water and Soil

The preferred water chemistry for Fleshy Owl's Clover as well as the water chemistry of the vernal pools in Grasslands Park is still an unexplored topic. The best approach to this would be to extract the source populations from areas experiencing similar precipitation patterns as well as similar soil composition. However, working with the soil, with its various contaminants, inhabitants, and composition, may prove to be the most difficult part of this entire process.

The vast majority of Fleshy Owl's Clover surveyed in the University of California, Merced and community area was found on gravelly loam, with the fewest being located on clay loam (Vernal Pool Recovery Plan 2005). This could mean that the soil particles at Grasslands Park, which tend to be more silty clay, may be too small compared with the sandy and gravelly loam that this plant is used to rooting in. However, there is still room for optimism: 1) The phenotypic plasticity of this plant is not well understood, so it may adjust accordingly 2) These pools still have the same basic soil constituents, it just may mean that source populations accustomed to soils most similar to Grasslands Park may want to be used for introduction. Aside from particle size, alkalinity should be considered as well. The preferred salinity of *C. campestris* is not known, so this information cannot be incorporated into restoration attempts until further research is conducted. As for pH levels, Fleshy Owl's Clover was typically found on soils with a pH ranging from 5 to 6.24 (Vernal Pool Recovery Plan 2005). The acidity of Grasslands Park's vernal pools was found to be highly variable, so before introduction more conclusive and/or pool specific data should be collected.

Ecological Set Up

Fleshy Owl's Clover is typically found sympatrically, in descending order of co-occurrence, with five other plants (Lazar 2006): 1) Fremont's goldfield 2) Downingia 3) Three colored monkey flower 4) Vernal pool popcorn flower 5) Coyote thistle. However, there is a lack of research that explains the interactions between *C. campestris* and these five plants. Fleshy Owl's Clover is hemiparasitic, so the presence of these other five organisms may aid in establishing populations of *C. campestris*, since they will be facing a new environment and could use an extra source of nutrients. We may want to introduce the five other plants into two vernal pools and *C. campestris* into two others, with only one pool hosting them simultaneously. This may elucidate whether or not Fleshy Owl's Clover needs these other plants present to be introduced as well as the problems it may pose for the other plants as they try and establish new populations themselves.

Another concern is how *C. campestris* is pollinated. There has been discrepancy in past research as to whether or not it is self-pollinated or bee-pollinated (Vernal Pool Recovery Plan 2005. If it is bee pollinated, we have to be certain that the right species of bee (or other unknown pollinator) is present in order for this annual plant to reestablish itself from year to year. However, these topics should be of a concern later in the management process since we will need the seeds to germinate in order for them to be relevant.

Management Strategies and Monitoring Plan

At first it may be useful to try and establish Fleshy Owl's Clover in only one pool, since it may make it difficult for other plants to establish themselves if a hemiparasite is draining their nutrients. If after three to five years this population seems to be established successfully and sympatric plants seem to be doing well, we may want to introduce *C. campestris* to other pools. This could offer insight into its cost and benefits for other plant species. Other options may be to introduce this plant after other plant populations have been established, because as a hemiparasite it may be useful to have already established healthy plant populations to exploit.

If the first attempt at establishment is unsuccessful, then I would suggest introducing these plants into a different vernal pool than the original. Monitoring the success of these plants should be done sometime in June and again in August. The reason for the June visit is that Fleshy Owl's Clover flowers in April and May (Vernal Pool Recovery Plan 2005), and it will be easier to identify/monitor the population's health if we have more growth to examine. The second visit towards the end of summer is recommended to ensure that these plants are surviving once they have flowered, giving them a chance to reproduce. In addition, I would recommend monitoring the source populations once in June as well; if these seeds are germinating and our introduced seeds are not then we will need to know why. Perhaps extracting seeds and placing them back in the same vernal pool they were taken from may help isolate the problem. This way we will know if the simple extraction and replanting is too much of a shock or if there is something problematic about the vernal pools in Grasslands Park that we need to address.

Another suggestion is to try and establish around 50 to 100 individuals in a few different pools. If certain populations are able to establish and others are not, then it will be beneficial to examine specific differences between the multiple habitats and understand what *C. campestris* requires for germination/successful establishment. This is probably the best option because we will be able to leave some pools free of *C. campestris* and we will be able to make comparisons across a few different restoration efforts. However, depending on how big of an impact we believe a hemiparasite will have on the other species, this could be detrimental to other plants' success. As far as monitoring is concerned, this option will require the same program as mentioned above.

The introduction of the seed is just the first step in the management process, as there are many other facets that require attention. Not much is known about Fleshy Owl's Clover and the benefits/problems of grazing, so we should be careful with how much we allow livestock into the area. However, Marty 2004 found that pools that are grazed continuously (October through June) had the highest number of natives. For Fleshy Owl's Clover, since it is a California native, a similar regime may be beneficial. More research is needed in order to make the best decision. Though direct interactions between *C. campestris* and invasive plants are not well understood, grazing does help diminish the invasive populations (Marty 2004). Grazing should be used for this purpose as well, with grazing between October and June once again being the most effective at targeting invasives (Marty 2004). As far as human traffic is concerned, more information is also needed, but it seems that the more infrequent visits the better. Introduced seeds will already be under enough stress to germinate so added pollutants may make it impossible. Also, as mentioned earlier in this report, *C. campestris* is most commonly found in larger soil particles, so soil compaction may increase the difficulty of establishing new populations.

Benefits and Research

There are numerous unexplored areas of research surrounding Fleshy Owl's Clover. Once this population is established, we will be able to monitor and understand a lot of helpful topics. In addition to those mentioned throughout the report, we may also understand: 1) How well larger populations of *C. campestris* can do outside of its typical range 2) Depending on the success of the plants after they germinate, what levels of adaptive radiation this species has experienced. Monitoring the success of this project at the June and August intervals and recording detailed data could lead to better protection for already established populations as well as set the stage for the introduction of Fleshy Owl's Clover into other vernal pools, a huge step in the conservation of this species.

SYNTHESIS OF *CASTILLEJA CAMPESTRIS* AND THE OVERALL GOALS

It is an extremely difficult process to restore vernal pools at Grasslands Park and try to meet all of the specific needs of their inhabitants in the process. Some species will benefit from the same management practices, while others will have opposing needs, and we must do our best to compromise and prioritize. As far as Fleshy Owl's Clover is concerned, it is a poorly understood species, so fitting it into the overall goal with complete confidence will be difficult. Grazing is one of the more difficult management topics, and it seemed that few plants or animals were indifferent to such pressures. *C. campestris* does not need grazing to be successful and has been found to survive with grazing pressure, so it should fit well with however grazing is regulated, as long as livestock are not aloud to graze October through June at their leisure. One huge benefit that we have in managing for *C. campestris* is that appears to be a decent fit for any of the vernal pools in Grasslands Park. However this may be due to the lack of research regarding its specific preferences and only introducing these plants will confirm or refute its compatibility. Managing Fleshy Owl's Clover should not require any extra attention and it should fit with any reasonable management plan (at least two to three site visits per year) since it is already established, albeit in small numbers, in Grasslands Park and seems to be able to withstand the major pressures (human and agricultural), inundation periods, ecological factors, and weather patterns that are already present in this vernal pool area. However, if further populations of Fleshy Owl's Clover fail to establish after the initial introduction, courses of action like those mentioned in this paper, such as using different pools in Grasslands Park or extracting seeds from different source populations, may need to be taken.

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Other native plants

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ENH 160

Distichlis spicata – Saltgrass Restoration Plan:

- Saltgrass information sheet
- Part I: Saltgrass restoration background, justification and literature review
- Part II: Saltgrass restoration goals and management plans
- References

Distichlis spicata – Saltgrass

Species Characteristics

- Native grass species from the Poaceae family
- Perennial species growing to a height of 6 to 18 inches
- Dioecious breeding, associated with a higher cost of female (versus male) reproduction which can cause spatial segregation of the sexes
- Flowers between May and September
- Pollination: wind; seed dispersal: wind, water, animal
- Typically low seed production, but seeds can remain dormant in seed bank for at least 4 years
- Seed germination has a 70-90% success rate and requires temperature of 68 ^{0}F or 20 ^{0}C

Habitat Requirements

- Distributed among moist valley and foothill grasslands, along margins of vernal pools and swales and in salt marshes
- Sandy, saline, alkaline soils with poor drainage
- Highly tolerant of salinity and a wide range of pH levels
- Shade intolerant
- Irregularly flooded pools and swales, water depth varying between 2 inches above soil water and 6 inches below soil surface

Plant and Animal Interactions

- Observed growing along margins of vernal pools and along swales with *Trifolium depauperatum* var. *hydrophilum*, saline clover and *Cotula coronopifolia*, brass buttons
- Essential feeding and resting habitat for the endangered *Pseudocopaeodes eunus obscurus,* Carson wandering skipper butterfly (distributed among grasslands and alkaline substrates)
- *Reithrodontomys raviventris,* Salt Marsh Harvest Mouse, also highly dependent on dense salt marsh vegetation such as saltgrass for sources of food and protection

Threat: Habitat Loss

- Populations in decline as a result of historic and current wetland and vernal pool habitat loss; more than 90% of original wetlands have been lost in California, the most loss experienced by any state in America
- In Central Valley, almost all vernal pool habitats have been altered, and about 66% or 11,310 km^2, have been destroyed; destruction in Central Valley is a result of agricultural and urban development, hydrologic regime alteration and channelization, grazing, fire and introduced species
- Specific threats to saltgrass (other than habitat loss) are unknown

Conservation and Management

- Section 401 of the Clean Water Act provides legal protection specifically for wetlands by instating water quality standards, designated uses and criteria, nonpoint source runoff filtration and an anti-degradation policy
- Endangered Species Act requires protection of critical habitat for the survival and recovery of listed species; saltgrass may not be listed as an endangered species throughout its entire distribution, it is essential for the survival of other endangered species such as CWS butterfly and Salt Marsh Harvest Mouse

- Saltgrass has an adaptive fire regime and is able to establish after fire through seedling establishment or lateral spread via rhizomes
- More information is needed on management measures and the spatial and temporal scales those measures need to occur

Saltgrass Restoration: Part I

I. Background and Justification

Species Characteristics

Distichlis spicata, commonly known as saltgrass, is a grass species from the Poaceae family and is native to North and South America. Saltgrass is widely distributed among salt marshes and salt flats along the Atlantic, Pacific and Gulf Coast. Saltgrass is also distributed among moist valley and foothill grasslands, as well as along margins of vernal pools and swales (USDA 2010). Under favorable conditions, saltgrass can grow in thick monotypic stands and clonal colonies of stiff grass.

Saltgrass is a valuable species to be targeted for restoration because it is an important colonizer in vernal pools and salt marshes recovering from disturbances such as major storms (Seliskar & Gallagher 2000). Not only can saltgrass grow in disturbed areas, it is a species that will aid restoration by promoting post-disturbance succession. Saltgrass restoration is essential as vernal pool destruction and degradation in the United States and globally continues to increase. Without the available habitat, saltgrass will not survive to provide its benefits.

Plant and Animal Interactions

Restoring saltgrass habitat is important and holds conservation value not only for salt marsh stability, but also for community and ecosystem interactions. There are many examples of species that depend on saltgrass for feeding and resting habitat such as *Pseudocopaeodes eunus obscurus*, commonly known as the Carson wandering skipper butterfly (CWS). Populations of CWS began suffering in the 1980s and 1990s when local habitat was lost to development (Sanford 2006). In 2001 the US Fish and Wildlife Service considered CWS to be high priority, and listed it for protection under the Endangered Species Act. CWS is distributed among grassland habitats and alkaline subtrates (Sanford 2006). Its two habitat requirements are larvae host plants and adult nectar; CWS larvae specilize on saltgrass and depend on saltgrass herbivory for survival (Sanford 2006). Sanford (2006) showed that as saltgrass communities receeded, CWS range consequently retracted. Since CWS is protected under the Endangered Species Act, protection can be extended to saltgrass as critical habitat for the butterfly.

Another example is *Anas cyanoptera*, commonly known as cinnamon teal (Seliskar & Gallagher 2000). Thorn and Zwank (1993) showed that during spring migration, one of the three food habitats most consumed by the cinnamon teal was saltgrass in vernal pools. Although not included in the discussion of vernal pool restoration, *Reithrodontomys raviventris,* commonly known as the Salt Marsh Harvest Mouse, is highly dependent on dense vegetation such as saltgrass, utilizing saltgrass for food and high tide protection (Whitaker et al. 2008). Therefore, saltgrass conservation is essential as endangered species and special interest species alike depend on its habitat for feeding and resting.

History of Degradation

The current state of the target goal for saltgrass restoration is establishing saltgrass seedlings in either intact habitats or in post-disturbance habitats. Populations of saltgrass are in decline as a result of historic and current wetland and vernal pool habitat loss. In California, more than 90% of original wetlands have been lost, the most loss experienced by any state in America (NOAA 2010). In California's Central Valley, almost all vernal pool habitats have been altered, and about 66% or 11,310 km^2, have been destroyed (WWF 2001). Alteration and destruction in the Central Valley is a result of agricultural and urban development, hydrologic regime alteration and channelization, grazing, fire and introduced species (WWF 2001).

Laws and Policies

National laws and policies have been passed to constrain further habitat destruction and achieve the target goal for saltgrass restoration. One example is the Clean Water Act of 1972 (CWA), known as the "cornerstone of surface water quality protection in the United States" (EPA 2008). Section 401 of the CWA provides legal protection specifically for wetlands (including saltgrass habitat) by instating water quality standards, designated uses and criteria, nonpoint source runoff filtration and an anti-degradation policy (EPA 2010).

Another national policy passed to constrain further habitat destruction and achieve saltgrass restoration is the Endangered Species Act (ESA) of 1973. Saltgrass may not be listed as an endangered species throughout its entire distribution, it is essential for the survival of other endangered species such as CWS butterfly and Salt Marsh Harvest Mouse. Therefore, it is illegal under the ESA to "harm or take" saltgrass since it is critical habitat for the survival and recovery of other listed species.

In addition to providing protection for saltgrass, the ESA may also be a potential source of funding for saltgrass restoration goals. For example, the CWS butterfly is a charismatic species that will draw attention and funding. Since part of the effort for protecting endangered species is ensuring their food source—saltgrass—funding allocated to CWS could also be allocated to saltgrass restoration.

II. Literature Review

The main factor affecting saltgrass restoration is habitat destruction as a result of anthropogenic land use and development. Habitat destruction is not only detrimental at the species level, but it also negatively impacts entire communities and ecosystem functions. Other than habitat destruction, which affects most vernal pool species, specific threats to saltgrass survival are unknown. Before saltgrass restoration targets are made, basic information is needed to know what makes saltgrass thrive.

Species and Vernal Pool Characteristics

According to USDA (2010) characteristics of saltgrass growth and biology include:

- Native perennial species
- Shallow-rooted
- Can grow to a height of 6 to 18 inches
- Dioecious breeding
- Flowers between May and September
- Wind pollinated
- Seed dispersal by wind, water and animal
- Grows from hard and scaly rhizomes as germination and seedling emergence is often problematic

And according to Silveira (2000) and NRCS (2010), saltgrass characteristics specific vernal pools are:

- Growth in moist valley and foothill grasslands and along margins of vernal pools and swales
- Mostly commonly found in small basins in moist, sandy, saline and alkaline soils
- Irregularly flooded and water depth varying between 2 inches above soil surface and 6 inches below soil surface

One adaptation enabling saltgrass to be widely distributed in saline soils is its ability to exclude salt. Salt exclusion occurs at the plants' roots and is a result of reverse osmosis, allowing roots to only absorb freshwater from the saline water (Mitsch & Gosselink 1993). Physical evidence of salt tolerance can be observed by examining saltgrass leaf blades, which contain salt crystals from highly saline environments where salt has been excluded (Glenn et al. 1999).

Another unique saltgrass characteristic is dioecious breeding. Dioecious plants are characterized by their separate sexes, having male and female organs in distinct individuals. There have been speculations over whether dioecious plants have an evolutionary advantage, which could also have implications for saltgrass restoration. Eppley (2006) found higher costs associated with female versus male reproduction, resulting in spatial segregation of males and females. This study also showed that males and females were found to have different competitive abilities causing sex ratio variation seen as early as the seedling stage in saltgrass (Eppley 2006).

Response to Climate Change and Management Practices

In addition to considering saltgrass' characteristics, it is important to determine how environmental variation and threats such as climate change impact saltgrass restoration. Research has been conducted on how climate change may negatively impact saltgrass in salt marsh habitats due to sea level rise, however, little has been written on impacts in vernal pool ecosystems.

The effects of common management measures such as grazing and fire in vernal pools need to be understood in order to prevent further threats to saltgrass survival. Grazing can have variable impacts on vernal pool species, but the effects of grazing on saltgrass survival remain unknown. Some information is available on the effects of fire on saltgrass survival. Saltgrass establishes by seedling establishment or lateral spread via rhizomes after minor fire disturbances due to its adaptive fire regime. However, more information is needed on the timing and intensity of the fire that can occur and still allow for saltgrass reestablishment (USDA 2010).

With every restoration project there are some levels of constraint and uncertainty which must be addressed in the target goals. Other than uncertainty and lack of information, another practical constraint is funding. Although a species may be an important part of an ecosystem, the costs may outweigh the benefits. A price cannot be placed on the ecosystem functions saltgrass provides such as ecosystem stability and plant-animal interactions.

Saltgrass Restoration: Part II

I. Goals

Preferred Habitat

The key goal for saltgrass restoration is providing ideal habitat for growth and survival. It is difficult to completely understand the ideal habitat for saltgrass because information about threats to survival is unavailable. It is clear however, that saltgrass has growth preferences specific to vernal pool ecosystems. Preferred habitat characteristics include moist valley and foothill grasslands; margins of vernal pools and swales; moist, sandy, saline and alkaline soils; small basins with irregular flooding; and areas with water depth varying between maximum 2 inches above soil surface and minimum 6 inches below soil surface (USDA 2010). Several of these characteristics are present in the Yolo County Grasslands Regional Park, the area targeted for restoration.

One essential goal of saltgrass restoration is ensuring that preferred soil type is chosen—sandy, saline and alkaline. Saltgrass is adapted to thrive in saline and alkaline soils; therefore, it is necessary to include it in the restoration plan. Grasslands Park features preferred soil types (pescadero soil) and salinity levels in two vernal pool complexes, R4 and R4A, which would be ideal for saltgrass restoration. Pools R4 and R4A also feature shallow depth, complex connections and disturbances (invasive species or agriculture proximity).

Several other vernal pool species, such as *Tuctoria mucronata* (Solano grass), *Astragalus tener* var. *tener* (Alkali milk-vetch) and special status native *Atriplex Joaquiniana* (San Joaquin Spearscale) will also benefit from this goal as they prefer saline and alkaline soils. The species listed above are present in Grasslands Park and their restoration would complement goals for saltgrass restoration. However, one tradeoff is that not all vernal pool species will be adapted to saline or alkaline soils. Drafting a restoration plan with this in consideration might include some kind of salinity threshold where certain pools have less saline conditions.

Irregular flooding is another saltgrass habitat requirement that should be considered as a goal in saltgrass restoration. Saltgrass prefers small basins with poor drainage and irregular flooding; a tradeoff to this restoration goal may be that other vernal pool species need long periods of inundation to survive (USDA 2010). One way to compromise to suit the requirements of a bigger species range is to allocate saltgrass seeding to areas of higher elevation or slopes that are less prone to long periods of flooding.

The establishment of both saline soil and irregularly flooded conditions would be long term goals centered on small-scale restoration. These goals need to be long term because they are promoting habitat requirements that are essential to saltgrass growth. These goals can be small-scale restoration targets because the saltgrass population is not confirmed to be threatened by any specific action (other than habitat loss). These goals can be reached by designating habitat in the R4 and R4A vernal pool complexes in Grasslands Park. Since these areas are already known to have the desired soil and water conditions, saltgrass restoration can begin on a small-scale in those complexes.

II. Restoration Plan

Adaptive Management

Since little is known about threats and need for saltgrass restoration, the drafted restoration plan for Grasslands Park will follow an adaptive management framework. Adaptive management is a decision making tool focused on learning and adapting. Adaptive management requires alliances among managers, scientists and stakeholders working together to create and maintain sustainable ecosystems (Department of Interior 2007). The Conservation Measures Partnerships published “Open Standard for the Practice of Conservation” including an adaptive management framework with the following steps: (1) conceptualize, (2) action plan, (3) implement and monitor, (4) analyze and adapt, (5) capture and share learning. Adaptive management presumes facts from scientific experiments are conditional and focuses on managing resources through a learning process (Grumbine 1994).

Methodology

To conceptualize and draft a restoration plan, factors such as the methods of restoration need to be considered. The methodology of restoration will include transplanting saltgrass seedlings, since seedling reestablishment is the natural strategy after fire or other disturbances. Since the spatial scale of the restoration plan will be small, the number of transplanted seedlings will start small (10-15) per pool, where each vernal pool complex features 2-4 pools. The exact number of seedlings is an estimate and should change once the observed transplanting locations are surveyed for space availability and quality (recommendations are based on the city of Mill Valley, Parks and Recreation Department Bayfront Park Wetland Mitigation Plan of 2007).

The temporal scale of the restoration plan will be long-term, at least five years to ensure saltgrass growth and survival (MV Parks and Recreation Department 2007). The long-term restoration plan will also including monitoring techniques, as evaluating the success of the plan for revision is an important part of adaptive management.

Monitoring

Monitoring will be conducted pre- and post-restoration, both of equal intensity as they are of equal importance. Pre-restoration monitoring will be conducted for one year on each of the vernal pool complexes chosen to introduce saltgrass seedlings. Pre-restoration monitoring will include water depth (if possible along margins), water temperature, water quality, conductivity and pH. By comparison to existing data, these measures could provide specific information about the environmental conditions in the vernal pool complexes before saltgrass transplanting begins.

Post-restoration monitoring will be conducted for five years and will include qualitative and quantitative measures of saltgrass success and growth in each of the designated areas (MV Parks and Recreation Department 2007). Qualitative measures will include general observations on growth (color, appearance, etc.) and evidence of herbivory. Quantitative measures will evaluate success and plant-animal interactions by saltgrass growth measurements as well as growth measurements of surrounding species.

If saltgrass seedlings fail to establish, then indicators (such as soil and water data collected pre-restoration) of each failing site will be considered and revised based on the adaptive management framework.

Problems and constraints

Potential problems that might arise are lack of cooperation and funding. Cooperation among managers, scientists and stakeholders may be difficult due to differing goals—conservation versus land value for example. Even if conservation is the only value, cooperation will still be difficult because the habitat requirements of saltgrass may not coincide with the habitat requirements of other vernal pool species. Lack of funding may be another problem because it is expensive to restore a species that requires constant monitoring and evaluation.

Ecological problems, such as herbivory or invasion should also be considered in the saltgrass restoration plan. There is the possibility of the saltgrass seedlings suffering from herbivory by other species. There is also the possibility of saltgrass seedlings expanding their native range and becoming invasive. Since it is difficult to predict these ecological problems, they are included in the post-restoration monitoring plan. And if they become an issue, herbivory or invasion will be included in a revision of the restoration plan following the adaptive management framework.

There is a high level of risk and uncertainty with this restoration plan because key information remains unknown regarding threats to saltgrass survival. The plan is associated with a high level of risk because if it is apparent that saltgrass populations have no specific threats (other than general vernal pool habitat loss), the effort and money spent may not seem worthwhile. However, that information is essential and would improve the saltgrass restoration plan.

Research questions

This restoration plan will help answer research questions such as ideal growth conditions for saltgrass in vernal pool habitats. Restoring saltgrass in the Grasslands Park vernal pool complexes may provide more insight into saltgrass' ecosystem role. Restoration could also address what other plant and animal species are able to coexist with saltgrass. Little information on each of these questions is available, so expanding the knowledge base with specific data would be beneficial.

It will also be important to learn how specific management actions impact saltgrass growth and survival. For example, grazing actively occurs in Grasslands Park to control for invasive species such as *Centaurea solstitialis,* commonly known as Yellow star thistle. The timing and intensity of grazing could have some impacts on saltgrass growth, and it is essential that those impacts are known. Another management action could be fire. Although it is known that saltgrass has an adaptive fire regime, specifics about timing and intensity of fire remain unknown. Monitoring saltgrass restoration while these management practices are occurring will provide more insight and useful data.

All of these research questions, and anything else that arises, can be answered with data from pre- and post-restoration monitoring. Quantitative measurements such as water depth, water temperature, conductivity and pH will provide more data on vernal pool conditions. Qualitative observational measurements will provide specific data on which plant and animal species successfully coexist in the Grasslands Park vernal pool complexes. All of the data acquired while monitoring will be used to improve the restoration plan while considering the adaptive management framework.

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ENH 160

3 June 2010

Fremont's Goldfields: *Lasthenia fremontii*

Part I: Background and Justification

Goals

The goals regarding *Lasthenia fremontii*, Fremont's Goldfields, are

1. maintain the presence of this species in the vernal pools of the Central Valley of California
2. restore the species to Central Valley vernal pools where it historically occurred
3. maintain the genetic diversity of the species

Lasthenia fremontii presents a compelling case for conservation not with the typical sense of urgency surrounding threatened and endangered species but with the importance of preventing the decline of a charismatic endemic that resides in threatened habitats. This species forms part of the species assemblages in many vernal pool systems in the Central Valley to which it is endemic (Calflora, 2010). It is also found in alkali vernal pools such as in the Sacramento National Wildlife Refuge (Silveira, 2000). Even though *Lasthenia* *fremontii* is not listed by any agency in the state or federal government as threatened or endangered, vernal pools face ever-increasing threats. It is therefore important to protect existing populations of *Lasthenia fremontii* and restore historic populations to maintain the biodiversity of vernal pools. More data should be gathered to assess the state-wide abundance of *Lasthenia fremontii*, and records of historic populations should be compiled to address restoration of the species in areas where it is not currently found. Although *Lasthenia fremontii* is common across the remaining California vernal pools, the decline in abundance from pre-European colonization levels probably mirrors the decline in vernal pool abundance, which has dropped to about 10% of the original level (Neale et al., 2008).

With the current state of knowledge on conservation, there is the opportunity to not only save species on the edge of extinction but also to prevent the decline of species that are at risk for decline in the future. To be able to forestall the endangerment of this species and the genetic impoverishment that often results would be a notable achievement for conservation. The genus is well known by wildflower enthusiasts, so even though *Lasthenia fremontii* is restricted to vernal pools, it is easily recognizable as a goldfields species and can therefore serve to bring awareness to the plight of vernal pools throughout California as a flagship species. The protection of *Lasthenia fremontii* might serve to protect other vernal pool species and their ecological interactions within its broad distribution.

Characteristics and Biology

There are 17 species of *Lasthenia*, a genus in the Asteraceae family, and most of which are found in the western United States (Plants Database, 2010). *Lasthenia fremontii* is an annual or perennial herb found between sea level and 2300 feet in California (Calflora, 2010). The plant produces small yellow inflorescences in dense patches that give rise to the name goldfields. The inflorescences are composed of both ray and disk florets, which resemble true flowers (Ornduff, 2010) and bloom March through May (Witham, 2010). *Lasthenia fremontii* is self-incompatible and therefore an outcrossing species.

Lasthenia fremontii is found within the high water lines of vernal pools (Schlising and Sanders, 1982) and reaches its highest densities on pool bottoms (Emery et al., 2009). It is an obligate wetland species which means that it requires wetlands at some point during its life cycle (Plants Database, 2010). Emery's study of *Lasthenia fremontii* at Mather Field lends support for the hypothesis that adaptation to environmental stresses keeps this species from invading the pool edges and the edges species from invading the pool bottoms (Emery et al., 2009). Drought and inundation tolerances are the most likely abiotic factors influencing these distributions within pools (Emery et al., 2009). Although competition among species is important, it is not the only factor contributing to their distributions within pools because the seasonal wet-dry cycles to which they are adapted impose other restrictions (Emery et al., 2009).

In one study of *Lasthenia fremontii*, the species was found to have genetic differences across the pools as the water receded slowly causing individual plants to bloom according to their position in relation to the water level, which resulted in pollination amongst those individuals blooming at the time (Emery, 2009). This did not appear to be an adaptive mechanism but rather one that might impose inbreeding depression in extreme circumstances (Emery, 2009).

Threats

Threats to *Lasthenia fremontii* entail specific threats like their preferred inundation depths and duration and more general threats that vernal pools across California face. In one study involving *Lasthenia conjugens*, a closely-related species, late spring rains in 2006 killed many vernal pool plants at a study site in central California (Collinge and Ray, 2009). In the experimental pools in which the focal species were planted, *Lasthenia conjugens* decreased precipitously in abundance by 81% compared to the previous year (Collinge and Ray, 2009), which lends support for the hypothesis that drought and inundation tolerance are key factors in determining survival and distribution. Climate change could affect the frequency of long inundation or short inundation or alter the weather patterns so as to disrupt the life cycle of *Lasthenia fremontii*. *Lasthenia conjugens* relies on animal pollination for seed set (Neale et al., 2008), as does *Lasthenia fremontii*, which is pollinated by insects including solitary bees and bee flies (Emery, 2009). Emery noted that *Lasthenia fremontii* does not have dispersal mechanisms for its seeds other than falling near the parent (Emery, 2009). In terms of genetic dispersal, *Lasthenia fremontii* would be reliant on pollinators because the seeds do not disperse far (Emery, 2009). However, solitary bees face competition from European bees, habitat loss, and pesticides (Black et al., 2009).

Invasive species that threaten vernal pool species probably threaten *Lasthenia fremontii* as well.

Policies

As a common species without a special designation for threat, *Lasthenia fremontii* would not have the backing of law for its conservation. However, it may be possible to conserve some populations of *Lasthenia fremontii* under legislation for protected vernal pool species where their ranges overlap. *Lasthenia fremontii* currently finds protection under the federal "No Net Loss of Wetlands" policy, but the mitigation involved often creates wetlands unlike those that were lost or fails to restore or create functional wetlands at all (Whigham, 1999). The California Environmental Quality Act requires identification of threats to the environment, including vernal pools, and action to avoid or mitigate those impacts (CERES, 2010). It is important to work within the legislation to conserve this species and its ecological interactions.

Funding Sources

There are numerous sources of funding for restoration of vernal pools. Funding would probably be easiest to obtain for vernal pools or complexes rather than individual species because vernal pools are composed of communities of organisms that affect each other. Some examples of funding for vernal pool research are grants from organizations like the California state government, city councils, and various non-profit organizations. One example from California is the use of a $500,000 federal Endangered Species Act grant to conserve vernal pool habitats in the San Diego area (City News Service, 2010). An example of funding from the state level is the application of grants through the Habitat Conservation Fund, which stipulates dollar-for-dollar matching funds but encourages cooperation among groups ranging from government agencies to non-profit organizations to schools to help raise funds (California State Parks, 2010). Some of the matching dollars can even be in the form of materials and services (California State Parks, 2010).

Questions for Further Research

The lack of information on *Lasthenia fremontii* suggests questions for further research:

What role does *Lasthenia fremontii* play in the local ecology of vernal pools?

Does it provide shelter for small animals?

Does the presence of pollinators for *Lasthenia fremontii* facilitate pollination for other vernal pool species?

What is the genetic distribution throughout California?

Are there populations with unique genetics?

How large is a typical seed bank, and how long can the seed bank persist?

How do populations fluctuate within pools over years to decades?

What are the impacts of invasive species?

Part II: Goals and Management Plans

Goals

The goals regarding *Lasthenia fremontii*, Fremont's Goldfields, are

1. maintain the presence of this species in the vernal pools of the Central Valley of California
2. restore the species to Central Valley vernal pools where it historically occurred
3. maintain the genetic diversity of the species

1. Maintain the presence of this species in the vernal pools of the Central Valley of California.

This goal may seem easy at the outset, but this requires that the majority of the remaining vernal pools in California stay intact. This goal is contingent upon preventing the destruction of any more natural vernal pools. There is considerable pressure to develop the lands containing vernal pools as well as to convert those lands to agriculture. Preserving all current vernal pools in California is not likely to happen, so planning for restoration and creation of new pools is necessary.

This goal would encompass a huge area of land from large vernal pool complexes to small, disjunct vernal pools. Pools both on protected lands and private lands would need to be considered especially since a large number of vernal pools lie on private lands.

The time frame for implementing greater protection to pools than currently exists could be gradual so long as the rate of vernal pool destruction does not increase above the current rate. However, the "No Net Loss of Wetlands" policy does not mandate assessment of ecological equality and instead focuses on the number and size of the wetlands, which has the effect of producing mitigation that often fails to produce the same ecological interactions and species assemblages. While this policy is federal, the California government can address these issues with new state legislation.

If the majority of vernal pools gain additional protection, that will not allow those areas to be developed as might be desired in this populous state. However, the remaining 10% of the original vernal pools is important to protect as a legacy for the future.

In the course of destruction of vernal pools as permitted after careful analysis and planning, mitigation for these vernal pools is required as part of the "No Net Loss of Wetlands" policy. The mitigation should be as close to the destroyed pools as feasible but in an area that has been evaluated as suitable for vernal pools and matches as closely as possible the geology and soil type of the destroyed pools. Careful analysis and adherence to the restoration and/or creation of pools is vital because too many mitigation plans fall through due to failed restoration techniques or leaving the pools unfinished for various reasons such as funding.

2. Restore the species to Central Valley vernal pools where it historically occurred.

This goal will likely be difficult. Records about species occurrences can be spotty to nonexistent. However, comparing vernal pools with and without *Lasthenia fremontii* can allow for inferences to be made on locations that might have had *Lasthenia fremontii*. Available herbarium records will aid this goal tremendously.

The time frame for this is relaxed because the populations of *Lasthenia fremontii* are stable. This goal should be implemented after established populations gain more protection.

3. Maintain the genetic diversity of the species.

Genetic diversity can be maintained by ensuring that a number of genetically different populations are protected throughout the state. If enough pools are protected, a good portion of the genetic variation within *Lasthenia fremontii* will be protected. Pools that represent unique genetics should have a priority for protection so that they don't get lost to development or stochastic events.

Genetic analyses using DNA microsatellite markers or similar techniques like AFLP along with gel sequencing provide information that can be used to determine allele frequencies among populations. It would be important to protect populations with statistically significant differences in allele frequencies or uncommon alleles. Targeting populations to sequence can be simplified by sampling populations across vernal pool types affected by different environmental stresses. Populations tend to be most genetically divergent under differing conditions such as climate, soil type, and interspecific interactions. These differences can be attributed to both evolutionary adaptation and chance.

Maintaining genetic diversity will be an ongoing issue. However, protection of a sufficient number of pools will minimize the effort needed to achieve this goal. Ongoing monitoring of the genetics will keep tabs on how well the goal is being achieved. Monitoring will be time intensive.

Restoration Plan

General Focus

The primary focus of the restoration plan is monitoring the abundance and distribution of *Lasthenia fremontii*. The restoration plan secondarily focuses on reintroduction to natural pools and introduction to created pools as well as research into the biology of the species in order to gain a better understanding of its preservation and its ecological functions.

Course of Action

Catalog all populations of *Lasthenia fremontii* to be able to get a feel for the scope of what needs protection. Record small scale within-pool distributions, mid scale across complexes of pools, and large scale groupings across the state.

Evaluate which lands will be easiest to increase protection of vernal pools as well as which vernal pools will suit the requirement of a variety of populations of *Lasthenia fremontii*. The criteria for selection should involve the cost to protect; threat and immediacy of destruction; proximity to other developments or agriculture; and economic, ecological, and genetic value.

Sample the genetics of many vernal pools throughout the state and highlight unique populations. Genetically distinct populations should be preserved as a form of diversity (intraspecific) and to preserve the species' ability to cope with climate change and different habitats. Identifying key areas of genetic differentiation will also enable selection of populations to focus on preserving to make the most out of available funds.

Compile the information from the previous steps to decide which pools to protect from destruction (no option for mitigation) and to decide what uses can occur on the land such as grazing, recreation, etc. *Lasthenia fremontii* may be tolerant of grazing due to its statewide abundance, so this activity would be allowable at a level consistent with the requirements of rare species that have priority at those locations. Recreation such as hiking and wildflower observation should be allowed to the extent that the pools are not entered when water is standing. This seems to be the best practice for other vernal pool species due to the fragile nature of pools when wet.

Determine sites that require restoration. Seed will need to be collected from nearby sites of the same pool type from several pools while making sure to sample across individual pool when sampling from larger pools. This follows the local seed sourcing model while taking into consideration adequate genetic diversity. Genetic sequencing of potential seed sources is ideal, but selecting from the same pool type can be used as a surrogate for DNA analysis. This follows that populations in similar environments have more similar genetic compositions than populations in different environments. Restoration sites might benefit from wide sampling due to the outcrossing nature of *Lasthenia fremontii*. This is also in light of the propensity for inbreeding in this species. Seed can be collected under the conventional guideline of less than five percent of the seed of each source population. Statewide abundance is good, so subsequent collections from strong populations at ten year intervals are allowable. One seed head from each plant in the collection group is standard.

Seeds could be applied within the first one or two years to establish a population, but continued application of seeds does not seem to affect the dominance of the species once the vernal pool species establish (Emery, 2009).

Determination of steps to achieving the goals will probably take a few years. This is reasonable to assume because the amount of information collected would be vast.

Lasthenia fremontii is common at present and can survive well enough until some decisions are implemented on the ground unless the rate of vernal pool degradation increases. The information and decision making will involve consideration of the entire Central Valley.

After decisions to protect the species, monitoring of the populations should begin. The first steps in performing field work can be considered data collection for the purpose of deciding what to protect, but decisions will continue to be made in the face of ongoing data collection.

Monitoring should involve abundance, distribution, phenology, genetics, and interactions with people and other organisms. Not much is known about the effects of grazing on *Lasthenia fremontii*, so this will be an opportunity to shift from monitoring to studying with a question in mind. Conventional quadrat sampling during spring when the plants flower (March through May) gives abundance within pools that can be extrapolated to the statewide abundance. Due to the annual lifecycle of most individuals, monitoring should occur yearly for at least ten years to account for yearly fluctuations. Once the general trend is established, monitoring should occur no less than every three years. Annual species like *Lasthenia fremontii* can change in abundance every year, so frequent monitoring is essential to get signals of declining trends.

Potential problems that arise are limited funds and jurisdiction to assume control of vernal pools containing *Lasthenia fremontii*. Genetic sampling and yearly monitoring are labor intensive and costly but less so than restoration activities. The goal of conservation is less costly than restoration.

In order to improve the plan, some questions should be addressed. Questions about the general biology, inundation depth and duration, and ecological function will help with restoration practices. The species interactions are not well-known, including those with invasive species, so this could improve restoration. The benefit of a wide-ranging species allows for multiple comparisons and experimental designs.

Part III: Synthesis of Goals

The goals and restoration practices for *Lasthenia fremontii* fit well with most of the key goals for the other vernal pool species in the compilation of the species cases. Because *Lasthenia fremontii* is a broad-ranging species, it can do well with different strategies for restoration as long as the pools are deep enough to provide adequate inundation for optimal growth. This does, however, conflict with goals for species that require short inundation periods in shallow pools. The literature does not state the inundation requirements for *Lasthenia fremontii* and makes note of the wide distribution, so the short inundation and shallow pool requirements of other species might not exclude *Lasthenia fremontii* from establishing and maintaining healthy populations in restoration sites or created pools. *Lasthenia fremontii* could be added to restoration pools for diversity without as much worry if the species fails to establish because it is not threatened.

Fact Sheet for Fremont's Goldfields/Vernal Pool Goldfields, *Lasthenia fremontii*

Species characteristics:

Lasthenia fremontii is an annual herbaceous plant in the daisy family, Asteraceae.

It has bright yellow inflorescences composed of both ray and disk florets that combine to resemble a flower. The species blooms March through May and is self-incompatible (an outcrossing species).

It is one of seventeen species of goldfields (*Lasthenia*), which are found predominantly in the western United States at low elevations (sea level to 2300 feet).

It grows in dense patches giving rise to the name goldfields.

As an obligate wetland species, it is found only in vernal pools including alkali vernal pools, and wet meadows. It is restricted to intermediate pool depths and found almost exclusively within the high-water line of pools.

Although it is endemic to the Central Valley of California, it is a common species and not listed as endangered or threatened by any agency.

Importance:

The ecological functions of *Lasthenia fremontii* are not well-documented.

Questions for further research and study:

Does *Lasthenia fremontii* act as to attract pollinators?

Does it provide dense cover for invertebrates and other small animals?

Constraints:

Although the plant is common, it is probable that gene flow does not occur readily among vernal pool populations and even within individual vernal pools that have longer inundation periods that lead to sequential flowering as the water level drops. As an obligate outcrosser, it is subject to inbreeding within the bands that form as the water recedes and pollinators attend to those plants flowering at the same time.

Opportunities:

This plant is endemic to the vernal pools of the Central Valley of California but has an appeal to the general public. Many people know of goldfields whether or not they can distinguish the different species. As a well-known plant that many people like, it has the potential to lend support to the conservation of vernal pools. We also have the opportunity to preserve a species before it reaches low numbers or becomes genetically impoverished. It is this forethought regarding species at risk for future decline that is becoming more important in determining conservation decisions.

Target goal:

Maintain the species abundance and distribution and ensure its future survival. This benefits other species in the vernal pools because it is so widespread and its preservation will protect other species within its range.

Restoration techniques and plans:

There is no mention of restoring this species, but as an outcrosser, maintenance of genetic diversity is important. The foremost priority should be to protect the current populations. If there are pools that historically contained *Lasthenia fremontii* populations or new pools created in areas that would likely have had this species, then seed should be selected from the nearest pools while making sure to get seed from different bands across the source pools to get diverse genetics.

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<u>Psilocarpus (wooly marbles) fact sheet</u> Jill Baty

Common name: Wooly marbles
Genus: *Psilocarphus*
Family: Asteraceae

<u>About the species</u>

-3 species of Psilocarphus at Grasslands Regional Park

- -*P. brevissimus* var. *brevissimus*- tends to be on pool bottoms and other long-inundated places
- -*P. tenellus* var. *tenellus*- tends to be found in drier edge-to-upland sites
- -*P. oregonus* – tends to be found in vernal pools (probably in similar habitat to *P. brevissimus*)
- -Related *P. brevissimus* var. *multiflorus* has been found elsewhere in Yolo and Solano Counties, but is not known to occur at Grasslands Park.

-Most information available is on *P. brevissimus* var. *brevissimus*

<u>Habitat preferences</u>

Recorded *Psilocarphus* habitat conditions					
		Psilocarphus brevissimus	*Psilocarphus tenellus*	*Psilocarphus oregonus*	Data sources
Average inundation periods		34 days 50 days	20 days	?	Hammersmark et al 2009 Bauder 2000
Range of *Psilocarphus* cover		0.5 - 55% (mean 9.1%) Mean 3%	?	?	Hammersmark et al 2009 Buck 1998
Co-occurring cover	Total vegetation	29.7 - 82.5%	?	?	Hammersmark et al 2009
	Bare ground	14.2 - 70.6%	?	?	Hammersmark et al 2009
	Litter	0 - 12.1%	?	?	Hammersmark et al 2009
Water table depth		-33.4 to 145 cm	?	?	Hammersmark et al 2009
Depth of plants below the overflow elevation (fill elevation of the pool)		60% of occurrences were more than 13 cm below overflow elevation	?	?	Bauder 2000

Some native plants known to co-occur with *P. brevissimus* var. *brevissimus* (Downingio bicornutae-Lasthenietea fremontii vegetation class (Barbour 2003)		
	State-wide Barbour et al 2003	Butte County Schlising and Sanders 1982
Callitriche marginata	x	
Downingia bicornuta	x	
Eryngium vaseyi	x	
Lasthenia fremontii	x	x
Navarretia leucocephala ssp. *leucocephala*	x	x
Pilularia americana	x	
Plagiobothrys stipitatus var. *micranthus*	x	

<u>Management considerations for *P. brevissimus* var. *brevissimus*:</u>

- Common plant
- Long inundation periods
- May decline in cover following fire, but recovers within a year
- Responds positively to grazing, and can persist in longer-inundated cattle hoof prints (microdepressions)

<u>Threats:</u>

- Land conversion to agricultural and urban development and other habitat destruction
- Altered hydrology
- May be out-competed by *Spergula arvensis* (which is not currently at Grasslands Park)

Psilocarphus Conservation at Grasslands Regional Park

Three species of *Psilocarphus* (family: Asteraceae) are known to occur at Grasslands Regional Park: *Psilocarphus brevissimus* var. *brevissimus* (wooly marbles), *Psilocarphus oregonus* (Oregon wooly marbles) and *Psilocarphus tenellus* var. *tenellus* (slender wooly marbles). *Psilocarphus brevissimus* var. *multiflorus* (Delta wooly marbles) has not been found in Grasslands Regional Park, but is known to occur in near-by Sacramento County and Solano County locations. *Psilocarphus brevissimus* var. *multiflorus* is a rare species on the CNPS 4.2 list (limited distribution, fairly endangered in California). The three species of *Psilocarphus* that have been found in the park are fairly common vernal pool species. None of these species are on any CNPS rare plant list, nor have they been considered for any list (CNPS inventory of rare and endangered plants). As of April of 2010, *Psilocarphus tenellus* var. *tenellus* is undergoing name changes. In the future, it will be known in the Jepson Manual of Higher Plants of California as *Psilocarphus tenellus*, and the related *Psilocarphus tenellus* var. *globiferus* will be known as *Psilocarphus chilensis* (Calflora taxon report).

Figure 2: *Psilocarphus brevissimus* var. *brevissimus.* Photo credit: Carol W. Witham 2004

Figure 2: *Psilocarphus oregonus*. Photo credit: Doreen L. Smith 2009

Figure 1: *Psilocarphus tenellus* var. *tenellus*. Photo credit: Keir Morse 2008

Although the three *Psilocarphus* species of Grasslands Park are not rare or endangered, their populations need to be considered in managing for the health of vernal pools at the park, since between 60 and 90 percent of California's vernal pools have been lost to agricultural and urban development since the mid-nineteenth century (Holland 1978). The species therefore presumably occur only in 10 to 40 percent of their historic range. Many of these occurrences are in protected vernal pool habitats, but unprotected habitat continues to be lost. Of the vernal pool habitat remaining in 1978, approximately 13% has been lost to agricultural and urban development statewide. However, in Yolo County a full 75% of vernal pool habitat remaining in 1978 had been lost by 2005 (Holland 2009). Conservation of *Psilocarphus*, a characteristic vernal pool genus and its associated habitat at Grasslands Park is important.

<u>Habitat preferences</u>

The three species of *Psilocarphus* found at Grasslands Regional Park can occupy a wide range of somewhat distinct habitats. *Psilocarphus brevissimus* var. *brevissimus* is found in vernal pools and flats below 2500 meters. *Psilocarphus tenellus* var. *tenellus* is found on dry slopes on generally disturbed soil and rarely in vernal pools from 10 to 2000 meters in elevation. *Psilocarphus oregonus* is found in vernal pools and rarely on moist slopes from 10 to 1500 meters. All three species are found throughout the state, with *Psilocarphus oregonus* extending only as far south as Santa Barbara County (Hickman 1993, Calflora taxon report).

In a vernal pool complex in San Diego County, *P. brevissimus* was found in places that were inundated on an average of 50 days during the wet season, while *P. tenellus* was found in places that had been inundated for an average of 20 days. *Psilocarphus brevissimus* was substantially more common in a moderately wet year (34.04 cm precipitation) (Bauder 2000).

Recorded *Psilocarphus* habitat conditions					
		Psilocarphus brevissimus	*Psilocarphus tenellus*	*Psilocarphus oregonus*	Data sources
Average inundation periods		34 days	20 days	?	Hammersmark et al 2009
		50 days	?	?	Bauder 2000
Range of *Psilocarphus* cover		0.5 - 55% (mean 9.1%) Mean 3%	?	?	Hammersmark et al 2009 Buck 1998
Co-occurring cover	Total vegetation	29.7 - 82.5%	?	?	Hammersmark et al 2009
	Bare ground	14.2 - 70.6%	?	?	Hammersmark et al 2009
	Litter	0 - 12.1%	?	?	Hammersmark et al 2009
Water table depth		-33.4 to 145 cm	?	?	Hammersmark et al 2009
Depth of plants below the pool overflow elevation (fill-elevation of pool)		60% of occurrences were more than 13 cm below overflow elevation	?	?	Bauder 2000
Inter-annual persistence of species in a plot		100%	?		Hammersmark et al 2009
		90%		51%	Buck 1998

* Note: Hammersmark et al 2009 study was in Siskiyou County; Bauder 2000 study was in San Diego County; Buck 1998 data were collected along a 300 km stretch through northern and central California.

<u>Associated species</u>

Plants in vernal pools are often found in groups of species that co-occur. All vernal pools in California fall into the Downingio bicornutae-Lasthenietea fremontii vegetation class, of which *Psilocarphus brevissimus* var. *brevissimus* is an indicator species (Barbour et al 2003).

Vernal pool plants associated with *Psilocarphus brevissimus* var. *brevissimus*				
	State-wide Barbour et al 2003	Butte County Schlising and Sanders 1982	Siskiyou County Hammersmark et al 2004	San Diego County Bauder 2000
Alopecurus saccatus	x			
Callitriche marginata				
Crassula aquatica	x			
Deschampsia danthonioides	x	x		x
Downingia bacigalupii			x	
Downingia bicornuta	x			
Downingia cuspidate				x
Eleocharis acicularis var. *acicularis*	x			
Eryngium vaseyi	x			
Isoetes orcuttii	x			
Juncus bufonius var. *occidentalis*	x			
Lasthenia fremontii	x	x		
Navarretia leucocephala ssp. *leucocephala*	x	x		
Pilularia americana	x			
Plagiobothrys stipitatus var. *micranthus*	x			
Pogogyne abramsii				x
Pogogyne zizyphroides	x			
Veronica peregrine ssp. *xalapensis*	x			

In some cases, *Psilocarphus brevissimus* var. *brevissimus* may be limited by competition with non-native plants. In some artificial pools at the Travis Air Force Base in Solano County, *Psilocarphus brevissimus* dominated deep zones in the absence of *Spergula arvensis*, indicating that it may not be able to compete with the non-native (Moore et al 2001).

Many vernal pool plants are important sources of food for animals in vernal pool grasslands. Pocket gophers have been shown to eat small amounts of *Psilocarphus brevissimus* in San Diego vernal pool complexes. In late spring, vernal pool forbs, including *Psilocarphus brevissimus*, comprise up to 0.4% of pocket gopher diets (Hunt 1992). It is possible that these plants are important to other herbivorous and granivorous animals as well.

Phenology: Germination, flowering and seed set

Little has been documented about the phenology of *Psilocarphus tenellus* var. *tenellus* or of *Psilocarphus oregonus*. *Psilocarphus brevissimus* germinates early, even when compared with other vernal pool plants: 95% of individuals germinated by March in a greenhouse study. In the same study, the lowest germination was in treatments that were constantly inundated (Bliss and Zelder 1998). *Psilocarphus brevissimus* may fail to germinate under continuously (winter to spring) inundated conditions (Lin 1970). The plant flowers in April to May, and may be in fruit at the end of April (Munz 1968, Ramaley 1919).

Management considerations

All species of *Psilocarphus* known to occur at Grasslands Park are common. A closely related sub-species, *Psilocarphus brevissimus* var. *multiflorus*, or Delta Wooly Marbles, is listed on the CNPS Rare Plants List as 4.2 (limited distribution, fairly endangered in California) (CNPS inventory of rare and endangered plants). This subspecies is known to occur in both Sacramento and Solano Counties, at the Cosumnes River Preserve and at the Jepson Prairie Reserve. If this species is found at Grasslands Park, managers should be even more vigilant about protecting habitat for all genera of *Psilocarphus*.

Psilocarphus brevissimus var. *brevissimus* has been shown to respond positively to grazing. The impressions made by cattle hooves may serve as longer-inundated microhabitats for some *Psilocarphus* (Barry 1998). It is likely that *Psilocarphus* species also benefit from reduction of upland biomass by grazing that was shown by Marty (2005). There is some indication that

Psilocarphus brevissimus var. *brevissimus* may respond negatively to fire. One year post-controlled burn, *Psilocarphus brevissimus* var. *brevissimus* populations have been seen to decline, but this observation was not made in the second year following the fire (Cox & Austin 1990). Many questions as to the best management of *Psilocarphus* remain.

Key Research Questions:

Questions about *Psilocarphus* fall under two broad categories: what is the natural history of the genus, and how will the genus respond to various management practices.

Natural history:

- How does *Psilocarphus* disperse?
- How genetically distinct are populations of *Psilocarphus* in the park from one another? How genetically distinct are populations in the park from those elsewhere in the region?
- What animals eat *Psilocarphus* seeds? Which animals eat the plants? Is it susceptible to any diseases?
- How long are *Psilocarphus* seeds viable and under what conditions? If seeds remain intact after they have been eaten and defecated, how does this affect germination rate?
- What are the sizes of *Psilocarphus* seed banks? Does this vary between species? Does the seed bank have large inter-annual fluctuations?
- What percentage of the *Psilocarphus* seed bank germinates in a given year?
- How are *Psilocarphus* flowers pollinated?
- Is *Psilocarphus* out competed by *Spergula arvensis*? How likely is *Spergula arvensis* introduction to Grasslands Park?
- What factors drive the distribution patterns of *Psilocarphus* at Grasslands Park? How feasible is it to expand the range of *Psilocarphus* within the park?
- How does the population size of *Psilocarphus* fluctuate annually at Grasslands Park? What biotic and abiotic factors drive those fluctuations?
- What is the specific natural history of the at-risk *Psilocarphus brevissimus* var. *multiflorus* (not currently found at Grasslands Park)?

Management:

- How does *Psilocarphus* respond to different frequencies and intensities of fire at Grasslands Park?
- How does *Psilocarphus* respond to different grazing regimes (grazer species, timing, duration, frequency, intensity) at Grasslands Park?
- How does *Psilocarphus* respond to other disturbances at Grasslands Park (vehicle traffic, foot traffic, infrastructure removal)?
- How do populations of *Psilocarphus* correlate with populations of threatened and endangered species at Grasslands Park? What is the possibility of using it as any sort of indicator species?
- What could be done to increase the range of *Psilocarphus* within Grasslands Park?
- How can management benefit the at-risk *Psilocarphus brevissimus* var. *multiflorus* (not currently found at Grasslands Park)?

Key to *Psilocarphus* (Hickman 1993)

1. Largest head 6–14 mm; longest chaff scale generally 2.8–4 mm, or if shorter then hidden by dense shaggy hairs

    2. Largest head 9–14 mm, ± ovoid, receptacle deeply lobed; chaff scales narrowly cylindric, length > 3 × width, wing ± 1/2 distance from base to tip of scale……………………………………………………………………... *P. brevissimus* var. *multiflorus*

    2' Largest head 6–9 mm, spheric, receptacle entire or shallowly lobed; chaff scales obovoid, < 3 × width, wing ± 2/3 distance from base to tip of scale….. *P. brevissimus* var. *brevissimus*

1' Largest head generally < 6 mm; longest chaff scale generally < 2.8 mm, visible through thin, ± appressed, cobwebby or silky hairs

    4. Leaves linear to narrowly oblanceolate, generally > 5 × width, generally > 3 × heads; fruit ± cylindric…………………………………………………… ……………………*P. oregonus*

    4' Leaves generally ovate to obovate, generally < 5 × width, < 3 × heads; fruit ± obovoid……………………………………………………………….. ……………………...*P. tenellus*

        5. Uppermost leaves ovate to widely elliptic, generally < 2 × width, ± appressed to heads; disk flowers generally 4-lobed…………………….. …………………var. *globiferus*

        5' Uppermost leaves oblanceolate to obovate, generally > 2 × width, spreading below heads; disk flowers generally 5-lobed………………… ……………………var. *tenellus*

<u>Restoration Plan: *Psilocarphus* genus (wooly marbles)</u> Jill Baty

The three members of the *Psilocarphus* genus found at Grasslands Regional Park do not face an immediate threat of extirpation. State-wide and regionally, the populations of these species are healthy. At Grasslands Park, the populations of these plants have not been extensively studied, but they are presumed to be viable.

Outline:

1. Goals
   a. Maintenance of *Psilocarphus* populations at Grasslands Park
   b. Expansion of *Psilocarphus* range within Grasslands Park
   c. Research *Psilocarphus* natural history and responses to management practices
2. Restoration and monitoring scenarios
   a. Introduce and maintain an appropriate grazing and fire regime at the park
   b. Prevent intentional and accidental destruction of *Psilocarphus* habitat
3. Figure: Schematic diagrams of threats to *Psilocarphus* at Grasslands Park

Goal 1: Maintain average annual population size of *Psilocarphus* at Grasslands Regional Park during the next ten years.

In order to maintain the populations of *Psilocarphus* at Grasslands Park, Yolo County should protect four critical areas of *Psilocarphus* ecology: habitat area appropriate for *Psilocarphus*, germination and survival of *Psilocarphus* individuals, pollination and reproduction of *Psilocarphus*, and dispersal opportunities for the plants.

Dispersal:

Because these species are reasonably abundant throughout their ranges, not much research has been done on their dispersal mechanisms. Likely mechanisms include wind and water within and between pools, and animal dispersal. Because granivory on *Psilocarphus* seeds has not been shown to be important, it is likely that offspring stay in the same pools as their parents. In order to maintain *Psilocarphus*' potential for dispersal, connectivity between vernal pools at Grasslands Park should be maintained. Native granivores, potentially including small mammals, birds and invertebrates, should also be maintained.

Pollination and reproduction:

Because of their very wooly flower heads, self-pollination is assumed to be the most important form of pollination for *Psilocarphus* flowers (Douglas et al 2003). It is possible that pollinators play a small role, so it is advisable to ensure the survival of native pollinators at Grasslands Park. Once pollination has occurred, *Psilocarphus* individuals need to survive to seed set and seeds need to survive to germination. There is some evidence that the use of controlled burns in October may not allow *Psilocarphus* seeds to survive to germination (Cox & Austin 1990). In order to maintain the long-term viability of *Psilocarphus* at Grasslands Regional Park, all *Psilocarphus* populations should not be burned every year. Likewise, in order to maintain seed production, Grasslands Park should not be over grazed. The precise numbers of individual *Psilocarphus* plants that need to reproduce annually to maintain an appropriate seed bank is not known. Populations of these plants should, therefore, be monitored annually so that any declining trend in population size is detected early. Additionally, researching the size and dynamics of *Psilocarphus* seed banks will aid in detecting declining populations.

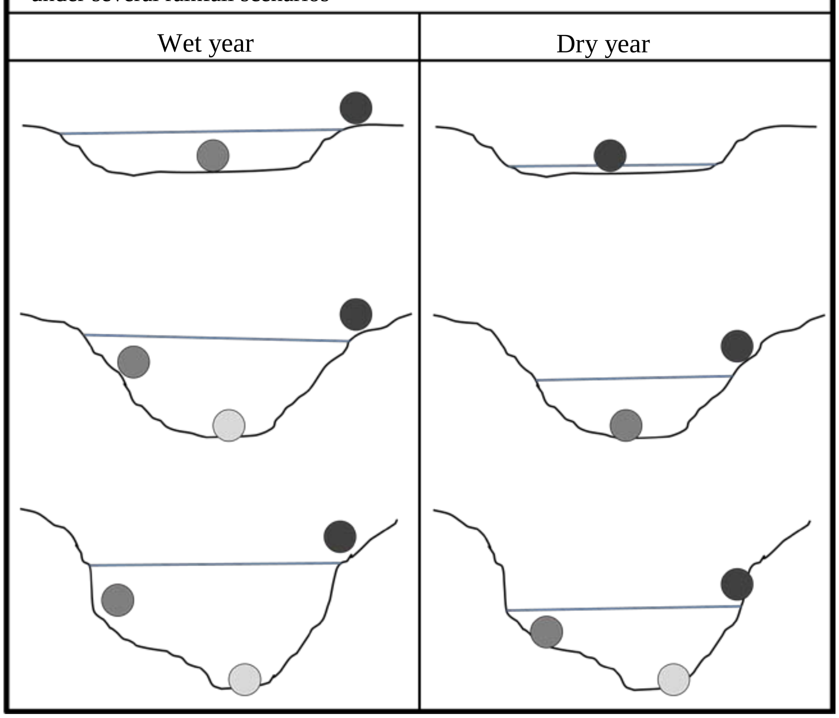
Germination and survival:

Inundation period is important to the germination of *Psilocarphus*. It is important that pools with a variety of depths are maintained at Grasslands Park to accommodate each of the three *Psilocarphus* species. This way a range of appropriate habitat will be available to all three *Psilocarphus* species in a variety of pools and under a variety of rainfall scenarios (Figure 1). Likewise, it is important that non-native grasses are suppressed in a way that prevents them from drying vernal pools early in the spring.

There is some possibility that the survival of *Psilocarphus* is lessened by the non-native *Spergula arvensis* (Moore et al 2001), but no study has definitively shown whether or not *Spergula arvensis* actually outcompetes *Psilocarphus* brevissimus var. brevissimus. If *Spergula arvensis* is found at

Grasslands Park, it should be eradicated as early as possible to increase the likelihood that eradication is successful. *Spergula arvensis* does not naturally disperse long distances, but may be transported in soil- especially on agricultural equipment (Alaska Natural Heritage Program 2006). In order to prevent the introduction of *Spergula arvensis* to Grasslands Park, visitors and workers should avoid transporting soil from contaminated sites. Yolo County should alert groups, including employees, contractors, herders and park visitors, of the detrimental consequences of bringing contaminated soil into the park. Likewise, Yolo County should not inoculate any vernal pools at Grasslands Park with soil collected at sites where *Spergula arvensis* is known to occur.

Figure 1: pools of a variety of depths can support all three *Psilocarphus* species under several rainfall scenarios



Habitat area:

Maintaining habitat quality is critical to the continued survival of *Psilocarphus* at Grasslands Park. Factors that could contribute to habitat loss or degradation at the park include, grazing regime, hydrologic regime, accidental destruction, and park land development. In order to maintain high quality habitat, the park should be grazed on an appropriate schedule (timing, duration, frequency, and intensity) such that non-native grasses do not drive pool hydrology. Specific recommendations for the optimal grazing regime at Grasslands Park will need to be determined experimentally. Generally the park should be grazed in the winter or early spring to a level of between 300 and 500 lbs/acre of residual dry matter (RDM). Accidental destruction of habitat could happen due to the actions of herders, contractors, employees, and park visitors. It is critical that these groups clearly understand the delicacy of *Psilocarphus* habitat in order to avoid unintentional habitat destruction. Park land development is not likely to destroy *Psilocarphus* because of the protections on listed species which restrict development in the park.

Goal 2: Expand habitat that is suitable for *Psilocarphus* at Grasslands Regional Park within the next fifty years.

In the future, it may become possible for Yolo County to expand the habitat that is suitable for *Psilocarphus* at Grasslands Park. Major human-induced factors preventing the expansion of *Psilocarphus* include development at the park (recreational, abandoned Air Force infrastructure). If these developments are removed, and the vernal pool landscape restored, *Psilocarphus* would be able to expand its range. Likewise, *Psilocarphus* might be able to expand its range if the natural hydrology of the park were to be restored. This scenario is highly unlikely; the cause of hydrological alteration is flood control measures on Putah Creek. These flood controls protect life and property in the city of Davis and surrounding agricultural lands.

Goal 3: Answer questions about the best management of *Psilocarphus* at Grasslands Regional Park

Questions about *Psilocarphus* fall under two broad categories: what is the natural history of the genus, and how will the genus respond to various management practices.

Natural history:

- How does *Psilocarphus* disperse?

- How genetically distinct are populations of *Psilocarphus* in the park from one another? How genetically distinct are populations in the park from those elsewhere in the region?
- What animals eat *Psilocarphus* seeds? What animals eat the plants? Is it susceptible to any diseases?
- How long are *Psilocarphus* seeds viable and under what conditions? If seeds remain intact after they have been eaten and defecated, how does this affect germination rate?
- How are *Psilocarphus* flowers pollinated?
- What percentage of the *Psilocarphus* seed bank germinates in a given year?
- Is *Psilocarphus* out competed by *Spergula arvensis*? How likely is *Spergula arvensis* introduction to Grasslands Park?
- What factors drive the distribution patterns of *Psilocarphus* at Grasslands Park? How feasible is it to expand the range of *Psilocarphus* within the park?
- How does the population size of *Psilocarphus* fluctuate annually at Grasslands Park? What biotic and abiotic factors drive those fluctuations?

Management:

- How does *Psilocarphus* respond to different frequencies and intensities of fire at Grasslands Park?
- How does *Psilocarphus* respond to different grazing regimes (grazer species, timing, duration, frequency, intensity) at Grasslands Park?
- How does *Psilocarphus* respond to other disturbances at Grasslands Park (vehicle traffic, foot traffic, infrastructure removal)?
- How do populations of *Psilocarphus* correlate with populations of threatened and endangered species at Grasslands Park? What is the possibility of using it as any sort of indicator species?
- What could be done to increase the range of *Psilocarphus* within Grasslands Park?

Restoration and Monitoring

Because of the abundance of *Psilocarphus* at Grasslands Park and the barriers to increasing the plants' ranges within the park, conservation of the genus is advisable over restoration at this time. Restoring the range of *Psilocarphus* at Grassland Park would entail broad-scale hydrologic restoration and elimination of developments at the park. In order to conserve the species, as outlined under Goal 1 above, it is important that the species are able to disperse, germinate, survive, and reproduce. The following conservation plan focuses on ensuring the life cycle completion of *Psilocarphus* species at Grasslands.

Objective 1: Introduce and maintain an appropriate grazing and fire regime at the park

Appropriate use of grazing and fire at Grasslands Park will reduce the ability of non-native grasses to dry vernal pools early.

Grazing regime:

Use sheep, goats or cattle to graze Grasslands Park from early winter through mid spring. The timing, duration, frequency and intensity of grazing should be managed such that the residual dry matter at the park at the end of the summer maximizes the cover of native species at the park. General recommendations for the amount of RDM to remain range from 300 to 500 lbs/acre (Barry 1998, EBMUD Safe Harbor Agreement2009). Ensure good relationships and communication with herders and intact infrastructure so that annual grazing is possible. Yolo County may consider contracting with a local grazer to facilitate these transactions.

Fire regime:

Use prescribed burns to decrease the cover of non-native and invasive plants in late spring. The timing and frequency of burning should maximize the cover of *Psilocarphus* two years following the burn. Too frequent burning may reduce the seed bank of *Psilocarphus*, so population sizes should be closely monitored if controlled burns are used for management.

Research needs:

- What levels of residual dry matter result in the highest levels of *Psilocarphus* cover for one and two years following grazing? Does this vary between the three *Psilocarphus* species?

- At what fire return interval does the population of *Psilocarphus* stop replenishing its seed bank? What are the size and dynamics of the *Psilocarphus* seed bank? How long do *Psilocarphus* seeds remain viable? Does this vary between the three *Psilocarphus* species?
- What is the optimal timing of grazing for *Psilocarphus*? Does this vary between the three *Psilocarphus* species?
- What is the optimal intensity and duration of grazing for *Psilocarphus*? Does this vary between the three *Psilocarphus* species?
- Are cattle or sheep and goats better suited to grazing to maximize cover of *Psilocarphus*? Does this vary between the three *Psilocarphus* species?

Metrics and monitoring:

- Annual cover of *Psilocarphus brevissimus* var. *brevissimus, Psilocarphus tenellus* var. *tenellus,* and *Psilocarphus oregonus* in late spring
- Annual cover of non-native grasses in late spring
- Annual measurement of residual dry matter in late summer
- Inundation period of pools
- Population in the seed bank

Objective 2: Prevent habitat destruction

Psilocarphus species require adequate habitat to maintain viable populations.

Intentional destruction:

Do not allow any new development or infrastructure at Grasslands Park. Do not allow new development or infrastructure on undeveloped land in the park. New developments or infrastructure could include roads, recreational facilities, buildings and utility infrastructure.

Accidental destruction:

Prevent additional accidental destruction of *Psilocarphus* habitat at Grasslands Park. Sources of accidental destruction could include removal of Air Force debris, disking vernal pools, introducing invasive plants in soil, vehicles, or clothing, over grazing, or other means. Yolo County should introduce a training course for all individuals who conduct work at Grasslands Park on the delicacy of vernal pool habitats. Additionally, all contractors, employees and others working at Grasslands Park should remove mud, soil and seeds from their persons, equipment and vehicles before working at Grasslands Park. Furthermore, Yolo County should use signage to educate visitors on their potential impact on vernal pool habitat.

Research needs:

- How do employees, contractors, herders and others working at the park perceive the resilience of vernal pool habitats? What is their understanding of their role in preserving these habitats?
- How do park visitors perceive the resilience of vernal pool habitats? What is their understanding of their role in preserving these habitats?
- Is signage an effective way of preventing accidental destruction (trampling, botanical collections, or other methods) of vernal pool habitats by park visitors?
- Is a training course an effective way of preventing accidental destruction of vernal pool habitats by employees, contractors, herders and others working at the park?
- How can employees better communicate to visitors, contractors, herders and others in order to prevent accidental destruction of vernal pool habitats?

Metrics and monitoring:

- Annual cover of *Psilocarphus brevissimus* var. *brevissimus*, *Psilocarphus tenellus* var. *tenellus*, and *Psilocarphus oregonus* in late spring. Annual or biannual measures of seed bank size of the three species in early fall.
- Extent of cover within the park of *Psilocarphus brevissimus* var. *brevissimus, Psilocarphus tenellus* var. *tenellus*, and *Psilocarphus oregonus* in late spring
- Annual cover of invasive species in late spring
- Monitor for new invasive species, especially *Spergula arvensis*
- Monitor the numbers of visitors to the park annually
- Monitor the visits by individuals working at the park annually

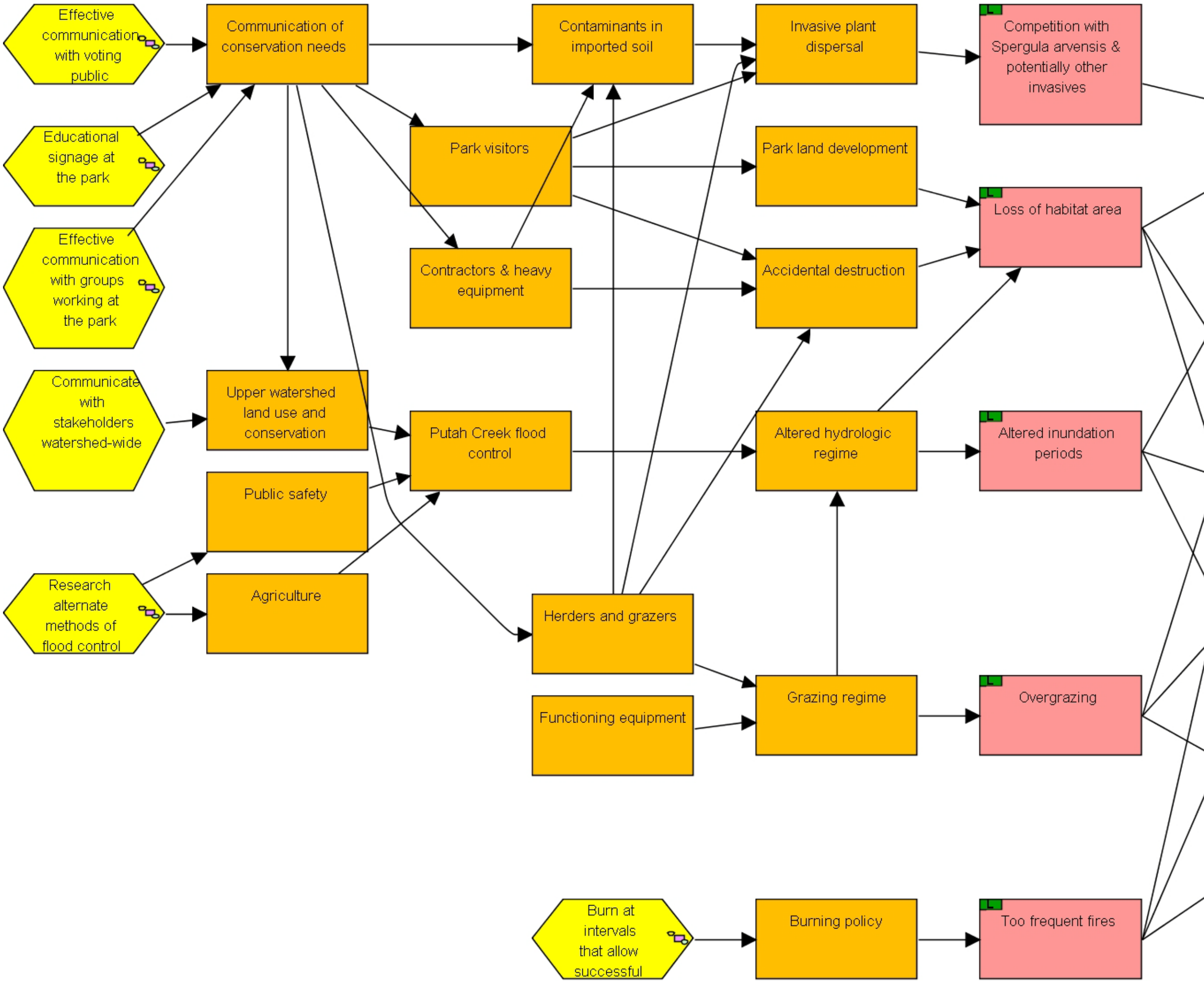


Figure 2: Schematic diagram of threats to *Psilocarphus* conservation at Grasslands Regional Park conservation at Grasslands Regiona

Part III

Based on management needs for other species and goals in Grasslands Regional Park, conservation of the three species of *Psilocarphus* should be quite feasible. These species are widespread and common in vernal pool grasslands and occur under wide ranges of conditions. There is some evidence that burning has the potential to decrease the population size in the short-term, so any management prescribing fire may be in conflict with *Psilocarphus* conservation.

Evidence that would indicate that *Psilocarphus* conservation is in conflict with restoration and conservation of other important species at Grasslands Park does not exist. However, much about the natural histories of these species remains unknown. Likewise, the species' responses to management practices, including grazing, fire, and pesticides and herbicides are largely unstudied. An adaptive management approach will allow managers at Yolo County to continue to improve management of the site.

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Eric Hoang

ENH 160

Coyote Thistle (button celery) *Eryngium spp.*

PART I

The genus *Eryngium* includes about 230 species of annuals and perennials usually with spiny leaves and thistle-like flowers. The species of focus in this report are those which are endemic to California's vernal pools. Three specific species of focus are *E. vaseyi*, *E. constance, E. spinosepalum*. The low distribution and abundance of these species is a threat to their existence. Although scientists do not think genetic drift or other intrinsic problems are of much concern, extreme conditions such as climate change or catastrophic weather can potentially eliminate all existing populations of the coyote thistle because of their limited distribution. It is important to restore habitats and protect California's vernal pools to ensure the continued survival of the coyote thistle.

Life History and Habitat

The both *E. vaseyi* an *E. constancei* have similar life cycles. They are perennial plants in the Apiaceae (carrot) family. They grow from a taproot into one of two forms, aquatic and terrestrial. When the pool is filled, the coyote thistle plant has long hollow leaves to carry air to the roots. When the pool dries, the leaves become broad and terrestrial-like. During the summer, thistle-like flowers bloom and develop fruits and seeds in July-August. It is found in both hardpan and claypan vernal pools and in depressions at foothills below 1,200 feet in the San Joaquin Valley, adjacent to the base of the Sierra Nevada Mountains (UC Merced Planning).

Eryngium spinosepalum grows in both hardpan and claypan vernal pools. The only characteristics of pools that support *E. spinosepalum* are those described from the Stone Corral Ecological Reserve in Tulare County. There, the species grew in pools ranging from 16-18 inches deep. Soil pH ranged from 6.1 to 7.5. The range elevation starts at about 350 feet at Stone Corral Ecological Reserve to about 1,550 feet at Squaw Valley (US FWS p.185, 2004).

Distribution

The distributions of the species of concern are primarily endemic in California. *E. vaseyi* is endemic to vernal pools in the Central Valley and *E. constancei* is endemic to 3 vernal pools north of the San Francisco Bay. (US FWS p.193, 2004)

According to the California Natural Diversity Data Base (2001), there currently are 22 extant occurrences of *Eryngium spinosepalum* of 26 historically reported populations. There are also three 13 of the extant populations are in Tulare County, five in Fresno County, and two each are in Madera and Tuolumne. Populations of this species are often isolated with minor areas of concentration. (US FWS p.185, 2004)

Associated Species

The coyote thistle is commonly found associated with the Hoover's spurge (*Chamaesyce hooveri*), a federally endangered species, and other listed species. Protection of the coyote thistle will create a protection umbrella for the Hoover's spurge as well as other rare native plant species. However, the coyote thistle and the Hoover's spurge can be considered competitors. If a restoration effort is focused on the coyote thistle and Hoover's spurge is found nearby, restoration would probably be shifted towards the spurge due to its higher protection priority.

The vernal pool dodder (*Cuscuta howelliana*) is also a commonly associated species of the coyote thistle. The dodder is a parasite that attaches and feeds directly off of other plants. Because the dodder is a California native, complete removal is improbable but regulation and control is possible. Removal of the dodder will improve the survivorship of the coyote thistle and other vernal pool species. It can be argued that the presence of dodder can protect a community from being dominated by a single species because it is a parasite that affects multiple species. If a restoration effort is focused on a broader picture of a vernal pool, having dodder present but under control can be a positive. If a restoration is focused on *Eryngium*, the presence of dodder can be detrimental.

Additional Threats

Threats that endanger the existence of the coyote thistle include changes in the water supply or flood patterns, land conversions to agriculture or urban development, off-road vehicles, logging-caused erosion, and grazing. One population of the thisle in Fresno County was wiped by because the land was converted to an orange grove. Another in Tulare County was extirpated by urban and agricultural development. New dam proposals, road constructions and maintenance, grazing, and land development conversions are the major causes of decline of *Eryngium spinosepalum*. (US FWS p.185, 2004).

Current Protection

Of the *Eryngium* species, *E. spinosepalum* is the only one listed. Although it has no federal or state listing status, it is considered rare, threatened, and endangered by the California Native Plant

Society, thus it is a species of concern and a 'CNPS List 1B' species. It has been assigned a R-E-D code of 3-2-3, meaning it is distributed in only a few known areas, endangered in parts of its range, and endemic to California (Dittes p.33, 2004). There are no current conservation efforts for this species and the only protected occurrence of *E. spinosepalum* is at the California Department of Fish and Game's Stone Corral Ecological Reserve (US FWS p.187, 2004).

The main factors that affect the survival of *Eryngium sp.* are almost all related to human land-use. Converting land around vernal pools can bring many consequences on the natural ecosystem including nutrient runoff or water depth and availability. The example of the Fresno and Tulare populations of *Eryngium sp.* lost because agricultural and urban development provides evidence that human land use is a direct cause of the decline.

Challenges

An additional challenge to our planning is that we have gaps in our knowledge about the species *Eryngium spinosepalum.* Gaps include information on its pollinators, seed dispersal agents, and population dynamics.

Funding for restoring the coyote thistle could come from environmental groups or donations. Restoration of theses species requires the protection of land, so not much economic capital is needed. Simple fencing and signs can provide protection from human-disturbance.

PART II

Because there are many species of *Eryngium* with many distributions throughout the Central Valley's vernal pools, we can apply different restoration plans and see which plan works best for each individual species. It is possible that a restoration project that works perfectly at one site will completely fail at another. In restoring the coyote thistle, we must look at each site individually and consider each site unique in survival requirements.

GOALS

- Ensure adequate filling- (long term) Adequate pool filling each year is crucial to the survival of the coyote thistle and many other vernal pool species. This plant requires about a foot of water to germinate and survive. The required inundation period is unknown but because it is able to grow in 2 forms, aquatic and terrestrial, it should be able to adapt to changing inundation period.
- Regulate grazing- (short term) In a demonstration project in the Vina Plains, Tehama County, fencing was installed around vernal pools to observe the long-term effects of un-grazed vegetation. Within the vernal pools, the coyote thistle was found to be the most common plant, accounting for about 35% of the vegetation. Few individuals of the thistle were found around the pool edges.
    - Unfortunately, no studies were found for grazed pools. However, one can imagine that because coyote thistle grows inside of the pool, grazing during periods of inundation would have little effect. Once the pool dries and coyote thistle morphs into its terrestrial form with seeds, grazing could potentially lower its chance of seed dispersal.

    - Fencing off the pool at least 10 yards around the area- fencing can restrict or regulate grazing of the pool sites as well as off-road vehicles. A 10 yard buffer should be adequate for protection within the pools, the edges of the pool, and the soils surrounding the pools, which can have an affect on pool filling/draining. Nearby streams that carry water and controls the flooding to pools may be fenced off in dire cases.
- Limit reservoir construction- reservoirs and dams can create changes in the flooding and pool-filling patterns. To ensure the survival of coyote thistle, proper filling and draining at the right time is essential.
- Control parasite dodder- the parasite dodder is commonly found in vernal pool areas. It is often found attached to coyote thistle as well as many other native vernal pool species, so control or eradication of this pest would benefit the survival of coyote thistle greatly.
    - We must also consider that the dodder is a California native and complete eradication is not recommended.

MANAGEMENT PLAN

Challanges

Our restoration effort would benefit greatly if we had information on the seed dispersal techniques, pollinators, and population dynamics of the coyote thistle. Knowing how the coyote thistle naturally spreads its seeds would allow us to aid the distribution and germination of seeds in proper conditions. More information on how the *Eryngium Sp.* is pollinated would be helpful so we can bring in more pollinators for the plant if we see flowering or seed production issues. Information on *Eryngium* population dynamics can give us insight on how the coyote thistle responds in the presence of individuals of its own species as well as others. Population dynamics can also help us manage the plant spatially to control species or individual competition.

Because we do not know the natural seed dispersal methods of the coyote thistle, it is difficult to properly distribute the seeds and ensure suitable conditions for germination. However, based on the growth and life cycles of *Eryngium*, we can hypothesize that placing seeds in depression areas where water fills to at least one foot deep, or the center of the pool, should be adequate. Because many of the *Eryngium* species are endemic to small regions, seeds should be planted in the same area they were collected to maintain the overall regional heterogeneity.

A potential problem that we might face in our restoration is an invasion of the parasite vernal pool dodder. The dodder is native to California so complete eradication is improbable, however regulation and control is possible. Another potential problem that might be difficult to recognize is a lack of pollinators. This issue is especially difficult because we have little information on the pollination process of the coyote thistle. It is possible that the pollination insects may have inadequate habitat conditions outside of the vernal pool protection zone.

Monitoring

Monitoring of a restoration effort is important because it keeps track of how effective the restoration is. Recognizing problems early gives scientists time to make changes to their restoration plan and improving the effectiveness of restoration. Monitoring should occur at major phonological shifts in the plant life cycle. Such shifts include the germination period in the early spring, periods of inundation while the plant is in aquatic form, periods of dryness when the leaves change, and in the summer when the thistles form and seeds are produced. A sampling of vernal pool sites with records of *Eryngium Sp.*

should be selected for monitoring, at equal intensity, because the distribution of the species are so low. Because the coyote thistle is a common plant in vernal pools, the threshold of action should occur if a site that historically supports *Eryngium* falls below a certain number of individuals depending on the size of the pool and historic distribution.

Furthermore, monitoring can be used to gather information on population dynamics, seed dispersal techniques, and filling information gaps on the species. Any new information that we can gather benefits our chances of a successful restoration.

PART III

In restoring Grasslands Park, one must consider an incredible amount of information about many different species that all have differing requirements. Obviously a difficult task, any restoration project can be made simpler by focusing on a few species and providing conditions for those species requirements. Synthesis of differing species requirements can give us information about how many species can survive at different conditions, such as inundation periods. As an example, we can try to determine a range of tolerance for each species about required inundation periods. Setting the conditions to fit that range of tolerance can benefit the most species possible. In managing multiple goals, it is difficult to find a win-win situation because of the varying ranges of requirements and tolerances. There are always trade-offs in any restoration effort such that there will always be a species that cannot survive the determined range of tolerance. To accommodate multiple goals, restoration efforts should attempt to create a habitat that suits the most common required conditions. In restoring any site, we must look at each species individually and consider each site unique.

FACT SHEET

Basic info

- The Coyote-thistle is a perennial plant in the Apiaceae (carrot) family that grows in 2 forms:
  - The plant grows from a taproot with two forms
    - When in water, the leaves are hollow to carry air to roots
    - When the pool drains, the leaves turn prickly like a thistle
- Flowers in June
- Produces tiny, scaly dry fruits that contain 2 seeds
- One of the few native perennials that live in vernal pools
- Currently, the coyote thistle is by the California Native Plant Society as a 'federal species of concern' (CNPS List 1B)
- Pollinators, seed dispersal, and population dynamics are not known
- Plant size: 8-18 inches; flower 2-3 mm
- Eryngium Sp. includes about 230 species but vernal pool species include:
  - *E. vaseyi*
  - *E. constancei*

Life History

- *E. vaseyi and E. constancei* have similar life cycles:
  - germinate from seed in late winter or early spring
  - Develop broad leaves in the spring as water evaporates
  - Flower in the summer
  - Develop fruits and seeds in July-August
  - produces tubular leaves under water from perennial rootstock when pool refills
    - the deeper the pool, the better chance of survival

Habitat

- Eryngium Sp. is capable of growing in both hardpan and claypan vernal pools
- water around 16 inches deep
- pH of water of 6.1 - 7.5
- Elevation range: 350ft – 1,550ft

Distribution

- *Eryngium vaseyi* is endemic to vernal pools in California's Central Valley
- *Eryngium constancei* is endemic to only 3 vernal pools north of the San Francisco Bay

Disturbance and threats

- Affects to drainage, infiltration, and hydrology of pools including:
  - Water supply / flood control – changes to proper timing of filling and draining of pools
    - Reservoir constructions that might change the flows of streams and local water availability
  - Conversion of land for agriculture use
  - Urban development
  - Off-road vehicles
- Grazing: In a demonstration project in the Vina Plains, Tehama County, fencing was installed around pools to observe the long-term effects of un-grazed sites by vernal pools:
  - Within the vernal pool, coyote-thistle was the most common plant (about 35% of vegetation)
  - There were some plants scattered around the pool edges but <2% of vernal pool plants

Associated Species

- Competes against Hoover's spurge (endangered)
- Vernal Pool Dodder often grows on the coyote thistle (parasite)

Management Plan

- Fence off pools to restrict or regulate grazing & vehicles
- Limit reservoir constructions
- Ensure annual refilling of pools

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Sophie Sears

ENH 160- Restoration Ecology

Final Report

3 June 2010

Downingia in Vernal Pool Habitats

Introduction:

Vernal pools are unique and highly threatened wetland habitats of the California landscape (Keeler-Wolf 8). These vernal pool landscapes are among few habitats in the state that are still primarily dominated by native vegetation and wildlife (Barbour 129). There are as many as 200 plants that are restricted to the vernal pool habitats and found nowhere else (Barbour 9). The reason for this high endemism is due to the unique ephemeral properties of vernal pool cycles. Most plants and wildlife have evolved specialized characteristics to survive in the generally harsh landscape (Barbour 129).

Vernal pools are characterized by an impervious sub-surface soil layer that creates a combination of unique topography and hydrology, this results in fall to spring pooling with little to no downward percolation. This pooling drowns many plant species not adapted to vernal pools. In spring the sun starts to evaporate the water and native vernal pool vegetative species thrive in rings around evaporating pools. The spring bloom is followed by summer desiccation that can be persisted by native species of the vernal pools (Keeler-Wolf 8). These seasonally flooded landscapes have wildlife and vegetation that has evolved to complete life cycles in synchrony with the ephemeral pools (Keeler-Wolf 9).

Due to the often dry and seemingly unimportant habitat many former vernal pools sites have been written off as barren wastelands. This has lead to many vernal pools sites being converted into irrigated agriculture or urban development. These vernal pool habitats are highly threatened and it is thought that as much as 90% of California vernal pools have been destroyed (Barbour 129). Many of the species that occupy these habitats are threatened just as the vernal pools themselves. But there are native vernal pool species that have been able to continue to maintain a large population, despite degradation and the sensitive, often fastidious nature of vernal pool habitats.

Among this group of fairly widespread group of vernal pool species is *Downingia* spp. Dwarf Downingia, *D. pusilla*, is the one species of this genus that is endangered (*Jepson* 7). The focus of this research will be on three species of Downingia found at Grasslands Park: *Downingia bicornuta*, *Downingia insignis* and *Downingia ornatissima*. None of these species are threatened or endangered.

Justification:

Downingia spp. is a common vernal pool genus that has a significant role in the ecosystems of vernal pools. *Downingia* spp. provides a dependable source of cover and pollen for other, often sensitive vernal pool species. As an example, endangered species of solitary bees rely on a single species of *Downingia* spp. to complete their life cycles (Gray 254). So most *Downingia* species may not be threatened or endangered but there are vernal pool species that are rare or threatened and must have

Downingia present to complete their life cycles. This is a beneficial adaptation considering that *Downingia* is reliably present throughout the vernal pool blooming season.

Goals

Downingia is quite a common vernal pool species who's presence in the ecosystem is relied upon by rare or endangered species. *Downingia* population needs to be maintained and expanded where the population is not significant enough to support historic vernal pool associations.

General Biology

Identification: The genus *Downingia* in the Campanulacea or Bellflower family, is endemic to seasonal wet depressions and moist grasslands. The plants are small annual herb/forbs with small flowers less than a quarter of an inch in diameter. The flower has a majority of blue to purple color. White blotches with yellow dots are located on its larger lower petals (*Jepson* 30). The fruit is a capsule 4-8 cm long. *Downingia* vegetation grows low to the ground not reaching more that 3 inches in height. The erect stems have small pointed leaves at intervals (USDA). *Downingia* has been refered to as a "flower machine," rapidly focusing its energies on growing to flower then seed while little attention is given to the small minimal hollow stems and foliage (Baskin 386).

Life History: It actively grows spring to summer and bloom in early spring usually before many of the other vernal pool species (*Jepson* 8). It continues to bloom throughout the growing season. Due to its size and nature of the seed, spread rate is slow (USDA). The small capsules are designed to stay close to the parent habitat. This trait was observed to be similar to island biota where long dispersal distances into the matrix may not be beneficial (Solomeshch 399, 401).

Distribution: The *Downingia* species are all endemic to vernal pools of California or the West Coast of North and South America. *D. bicornuta* and *D. insignis* are found in California, Oregon, Nevada and Idaho. *D. ornatissima* is endemic to California.

Habitat Requirements: *Downingia* spp. is found throughout pools where the soil has been inundated by winter and spring pooling. Inundation tolerance ranges from 36 to 65 days (Solomeshch 402). A species of *Downingia* was observed to form apetalous flowers underwater and normal flower in the air. This trait is beneficial to get a foothold in before competitors (Solomeshch 400). *Downingia* cannot survive long inundation after germination, although it has evolved to withstand just enough longer than its competitors, but if stands too long the flowers disintegrate (Baskin 386). This is a reason why *Downingia* works so hard to produce flowers to seed before the next big rainstorm. *Downingia* will be found in greatest abundance at the bottom of vernal pools, but can commonly be found anywhere that the soil has been inundated. One source conducted a species assessment and found 35% of a pool's bottom species to be *Downingia bicornuta* (Barry 238). Created pools may have slopes that are unfavorably steep for *Downingia* (Solomeshch 419).

Environmental Preferences: Downingia prefers fine to medium textured soils and tolerates a pH between 6.0 and 8.2 (USDA). Requires winter cooling temperatures no lower than 47° to germinate in spring, this prevents germination in a rare summer rainstorm (USDA; Baskin 386).

Downingia has been seen to form “races” or biotypes that show differentiation within a population at the local scale. Soils are an especially strong means of selection in *Downingia* and other short lived plants. Observation of the type of vernal pools different *Downingia* species generally inhabit can give some clue to the correlation between species and the soil preferences (Elam 185). *Downingia bicornuta* is characteristic of Northern Hardpan vernal pools. *Downingia insignis* is characteristic of Northern Claypan Vernal Pools (Keele-Wolf 158).

~ Northern Hardpan Vernal Pools: Low, amphibious, herbaceous community dominated by annuals and grasses. Old, very acidic Fe-Si cemented hardpan sub-soils. Hummocky micro relief typical. Pools empty by evaporation (Keeler-Wolf 158).

~ Northern Claypan Vernal Pools: Low, amphibious, herbaceous community dominated by annuals and grasses. Lower micro relief than Northern Hardpan Vernal Pools and usually lower cover. Old, circum, neutral to alkaline, Si- cemented hardpan soils. More or less saline. Pools empty by evaporation (Keeler-

	Downingia bicornuta	*Downingia insignis*	*Downingia ornatissima*
Habitat	Vernal pools, roadside ditches, lake margins (Keeler-Wolf, 121)	Vernal pools, roadside ditches, lake margins (Keeler-Wolf, 121)	Vernal pools, roadside ditches (Keeler-Wolf, 121)
Distribution	California, Oregon, Idaho, Nevada (USDA)	California, Oregon, Idaho, Nevada (USDA)	Endemic to california (USDA)
Vernal Pool Type	Characteristic of Northern Hardpan Vernal Pools (Keeler-Wolf, 158)	Characteristic of Northern Claypan Vernal Pools (Keeler-Wolf, 159)	
Location in Pools	Central, deepest part of pools (Solomeshch, 408)	Large shallow pools, bottoms and feather edges (Silveira, 3)	Central, deepest part of pools (Solomeshch, 409)
Salinity	Not found in saline pools (Solomeshch, 408)	Found in saline pools (Solomeshch, 410)	Not found in saline pools (Solomeshch, 409)
Inundation time	36-65 days (Solomeshch, 402)	36-65 days (Solomeshch, 402)	36-65 days (Solomeshch, 402)
Soil pH		Alkaline soils ph>9 (Solomeshch, 414)	

Downingia bicornuta (Doublehorn Calicoflower)

Downingia insignis (Cupped Calicoflower)

Downingia ornatissima (Folded Calicoflower)

Species Associations

Downingia is one of the namesakes for the vegetative class that contains all vernal pool species, the Downingio-Lasthenietea class. *Downingia* and *Lasthenia fremontii* are often the poster child for vernal pools. These two species provide a flare to the vernal pools that is an attractive element bringing many people to vernal pools to enjoy the spring blooms. Other species commonly found among this association include: *Ranunculus bonariensis* var. *trisepalus*, *Gratiola ebracteata* and *Plagiobothrys undulata*, *Plagiobothrys stipitatus*, *Psilocarphus brevissimus* var. *micranthus.* (Barbour 18; Solomeshch 395). Patterns in species compostion changes are observed in data ranging from dry to wet years. Often in dry years among small pools annual hairgrass replaces *Navarretia* and *Downingia.* In dry years among larger pools *Navarretia* replaces *Downingia* (Silveira 13).

Previously mentioned was the important species association between Downingia and species of soliatary bees. Oligolectic insects such as *Andrena* spp., *Panurginus* spp., *Dialictus* spp., *Lasioglossum* spp. are known to collect pollen from a single genus or species (Keeler-Wolf, 150; Thorp). Many of these species are endemic to vernal pool and often have home ranges small enough to restrict them to a single average sized vernal pool. Generalist pollinators were also found among vernal pools but their contribution to pollen transfer is thought to be fairly insignificant (Solomeshch, 401). This relationship is vital to maintain since many of these solitary bee species are rare or endangered.

Threats

Like many of the vernal pool species, *Downingia* species are threatened by vernal pool habitat loss. This loss is due to a number of factors.

1- Conversion of vernal pool habitats to urban and agricultural lands.
2- Changes in a vernal pool hydrology.
3- Inappropriate livestock grazing such as over grazing, exclusion of grazing and bad timing of grazing.
4- Contaminants in the water or on the land.

5- Disruptive recreational use such as vehicular trampling.

6- Possible loss or decline of specialist pollinators.

7- Limited to poor management and monitoring (Solomeshch 417).

<u>Policies and Funding</u>

Since the *Downingia* species of focus are not threatened or endangered there may be limited funding opportunities. Vernal pool species that are threatened or endangered may beat out *Downingia* for funding. Sources for funding may include the California Native Plant Society, local or national government grants and non-profit organizations. Also funding may be obtained through other species associated with *Downingia*, such as the solitary bees.

<u>Restoration Goals</u>

There are three *Downingia* species that are found quite commonly in the Grasslands Park property. Goals for restoring the vernal pool habitats include maintaining the current populations of *Downingia bicornuta, Downingia insignis and Downingia ornatissima* and re-establish populations where they are missing or where the habitat could benefit from the added presence of *Downingia*. These *Downingia* species are found reliably during every spring blooming cycle. Therefore the ecology of many vernal pools has come to depend on these species being present. This is evident when observing solitary bees that rely heavily on a single genus or species for their pollen collection. Many of these solitary bees account for a major portion of the pollination, considerably more than common generalized pollinators (Solomeshch 401). Having a dependable population is necessary to have a healthy and diverse vernal pool community. Also many rare and threatened species rely heavily on the dependable *Downingia* populations for pollen collection and cover. It is important to maintain the numbers and genetic diversity of the regionally widespread populations.

	Small-scale	Large-scale
Short-term	Most to all vernal pools on the Grasslands property should host one of the Downingia species during a single season. **Why?**: So it can provide dependable habitat and attract pollinators to the vernal pool complex as a whole.	Maintain current population and genetic diversity of exisiting populations. **Why?**: So it can persist and continue role in community relationships.
Long-term	Develop new populations at the Grasslands Park, if needed, and restore vernal pool habitats. **Why?**: If populations decrease or are insufficient to support role in ecosystem then new populations considered.	Research species further **Why?**: To understand optimal requirements for implementing in future management and conservation plans.

traveling to unfamiliar and habitats where they cannot survive (Elam 185; Solomeshch 399).

Concentrate seed spreading to pool impressions. **Why?** *Downingia* tolerate a long period of inundation of 36 to 65 days to germinate. They commonly concentrate in the bottom of pools (Solomeshch 402). Seed should be spread before the first winter rains.

Monitor populations and communities also in relationship with associated species. **Why?** Rare and endangered species rely on *Downingia* to complete their life cycles (Solomeshch 401).

Grazing should be considered in a management plan. **Why?** Grazing, if done properly, can decrease the exotic species invading the vernal pool site. Also studies have shown *Downingia* only benefit from the micro-depressions left by grazer's tracks. Proper grazing is conducted at a time when plants are not in bloom or coming to seed. Also be careful not to overgraze. It would be beneficial to conduct further research on the benefits of grazing on vegetation throughout the Grasslands Park site. Cattle provided with additional water and feed can reduce non-native vegetation without overgrazing on vernal pool vegetation. Sheep may not be the best choice since they graze clser to the ground than cattle (Barry 240; Solomeshch 418).

Manage recreation so its impacts are as minimal as possible **Why?** Excessive recreation can lead to contamination with non-native invasive vegetation. Also overuse can lead to trampling and increased bulk density of the soil. Leading to compaction and inability for vegetation to thrive. Pollution may also be a problem with recreation. Try to limit and educate visitors.

Temporal scale: seed for years until healthy and abundant *Downingia* population is observed. Spatial scale: concentrate restoration efforts to vernal pool depressions.

<u>Monitoring techniques</u>

Pre-restoration monitoring should be conducted on hydrology characteristics such as time of inundation and average amount of precipitation the area gets. Also conduct monitoring of average pool depth, the average pH and salinity of water in pools. Monitor native and non-native species and report extent of exotic may have in. Monitor current disturbance regimes such as grazing or fire and decide wither these regimes would be beneficial during management. It is important to know the past use of the site. At the Grasslands property had formerly been used by the military. The site was contaminated but never used for agriculture. So much of the remaining impervious sub-soil layer is still intact. Evaluation of this layer should be conducted before a restoration plan is implemented.

Post-restoration monitoring should include more monitoring from the beginning to ensure seed establishes and that the first generation successfully makes it to seed. If this first round of *Downigia* succeeds in completing its life cycle then less monitoring would be required for future years. Periodic monitoring to inspect population numbers should be implemented. If population numbers start to decline rapidly this may be part of normal population fluctuations from year to year due to seed dormancy during unfavorable years, such as drought years. If populations do not come back then further restoration should be researched and considered. If after the first spring season the *Downingia* species are well established then monitoring during the next season could be minimal. If the restoration plan does not succeed then new techniques may include spreading seed at an earlier or later time. Also could consider using seed from different *Downingia* populations. Monitoring should occur until *Downingia* is reliably present in most vernal plant communities in the Grasslands vernal pool site.

Risks and uncertainties

It is impossible to know for sure if the choice of seed will establish or if the weather will be hospitable for germination and persistence during the following year. If a restoration plan fails it may be due to these factors such as amount of precipitation and temperature. If extreme or unusual weather such as drought, increased precipitation or abnormal temperature fluctuation takes place during a restoration year this should be factored into the resulting data. Also the impervious layer of soil that is characteristic of vernal pools is very hard to monitor integrity since it is underground. This can be estimated by inundation times to correlate various types of impervious layers present. There are also imaging techniques that basically take an x-ray of the ground, giving researchers ability to see past the upper soil layers. This could be considered but may be expensive and hard to come by the equipment so the exact condition of the impervious layer may be uncertain.

Additional Research

Downingia bicornuta, Downingia insignis and *Downingia ornatissima* are species found in the Grasslands site and are fairly common. For this reason there is limited research focusing on specific ecological preferences and requirements. Further research into specific habitat requirements and relationships would be beneficial to the optimal restoration and integration of *Downingia* into vernal pool communities. Soil and *Downingia* species pattern should be researched to discover what detailed soils different *Downingia* species prefer. Since this species is seen to be doing just fine on its own there has been a limited amount of research, with energies focused on threatened or endangered species. But since this species is quite common its relationships with other species is quite common too. More research into these relationships would be beneficial when creating a management plan. But I believe since this species is so common and integrated into the plant communities then it reliably needs to be present for the whole community to function at its prime. Many of the questions that are not answered due to *Downingia* seemingly healthy and abundant population have the potential to be answered through monitoring of current populations and of populations that have been manually seeded by the restoration team in natural or created pools.

Conclusions

Downingia is not the only or even most important species to be managed for and monitored. Many other vernal pool species are on the edge of extinction. Luckily supporting the life history of *Downingia* will bring similar management practices that will benefit many other species. *Downingia* is also fairly stable so there is a lower amount of energy required for monitoring, restoration and monitoring than the rare and endangered vernal pool species. It is important to view vernal pool habitat, its vegetation and wildlife as a cohesive ecosystem that cannot function properly if one part is missing.

Downingia Fact Sheet

(*D. bicornuta, D. insignis, D. ornatissima*)

Life History

- Downingia (*D. bicornuta, D. insignis, D. ornatissima*) is an annual forb in the Campanulacea or Bellflower family.
- Actively grows spring and summer.
- "Flower Machines," the small violet flowers dominate over the small hollow stem. They make flowers like machines in order to survive to seed before more rains comes and drowns the delicate flowers. (Baskin 386)
- Blooms early to mid-spring, usually before most other species

- Slow seed spread rate (USDA)
- Requires low temperature range for germination in order to prevent germination during a rare summer rainstorm (Baskin 386).

- Blue to purple flowers less than a quarter inch in diameter with blotches of yellow dots located on it larger lower petals.
- The fruit is a 4-8 cm capsule. The capsule does not distribute far from the parent habitat. This trait is said to be characteristic of island biota where dispersal into the matrix is not beneficial (Solomeshch 399, 401).

Distribution

- Endemic to vernal pools of California or the West Coast of North America.

Habitat Requirements

- Found throughout pools where soil has been inundated, but cannot survive long inundation after germination.
- Mostly found in central deepest part of pools (35% of vegetative cover was seen to be *Downingia bicornuta*) (Barry 238)
- Fine to medium textured soils
- Tolerates pH 6.0-8.2
- Minimum temperature 47°F (USDA)

Species Associations

- Associated with species of solitary bees (*Andrena* spp., *Panurginus* spp., *Dialictus* spp., *Lasioglossum* spp.) with small ranges that may restrict them to a single pool therefore contribution to majority of pollination compared to generalized pollinators.
- *Downingia* and *Lasthenia fremontii* are often the poster child for vernal pools. These two species provide a flare to the vernal pools that is an attractive element. Also found with these species are *Ranunculus bonariensis* var. *trisepalus, Gratiola ebracteata* and *Plagiobothrys undulata, Plagiobothrys stipitatus*, *Psilocarphus brevissimus* var. *micranthus* (Barbour 18; Solomeshch 395).

Disturbance

- Downingia is not resistant to fire
- Cannot survive inundation after germination
- Grazing produced little difference in species composition of a community where *D. bicornuta* found.

Threats

- Like most of our other researched vernal pool species, Downingia is threatened with habitat loss due to growing urbanization and agriculture
- Change in vernal pool hydrology interfere with Downingia completing it's life cycle.
- Disruptive recreational use.
- Possible loss or decline of specialist pollinators.
- Limited or poor management and monitoring (Solomeshch 417).

Goals

- Downingia is a common staple species of most vernal pools. In response, many other species, such as the solitary bees, have evolved to depend on Downingia for survival.
- It is critical to maintain these Downingia species so they can continue their important role within vernal pool communities.

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Part I: *Cuscuta howelliana*

Sigourney Fechtner

Background and Justifications

Cuscuta howelliana, commonly known as Vernal Pool Dodder, is a parasitic annual that is native to California [Calflora]. It is an obligate parasite, which means that it can only survive by attaching to a host plant and pirating water, nutrients and photosynthate. It uses penetration organs, called haustoria, to enter the cells of its host and tap into supplies. Since *Cuscuta howelliana* is sustained by its host plant, it has no need for roots or leaves of its own. It is easily identifiable by its stringy appearance and orange color (its stems are orange because they lack the green-pigmented chlorophyll used in photosynthesis). Its seeds germinate in February or March, and have carbohydrate reserves for seedling survival of up to two days before haustoral attachment to a host [Grewell]. In May or early June, *Cuscuta howelliana* produces small, inconspicuous flowers which are buried among the flowers of its host, and are pollinated by small insects as the host's flowers are pollinated [Splash]. *C. howelliana* dies with its host (dodder loses its source of reserves) between the end of summer and beginning of fall. In addition to its annual seeding cycle, *C. howelliana* can also reproduce vegetatively when its stems are fragmented [Grewell]. This poses a problem to management, as discussed later.

Though the general occurrence of *C. howelliana* is rare, it is most often found on species of *Eryngium* and *Navarretia* in vernal pools of California, specifically those in the Inner North Coast Ranges, the Cascade and Sierra Nevada Foothills, and the Great Central Valley areas [Jepson]. *C. howelliana* is found at vernal pool margins when its host is *Navarretia intertexta*

(Spiny navarretia), and within the pools when parasitizing *Navarretia leucocephala* (White navarretia) and *Eryngium castrense* (Vasey's Coyote-thistle) [Mather Field].

Management of *C. howelliana* is not a clear-cut decision, because the attributes of its parasitic qualities may promote species diversity within vernal pool systems [Grewell]. The level of concern is largely based upon the species *C. howelliana* is parasitizing. In cases where the host is a native, listed, endangered or is otherwise a species of concern, eradication of *C. howelliana* is the most likely response in order to protect that host species. In other cases, where *C. howelliana* might be found on a host that would otherwise dominate a community, a certain level of tolerance can be exercised for the benefit of the greater community.

Parties that might be interested in the management of *Cuscuta howelliana* are: the California Native Plant Society – *C. howelliana* is a native, and the CNPS might be interested in a strategy that weighs the benefits of eradication versus tolerance; the Center for Biological Diversity – vernal pools have a high diversity of rare native plant species, and *C. howelliana* is a threat to their physiological productivity and reproductive success; and the Nature Conservancy, which also seeks to protect natural ecosystems [CNPS].

Literature Review

Specific characteristics of *C. howelliana* make managing its spread somewhat difficult to accomplish. Seeds of the species are very small, and are easily transmitted from site to site by wildlife, humans, vehicles, etc., and the seeds can remain dormant within the seed bank for many years [Grewell]. It is also difficult to successfully eradicate *C. howelliana* by pulling because stem fragments left behind can re-establish the species at the "removal" site. General management strategies for *Cuscuta* in agricultural systems include: pre-emergent herbicides, 2,4-

D contact herbicides, and pulling and destroying the plant before seed set [USDA]. These methods of control might be effective strategies for *Cuscuta* species that parasitize agricultural crops, but herbicide use is not as practical for *Cuscuta howelliana* management. The pre-emergent and contact herbicides will also kill other vernal pool plant species, and could negatively impact sensitive invertebrate species, leaving the pools worse off than before. For Vernal Pool systems, the best policy for *C. howelliana* management includes: prevention of spread by sanitizing equipment and checking clothes and tires for seeds, eradication of occurrences of *C. howelliana* where it is a detriment to the community, or tolerance of dominant-suppressive host interactions.

Gaps in knowledge:

- History of *C. howelliana* in California – when first documented, where, extent of damage or occurrences of community benefits, what methods of management have previously been attempted (if any)
- Current state of populations – location, extent of infestation
- Host specificity – how easily *C. howelliana* can convert to new host species

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Part II: Management of *Cuscuta howelliana* for Yolo County Grasslands Park

Goals

There are three management goals that should be met when confronting the occurrence of *C. howelliana* in the park. The first, prevention, will attempt to inhibit the spread of this parasite to other pools within the site and also to entirely different sites. The time frame for this is especially sensitive starting in May or early June, when *C. howelliana* has flowered and will begin to set seed, because the seeds are very small and easily transmissible. This is potentially the most difficult management strategy to undertake because the seeds can stay viable in the seed bank for many years, and also because *C. howelliana* can also be spread vegetatively by fragmented stems. The second goal is eradication of the plant, and it involves complete removal if *C. howelliana* is identified at the site. The time frame for this is any time between germination in Februrary or March to flowering in May or June (eradicate before seed set). There is a threshold between eradication and the third goal, tolerance, that managers must address if *C. howelliana* is found at the site. While complete eradication will protect the vigor of *C. howelliana*'s host species, it may actually be a greater benefit to allow the parasite to reduce the chance that a dominant will take over the community. A tolerance plan will allow *C. howelliana* to remain in small populations, and will require consistent monitoring to ensure that it does not spread to different hosts or sensitive areas at the site.

The best management strategy for Yolo County Grasslands park would be to practice the tolerance strategy, if *C. howelliana* is ever found at the site. Eradication can be used as a supplemental plan if *C. howelliana* becomes too aggressive, as detailed later in the report.

Restoration plan

Meeting these goals requires more careful monitoring than actual labor. Prevention involves checking and sanitation between sites that have *C. howelliana* and those that do not. Look for small seeds on clothing, tires of vehicles, and tools and remove them (suggestion: use something sticky, like tape, to collect them from shoes, clothing and tires, because the seeds are easily wind-dispersed and could be scattered in the process of removal). Eradication involves recognition of the plant, and hand-removal of the stems, making sure to also remove stem fragments. It is probably a good idea to also remove the parts of the host with haustoral connections to *C. howelliana* because they might have enough stem attached to facilitate vegetative reproduction of *C. howelliana*, or the host may have *C. howelliana* flowers amongst its own. The plant material that has been removed should be bagged (to prevent further dispersal), taken off-site and burned to destroy *C. howelliana* seed and stem material.

The tolerance strategy again involves monitoring from early spring to early fall to make sure *C. howelliana* does not develop too aggressively, but occurs just enough to safely aid the establishment of a balanced community structure among the pools (by suppressing dominant species). To determine this, compare species diversity data for the site before the introduction of *C. howelliana* versus after, and observe whether species of concern are declining or increasing in number in the given time frame. This requires vegetation sampling, marking trends through time, and correlating those trends with the presence or absence of *C. howelliana*. If C. *howelliana* is supporting diversity, tolerance can continue; if it is hindering diversity, eradication must become the management goal. Species of greatest concern that should be monitored in the vegetation surveys include natives and natives of special status that are found within vernal pools. These are: *Neostapfia colusana*, *Castilleja campestris*, *Tuctoria mucronata*, and some species of *Plagiobothrys*, *Psilocarphus*, and *Gratiola*.

This plan requires year-round practice and execution, but focuses only within or at the margins of vernal pools. Montoring for prevention, using sanitation practices, and keeping records of species diversity are continuous practices, and should be maintained whether *C. howelliana* is or is not present at the site. Eradication should be concentrated between germination time in early spring and flowering time in early summer so that *C. howelliana* does not have the opportunity to replenish its reserves in the seed bank. Since *C. howelliana* is mostly found on hosts that reside within the pools, and occasionally on pool margins, the area for carrying out the management goals is fairly restricted and well-defined.

Potential problems and risks with the *C. howelliana* management plan might arise during the monitoring stage. Essentially, using this strategy at Yolo County Grasslands Park would be more of a research effort than an implementation of action. If *C. howelliana* is ever introduced to the site, in order to carry out the tolerance plan managers would have to have access to past vegetation data. Also, decisions would have to be made about how far back in time the data should go for trends to have statistical significance if past and present species compositions correlate to the presence of *C. howelliana*. Aside from problems with data, the biggest risk in this plan is that existing vernal pool communities will be subjected to open-ended (open-ended in the sense that managers do not know whether or not species within the community are being suppressed or aided by *C. howelliana*) management. To allow *Cuscuta howelliana* into vernal pools could mean hurting or helping natives and species of concern, but managers will not know which is the case until either of the options have already begun to occur.

This type of management, though risky and problematic, would be of great importance once implemented because (so far as this study of *Cuscuta howelliana* is concerned) no management effort has been conducted for this species thus far. All three goals, prevention, eradication and (especially) tolerance have been formed mainly from knowledge of the life cycle and botanical characteristics. It would be of great interest to observe the interactions of species in the community with this parasite, and truly figure out the role of *Cuscuta howelliana* in the grander scheme of things.

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Part III: Synthesis of Goals

The key goal of *Cuscuta howelliana* management synthesizes very well with one of the main goals of the class project. Since the *C. howelliana* tolerance plan requires species data for the vegetation at the site, managing for species of concern at Yolo County Grasslands Park will be a great complement. Within the project scope, native and native species of concern found in vernal pools will be closely monitored with respects to occurrence, frequency and spatial distribution, so that their progress at the site can be maintained or advanced. This kind of data will be helpful if the influence of *C. howelliana* is going to be understood, through time, so that adaptive management can occur accordingly.

Fact Sheet: *Cuscuta howelliana,* Vernal Pool Dodder

Background

- A California native
- Parasitic plant
- Distribution: Inner North Coast Ranges, Cascade and Sierra Nevada Foothills, Central Valley

Identification

- Yellow-orange and stringy

Life Cycle

- Annual
- Germination: February or March, on tissue of other plants, depends on carbohydrate reserves in cotyledons until haustorial attachment
- Penetrates host cell: parasitism of reserves
- Flowering: May or early June, hidden among hosts flowers
- Pollination: With pollination of host
- Also: Vegetative Reproduction by fragmentation of stems

Goals and Justifications

- Prevention: Limit spread
- Tolerance: it may cause the suppression of dominants, promotes diversity
- Removal: Eradication if too aggressive

Strategies, Constraints and Opportunities

- Prevention: Have small, easily transmissible seeds that can be spread by wildlife, humans, vehicles, seeds can remain dormant in the seed bank for years; pull and destroy plant before seed set
- Removal: can also pulling and destroy in areas where it has become too aggressive, take care because of vegetative reproduction strategy
- Tolerance: may suppress species that could act as dominants, leading to an increased diversity. Found on: Navarretia spp. (vernal pool margins: *Navarretia intertexta* , Spiny navarretia; vernal pools: *Navarretia leucocephala,* White navarretia) and Eryngium spp. (*Eryngium castrense,*Vasey's Coyote-thistle).

Plagiobothrys spp.

Scott Peacock

ENH 160

Part 1

Justification

California has hardpan, claypan, and volcanic basalt flows that have created the natural vernal pools we see today (Barbour, Pg. 8). Several plant species have evolved and adapted within California's vernal pools. Of those species, many are found in the genus, *Plagiobothrys*; commonly known as popcornflowers. *Plagiobothrys* spp. is an essential part of the vernal pool flora. Yet with various forms of degradation, vernal pools are disappearing. Once the vernal pools are gone, the unique flora will disappear as well. Knowing this, it's key to realize the importance of preserving and restoring vernal pools, as it will help protect *Plagiobothrys* spp.

- **Degradation**

  Vernal pools are thought to be among the most threatened wetland ecosystems in the state; estimates of habitat loss range from 66% to 90% (Buck, pg. 1). Historically, many vernal pools have been lost to agriculture (U.S. Fish and Wildlife Service, pg. I-17). Today, many vernal pools are typically lost due to a combination of urban expansion and intensive agriculture (U.S. Fish and Wildlife Service, pg. I-17). Introductions of invasive species, pollution, destruction, recreation, improper grazing management, and poor vernal pool monitoring have also caused a decline of healthy vernal pool ecosystems (U.S. Fish and Wildlife Service, pg. I-21). When vernal pools disappear so will many of the *Plagiobothrys* species. Because of this, it is important to understand the different forms of degradation since it will help define a plan of action to manage and restore vernal pools.

Current state of population

Since there are numerous vernal pool species within *Plagiobothrys*, it's hard to depict the current population since each species varies in number. Some species are abundant like *P. stipitatus*, whereas others are considered rare, endangered or even presumed extinct. Looking at the genus as a whole rather than by specific species, *Plagiobothrys* is quite common. The range in population sizes of vernal pool *Plagiobothrys* species is due to the diversity of vernal pool types.

- **Rare species opportunities**

  As mentioned above, some of the species in *Plagiobothrys* are rare or presumed extinct. By knowing that certain species have a reduced population, it provides opportunities to endorse a management plan for *Plagiobothrys* spp.

  For example, *P. hystriculus* is presumed extinct until a rediscovery of the species and if found, it will need a protection plan for the species and its habitat (U.S. Fish and Wildlife Service, pg. II-169). Bringing attention to this species will help encourage surveys to find possible existing populations, which may help further the protection of vernal pools (U.S. Fish and Wildlife Service, pg. II-169). Other rare species, like *P. glaber, P. strictus,* and *P. chorisianus var. chorisianus* may also encourage protection of vernal pools and the species.

Vernal Pool Types

It's important to know what type of vernal pool that is being dealt with since many of the *Plagiobothryus* species have adapted to a particular pool type. The generalized California vernal pool vegetation belongs to a single class Downingia-Lasthenia, which includes *Plagiobothryus stipitatus*

(Barbour, Pg. 4). Looking at three specific pool types, distinctive *Plagiobothrys* species are seen in each. Understanding these pool types will help determine the requirements of many *Plagiobrothryus* species and in turn, help develop a management plan.

- **Northern Hardpan Vernal Pool**

  This pool type has old Fe-Si cemented hardpan soils that are acidic. Evaporation empties the pools while rainfall from winter refills them. Species present include *Plagiobothrys stipitatus var. micranthus,* and *Plagiobothrys undulata* (Keeler-Wolf, pg. 158).

- **Northern Claypan Vernal Pool**

  These pools are similar to northern hardpan pools, but usually have but lower overall vegetation cover (Keeler-Wolf, pg. 159). The pool is built on alkaline Si-cemented hardpan soils. These pools consist of moderately old, slightly alkaline Si-cemented hardpan soils, which are often more or less saline (Keeler-Wolf, pg. 159). Species present include *Plagiobothrys leptocladus*, and *Plagiobothrys stipitaus var. stipitatus* (Keeler-Wolf, pg. 159).

- **Southern Interior Basalt Flow Vernal Pool**

  Species present: *Plagiobothrys undulatus.* (Keeler-Wolf, pg. 160)

General Biology

Found under the family Boraginaceae, the genus Plagiobothrys contains about 65 species that are distributed across the western part of North and South America. More than 15 species are endemic to California.

- **Identification-**

  The Plagiobothrys genus consists of herbaceous plants that are annuals or perennials, depending on environmental conditions. Most, if not all of the vernal pool species are annuals.

The flowers of Plagiobothrys spp. are tiny and bisexual with white or yellow coloration (UC/JEPS). The sepals of the flowers are partly fused. The inflorescence is a raceme or spike, which uncoils following maturation. The identification of the species often depends on the mature nutlets of the plant (UC/JEPS).

- **Life Cycle and Reproduction-**

It is difficult to find general information regarding life cycle and reproduction in the *Plagiobothrys* genus. Instead, this portion of the report is specified for the few individual species that had information available.

For all species, the main method of reproduction is by seed (COSEWIC, pg. 11). One seed is found in each of the four fruits, called nutlets, produced in a single flower (COSEWIC, pg. 11). In the species *P. hirtus*, it is seen that cross-pollination is achieved through insects such as moths, bumble bees, honey bees, hover flies, butterflies, and ctenuchids (U.S. Fish and Wildlife Service, pg. 11). *P. hirtus* is also partially self-pollinated (COSEWIC, pg. 12).

Seed dispersal methods seem to be unknown for *Plagiobothrys* spp. (COSEWIC, pg 12). The nutlet surface texture (hairy, smooth, etc.) may reflect how dispersal is achieved (COSEWIC, pg. 12). Water transportation may be a mechanism of dispersal (COSEWIC, pg. 12).

In terms of asexual reproduction, *P. hirtus* exhibits an isoetoid growth form, which is a type of submerged vegetation that allows it to survive over winter (U.S. Fish and Wildlife Service, pg. 10). The submerged rosettes interconnect by rooting at nodes and thus creating a vegetative mat (U.S. Fish and Wildlife Service, pg. 11). When the internodes rot away it causes a series of genetically identical species (U.S. Fish and Wildlife Service, pg. 11). Information in regards to this type of asexual reproduction was not mentioned for the other species.

- **Generalized Inundation Time**

It was found that 35-40 days was the overall approximate inundation time required for *Plagiobothrys* spp. (Keeley, pg. 4).

List of vernal pool *Plagiobothrys* species

Below is a table summarizing some of the *Plagiobothrys* species that are seen as part of the vernal pool habitat.

Species	Habitat	Nutlet	Inundation	Flower period	Rarity	Other
P. hystriculus	grassland, most likely vernal pools, and wet sites (Keeler-Wolf, pg. 139).	Nutlets have tiny barbed bristles (UC/JEPS).	N/A	April to May (U.S. Fish and Wildlife Service, pg. II-164).	Presumed to be extinct. Listed as 1A by CNPS (CNPLX).	Was found in Sacramento Valley (UC/JEPS).
P. stipitatus var. stipitatus	vernal pools, and wet sites in grasslands (Keeler-Wolf, pg. 140).	N/A	N/A	N/A	N/A	
P. stipitatus var. micranthus	Vernal pools, wetsites in grasslands, and in conifer forests (Keeler-Wolf, pg. 139). Grassy swales, alkaline, clayey (Plagiobothrys).	Nutlets lack prickles (Plants of Mather Field).	N/A	April to June (Plants of Mather Field)	Uncommon (Plagiobothrys).	Upright delicate plant
P. undulata	Hardpan vernal pools on high terrace or low terrace landforms (Barbour pg. 22).	N/A	N/A	N/A	N/A	

P. leptocladus	Thrive in slighty saline/alkaline pools (Barbour, pg. 48).	Nutlets are smooth with a keel on the back near the tip (Plants of Mather Field).	N/A	March to May (Plants of Mather Field).	N/A	Recognized as halophytes. Not a dominant species (Barbour, pg 48).
P. strictus	Moist sites near hot springs (Keeler-Wolf, pg. 140). Clayey, acidic sites. (Plagiobothrys).	1.5mm in size with a lateral scare at its base. (UC/JEPS)	N/A	N/A	State threatened specie (Keeler-Wolf, pg. 43).	Erect stem with lower cauline leaves (UC/JEPS).
P. stipitatus	Vernal pools, wetsites and roadsides (Keeler-Wolf, pg. 139). Does well in acidic sites (Lin, pg. 89).	Narrow, ribbed nutlet (UC/JEPS).	N/A	N/A	Uncommon (Plagiobothrys) .	Hollow stems (UC/JEPS).
P. trachycarpus	Vernal pools, wetplaces in grasslands, scrub and chaparral (Keeler-Wolf, pg. 140).	N/A	N/A	N/A	N/A	
P. humistratus	Vernal pools, wet places, and grassland habitats. (Keeler-Wolf, pg. 139) Often seen in depressions, and pool margins (Lin, pg. 8).	Nutlet is 2-2.5mm. Lance-ovoid, often bristled (UC/JEPS).	N/A	Seeds beginning of March and finishes it's life cycle in late April (Lin, pg. 43).	N/A	Endemic to California. (Calflora) Low species frequency (Lin, pg. 69).

P. greenei	Seen along vernal pool margins and on uplands (Barbour, pg. 32). Wet sites, grasslands, and woodland habitats (Keeler-Wolf, pg. 139).	Nutlet covered in long prickles (UC/JEPS).	Short inundatio n time (Barbour, pg. 26).	March to April (Plants of Mather Field).	Uncommon (Plagiobothrys) .	Resides in shallow pool communities (Barbour, pg 32).
P. glaber	Alkaline grasslands and vernally moist areas (Keeler-Wolf, pg. 139).	N/A	N/A	N/A	N/A	
P. bracteatus	Vernal pools, wet places in grasslands, coastal sagescrub, and chaparral (Keeler-Wolf, pg 139).	Nutlet scar is oblique (Plants of Mather Field).	N/A	April to June (Plants of Mather Field).	Common (Plagiobothrys) .	Inflorescenc e is bracted below the middle.
P. austinae	Volcanic rock vernal pools (Baurbor, pg. 35).	Bristly nutlet with prickles along its midribs (UC/JEPS).	Short inundatio n time (Barbour, pg.51).	N/A	N/A	Found in shallow pools (Barbour, pg. 51).
P. acanthocarpu s	Vernal pools, and wetsites (Keeler-Wolf, pg. 139).	N/A	N/A	N/A	N/A	
P. chorisianus var. chorisianus	Endemic to central western California (ESCTP).	N/A	N/A	February to May (ESCTP).	N/A	

P. Hirtus	Swales or seasonal wet meadows. Majority occur on the Conser soil silty clay loam series (U.S. Fish and Wildlife Service, pg. iii).	Basal scare. Tan-colored to black nutlets (U.S. Fish and Wildlife Service, pg. 1).	N/A	N/A	Federally listed as endangered (U.S. Fish and Wildlife Service, pg. iii).	Only found in Oregon (U.S. Fish and Wildlife Service, pg. 2).
P. figuratus	Wet areas, moist fields and open meadows (COSEWIC).	4 egg-shaped, wrinkled nutlets (COSEWIC , pg.4).	N/A	May to June (COSEWIC , pg. iv).	Endangered (COSEWIC).	Found in British Columbia (COSEWIC, pg. iii).

Management Considerations

Climate change

It has been seen that years with higher average temperatures likely have less diversity than cooler years (Buck, pg. 16). This is possibly due to higher evapotranspiration rates within the pool. A positive relationship is seen between precipitation and species richness (Buck, pg. 16). Knowing this, it's important to incorporate climate warming in the management plan. Vernal pools are sensitive sites, and a change in temperature can drastically affect its vegetation. For example, *Plagiobothrys stipitatus* dominates deeper pools (Barbour, pg. S-1) and with changes in temperature and precipitation, it can affect the depth of the pools and thus affect the inundation time for *P stipitatus*. Scientists believe that most areas in the world may continue to warm (Basic Information). If higher temperatures persist, the pools will become shallower and affect the distribution of *P. stipitatus*. Other species, such as *P. greenei*, thrive in shallow pools where climate change can also have a negative effect on the distribution. The fact that climate change is occurring must be incorporated in the management plan for *Plagiobothrys*.

Grazing

Incorporating grazing management is not essential for *Plagiobothrys* sp. to survive. According to the Barry report, a site that was fenced off from grazing for the past fifteen years contained 25% *Plagiobothrys* sp. in the vernal pool vegetation coverage (Barry, pg. 238). However, the report wasn't clear on which *Plagiobothrys* species it contained or the size of the vernal pool. Even though grazing is not a necessity as shown by the Barry report, it should be incorporated in the management plan since mircodepressions from hooves prints (3in to 6in deep) can create suitable habitats for *Plagiobothrys* spp. (Barry, pg 238). Also, grazing can help maintain the appropriate inundation time needed for *Plagiobothrys* spp. by limiting the competition from invasive plant species (Barry, pg. 240). To reiterate, *Plagiobothrys* spp. can survive without grazing but benefits from controlled grazing are seen.

Natural vs. created pools

Plagiobothrys stipitatus thrives in the deeper parts of pools (Moore, pg. S-1). It was discovered that this particular species has a greater frequency and relative cover in artificial pools than natural ones. The reason is due to the fact that artificial pools are generally created deeper than natural ones (Moore, pg. 40). There was not enough information to adequately describe the affect of created vernal pools on the other species in *Plagiobothrys*.

Sources of funding/help

Plagiobothrys contains several vernal pool species that are native to CA, some which are rare. The California Native Plant Society may be a potential source of funding/help. Their mission is to conserve native plant species (Conservation-California Native Plant Society). Funding also may be available from the Environmental Protection Agency, and non-profit organizations like the National Fish and Wildlife Foundation.

Part II: Goals and Management Plans For *Plagiobothrys* spp.

Key Goals:

Goal 1- Monitor existing *Plagiobothrys* spp.

Objective 1- Evaluate the size, density, and distribution of existing populations

Goal 2- Management of habitat of existing populations

Objective 1- Reduce competition from invasive non-natives by grazing

Upland invasive plants: yellow starthistle, medusahead, barbed goatgrass Vernal pool invasive plants: perennial pepperweed, swamp grass

Objective 2- Observation of stressors

Adjacent agriculture fields and roads

On-site recreation

Goal 3- Develop new populations if needed

Objective 1- Collect seeds from extant populations residing in on-site pools

Objective 2- Establish a seed bank

Objective 2- Monitor new populations

Goal 4- Research species further to aid in understanding of recovery

Objective 1- Research on pollinators needed to encourage genetic diversity

Objective 2- Research the optimal requirements for species

Factors such as inundation time, pool depth, pH

Restoration Plan

Monitoring:

To implement an effective monitoring plan for *Plagiobothrys* species, it's important to know what species already exist at the site. In 2005, *P. humistratus, P. stipitatus var. micranthus, and P. stipitatus var. stipitatus* were identified at the Yolo County Grasslands Regional Park (Yolo County). From now on, the rest of the report will be focused on these three species, which as a collected whole will be termed as "site species". No data on existing *Plagiobothrys* spp. populations was recorded in 2010. Assuming that those populations still exist from 2005, the next step is to record the population dynamics of each of the site species. To do this, populations can be measured by quadrants placed at each of the different pools presented at the Yolo County Grasslands Regional Park. The quadrant system estimates population frequency and number of individuals in a given population. The Transient Patterns in the Assembly of Vernal Pool Plant Communities report did this by using a square frame (0.50m x .050m) divided by 100 subquadrants (Collinge, pg. 3315). It's important to acquire this data during the flower phase (April-May) since it's much easier to identify the different species. This should be done annually, as population size will change every year due to changes in climate and by impacts from natural and artificial sources. Population locations should also be mapped annually, along with data such as percent reproduction and recruitment (U.S. Fish and Wildlife Service, pg. 33). The data obtained by monitoring can help approximate the population dynamics of the site species and thus allow us to understand what measures need to be taken in management and even restoration. If monitoring continuously shows well-established *Plagiobothrys* spp. populations, it can be reduced to once every two years. If population size is still abundant after six years, monitoring can be reduced further.

The species present at the Yolo County Grasslands Regional Park in 2005 have no federal or state status as threatened/endangered. Regular monitoring can keep managers informed of the species populations, as there is a tendency to disregard the common species and focus on the endangered/threatened species at the site. According to one source, *P. stipitatus var. micranthus* was termed “uncommon” (Plagiobothrys). Because of this, monitoring should be emphasized more on this species.

Management:

Regardless of the abundance of the site species, grazing needs to be considered in the management plan. Grazing helps limit the population of non-native invasive species, such as yellow starthistle, medusahead, barbed goatgrass, medusahead, and perennial peppergrass, all of which are seen at Yolo County Grasslands Park. This is important since non-natives are known to outcompete native vernal pool species, and also transpire water out of the pools. Cattle are the species of choice for grazing in vernal pool areas as they consume mostly grasses (Barry, pg. 240). Water and feed should be set at various locations can improve their distribution and also keep them from focusing solely on the vernal pool vegetation. Cattle should be utilized in early spring when they will consume the invasive grasses (Barry, pg. 240). By grazing early, it allows consumption before the grasses have reached maturity thus limiting their dispersal. Grazing at this time also allows decent sized hooves prints to form because of the moist ground. This creates suitable habitats for *Plagionbothrys* spp. to reside in (Barry, pg 238). When the pools begin to dry up, cattle will venture in the vernal pool area. This will help remove residual dry matter therefore encouraging fall germination of vernal pool margin species. *P. humistratus* is known as a vernal pool margin species and this may be a good strategy to increase it’s germination rate (Lin, pg. 8).

The exact time to remove cattle is not clear. It can be assumed that they should be removed soon after they reach the vernal pool vegetation. Sheep should not be used due their tendency to graze close to the ground (Barry, pg. 239). Monitoring of grazing is needed to ensure heavy grazing does not occur. Direct impacts (vegetation damage etc.) of heavy grazing on the site species is not known and should be researched.

Yolo County Regional Grassland Park has human visitation, active/passive recreation, neighboring agriculture crops and roads, all of which can impact the site species. Some examples of potential problems include, herbicide/pesticide drift from neighboring agriculture fields, and destruction of pools by farm equipment or vehicles. A monthly visual observation of the pools should be sufficient enough to insure that there are no obvious stressors in place. Good communication with neighboring farmers is important to have in case a problem does arise. It's important to note that Pool 4 may have non-point source discharge from farm drainage according to observations recorded from UC Davis ENH 160 lab. If site species are present at this pool, a more careful monitoring protocol will be needed.

Population reestablishment of site species:

The population size and frequency obtained by the monitoring protocol for each of the three site species (*P. humistratus, P. stipitatus var. micranthus, and P. stipitatus var. stipitatus*) is needed to determine if population reestablishment will be necessary.

Reestablishment of *Plagiobothrys* spp. by seed can be a method of restoring the species populations because of prolific germination (*P. hirtus* as a reference species). The pollination process is not clear for any of the three site species. Looking again at *P. hirtus*, it is seen that cross-pollination (by insects) and self-pollination occurs. From this, it is possible that the same pollination process occurs for the three site species. Further study is needed ensure this is true. Knowing that the species may be partially self-pollinated, it's important to collect seed from numerous individuals to preserve genetic diversity. Seed collection of the species should be done onsite. This is done to preserve any locally adapted genotypes that may occur and to avoid outbreeding depression (U.S. Fish and Wildlife Service, pg 32). One report stated that they collected 10 seeds per individual. They did this for 10 different individuals per pool, thus collecting 100 seeds from each pool (Collinge, pg. 3315). When populations are particularly low, a seed bank should be initiated. When saving collected seed, the seed should be stored in a cool and dry environment. The seed should be used within one year to ensure viability.

Seed should be distributed before winter rains (Collinge, pg. 3315). One method of distribution is by combining the seed with fine sand and scattered over the soil surface (Collinge, pg. 3315). After new populations are established, monitoring of the new populations will be needed to determine the effectiveness of the seeding and the establishment of the population. Monitoring of new populations should follow the same protocol that was stated earlier.

Research:

Understanding the optimal growing requirements for each of the site species is key for determining which pool site is appropriate for each of the three site species. Due to lack of information on each of the three site species; it's difficult to determine what pools are best suited for each species. Knowing optimal requirements for each species, such as inundation time, pH, pool depth, can help in choosing which pools the seed should be distributed and how the species will react to disturbance. There is no information on the inundation time needed for *P. humistratus, P. stipitatus var. micranthus, and P. stipitatus var. stipitatus.* Once more information is obtained on each specific species; a more detailed management plan can be incorporated.

Also, research is necessary on which insect species are pollinators of *Plagiobothrys* at Yolo County Regional Grassland Park and how readily available the pollinators are. By understanding what insect pollinates each of the site species, cross-pollination can be encouraged and genetic diversity can further be obtained.

A further understanding of the current populations of *P. humistratus, P. stipitatus var. micranthus, and P. stipitatus var. stipitatus* at Yolo County Regional Grassland Park is key for an effective management plan.

Part Three

The three *Plagiobothrys* species present at Yolo Regional Grassland Park are relatively common. Knowing this, along with having limited amount of information on the species, caused a somewhat generalized management plan. Fortunately, this will make the synthesis with other management goals rather easy. One win-win situation seen is the idea of a grazing plan, which was also recommended for managing other species. This should benefit *Plagiobothrys spp*. and other species at the same time. The monitoring of *Plagiobothrys spp*. is somewhat universal and can easily be adapted into the monitoring plans of other species. Having limited information does bring a downfall since the unknowns could potentially conflict with the management of other species. Once the unknowns are figured out, a revised management plan should be considered.

Fact Sheet

Plagiobothrys spp.

Background

Order: Lamiales

Family: Boraginaceae

Genus: *Plagiobothrys spp.* (Popcornflower)

Contains 65 species, 15 of which are native to California. Globally distributed from western South and North America

Identification

Species identified by the characteristics of the four nutlets. Small white to yellow bisexual flowers with partly fused sepals. Inflorescence is a raceme/spike. First coiled then straightens at maturity.

Life Cycle

Main method of reproduction is by seed. Seed dispersal mechanisms are not apparent but may rely on water. Insect cross-pollination and self-pollination is seen in *P. hirtus*. Insects such as bubble bees, honeybees, hover flies, butterflies. *P. hirtus* seen with prolific germination. Asexual reproduction is seen in P. Hirtus.

Justification

Many species seen within *Plagiobothrys* are part of the vernal pool flora. Some of which are endangered or even presumed extinct

Rare California *Plagiobothrys* Species

Provide an opportunity to further protect vernal pools

P. hysticulus, P. glaber, P. strictus, P. chorisianus var. chorisianus

Other Rare *Plagiobothrys* Species

P. figuratus, P. hirtus

Northern Hardpan Vernal Pools

Fe-Si cemented hardpan soils that are acidic. Pools recharge by rainfall.

P. stipitatus var. micranthus, P. undulata

Northern Claypan Vernal Pools

Defined by Alkaline Si-cement hardpan soils that are more or less saline. Has lower overall vegetation cover.

P. leptocladus, P. stipitatus var. stipitatus

Deep Pool Species

P. stipitatus

Dominates deeper pools, does well with acidic sites. Diagnostic specie for vernal pool class called Downingia-Lasthenia

Management

Natural vs. created pools:

Created pools had an abundant amount of *P. stipitatus*

Grazing*:*

Hoove prints from cattle created micro-depressions that helped form a suitable habit for *Plagiobothrys* spp.

Grazing is also a way to help rid exotic/invasive plants

Climate change:

Should be considered when making the management plans.

Climate change could affect the inundation time for *Plagiobothrys*.

Yolo County Grasslands Regional Park

Species present

P. humistratus, P. stipitatus var. micranthus, and P. stipitatus var. stipitatus

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Invasive plants

Perennial Pepperweed, *Lepidium latifolium*
Part I: Background and literature review

Taraneh Emam

I. Introduction

Invasion by non-native plants can have extremely negative consequences for the native community. Invasive plants can alter abiotic conditions, such as soil quality and water availability; and biotic conditions, such as plant biodiversity, soil communities, and forage quality. The effects that invasive plants have may be additive, in that they increase linearly with increasing size of the invasive plant population, but often they can also cause effects out of proportion to their abundance. Perennial pepperweed, *Lepidium latifolium*, is an invasive plant of high concern in California which is capable of altering both biotic and abiotic conditions, and can have nonlinear impacts on the native community (Cal-IPC 2003). Therefore, control and early detection of pepperweed is very important to manage infestations (Renz et al. 2002).

Perennial pepperweed in rosette form

Pepperweed in flower

(Renz et al. 2002)

II. Background

Native to southeastern Europe and west Asia, pepperweed is thought to have been introduced to Yolo County in shipments of sugar beet seed during the early 19th century (Young et al. 1995). It is now present in nearly every county in California, and in all other states in the western U.S. as well as parts of New England (USDA PLANTS).

Laws and policies relating to pepperweed

Pepperweed is ranked a B list noxious weed by state standards (USDA, NRCS 2001), and according to the California Invasive Plant Council it is ranked as of high concern and scores an "A" for impact on communities, invasiveness, and distribution in California. It has the ability to spread very rapidly, infestations expanding up to more than 2m per year through vegetative reproduction (Cal-IPC 2003). Pepperweed is listed at the state level as a noxious weed, or is prohibited, in 15 U.S. states including California, where it has a B rating. The California Department of Food and Agriculture defines a B rated weed as follows:

> "[A] pest of known economic or environmental detriment and, if present in California, it is of limited distribution. B-rated pests are eligible to enter the state if the receiving county has agreed to accept them. If found in the state, they are subject to state endorsed holding action and eradication only to provide for containment, as when found in a nursery. At the discretion of the individual county agricultural commissioner they are subject to eradication, containment, suppression, control, or other holding action." (CDFA Encycloweedia)

III. Literature review

Biological characteristics and invasiveness of pepperweed

Perennial pepperweed is a forb that begins yearly growth in a rosette form, which becomes bushier and then flowers in the summer, followed by production of seeds and senescence of aboveground structures. A range of phenotypic states, from vegetative to senescent, may be present concurrently within a local area. The timing of phenological events has been found to follow water availability, and could relate to soil stress and intraspecific competition instensity as well (Andrew and Ustin 2009).

Pepperweed is particularly difficult to control due to several biological characteristics. Local spread occurs mostly through vegetative means, through resprouting from perenniating root systems and root fragments as small as 2.5 cm (Howald 2000). Pepperweed also produces abundant seed set - this may be responsible for colonization of previously uninvaded ranges although seedlings are rarely seen in already established stands of pepperweed. Although they possess no specific mechanism for long-range dispersal, seeds may be carried by wind, animals, or humans over long distances, which can result in new infestations. Root segments carried downstream can also lead to new infestations.

The majority of pepperweed root biomass is located in the upper layers of soil, but roots can also grow deeper than 3m to tap into the water table. Pepperweed is sensitive to water stress, and deep root growth allows it to persist through dry periods (Renz and Blank 2004). Plasticity in root allocation may also contribute to avoidance of water stress (Renz 2002). Research indicates that only a small range of water potential allows for maximum growth of pepperweed, and its success rapidly declines as soils become drier or more inundated than this optimum. However, pepperweed is highly tolerant of periods of inundation such as found in vernal pools – although it does not have optimal growth during flooding, it is able to develop flood-adapted physiological features such as adventitious roots and aerenchyma to survive long periods of inundation. In experimental studies, pepperweed survived 50 days of inundation with adaptations characteristic of facultative hydrophytes (Chen et al. 2002, Chen et al. 2005)

Effects of pepperweed invasion on vernal pools

The shallow water table and wetland characteristics of vernal pools make them especially vulnerable to invasion by perennial pepperweed, which commonly colonizes areas of high water availability and saline or alkaline areas. Pepperweed has been documented in saline and alkaline vernal pools, playas, sinks, and meadows; and is able to colonize both short-inundated and long-inundated pool types (Barbour et al. 2007). Pepperweed grows within the vernal pool itself, where it is a direct threat to the vernal pool community and can also alter abiotic processes (Yolo County Planning and Public Works Dept. 2005).

Soil feedbacks: Salinity and nutrients

Pepperweed can alter soil characteristics by redistributing ions within the soil profile, and promotes its own growth by increasing soil salinity. It acts as a "salt pump," extracting ions such as calcium and magnesium (Ca^{2+} and Mg^{2+}) from deeper soil and relocating them to the soil surface. This increases the calcium:sodium ratio, which displaces sodium ions from the soil. Sodium ions are then leached out of the soil during wet periods (Renz and Blank 2004); however, in the case of vernal pools, this could result in increased concentrations of sodium in the vernal pool itself. Similarly, the deep roots of pepperweed allow it to access nutrients in lower soil layers, which are redeposited on the soil surface in the form of litter. This results in greater availability of phosphorous and nitrogen in the upper layers of soil (Blank et al. 2002, Ehrenfeld 2003).

The redistribution of ions and deep-rootedness of pepperweed also alter soil physical properties, improving soil structure and lessening compaction in natric soils. Blank and Young (2002) suggest that pepperweed could be useful for restoring sodic or natric soils; however, in naturally alkaline soils, this effect is undesirable and has negative consequences for the native community which is adapted to such conditions.

Relationship of pepperweed with native vernal pool species

Pepperweed invasion is detrimental to native species in many ways. Its effect on soil salinity favors the growth of salt-tolerant plants, and by increasing soil nutrients it negatively affects plants adapted to nutrient-poor soils. Pepperweed begins growth earlier in the season than most natives, and is able to shade out native plants. The dense stands and thick layer of litter, which is slow to decompose, make it difficult for native plants to re-colonize the area as well (Cal IPC 2003, Renz and Blank 2004). Pepperweed has been noted as a direct threat to several listed rare vernal pool plants, such as Crampton's tuctoria (*Tuctoria mucronata*), alkali milk vetch (*Astragalus tener* var. *tener*), and Colusa grass (*Neostapfia colusana*) (Yolo County Planning and Public Works Dept. 2005). By degrading native habitat and replacing native plant species, pepperweed may also harm wildlife such as migrating waterfowl (Cal-IPC 2003).

Past research in the San Francisco Bay has shown that dodder, *Cuscuta subinclusa*, preferentially colonizes pepperweed and reduces seed weight and germination of pepperweed by 27 and 42%, respectively (Benner and Parker 2004). However, when pepperweed is abundant and is highly colonized by *Cuscuta*, increased infections of native plants by *Cuscuta* may result (D. Benner, *pers comm*). It is unknown whether vernal pool dodder, *Cuscuta howelliana*, is similarly promoted by pepperweed growth or if this negatively affects natives.

Methods for management

Control of populations of perennial pepperweed is most effective in early stages of invasion, before large amounts of underground biomass has been established. Survey and identification of rosettes in early spring can allow opportunities to prevent further spread. In large infestations, it is recommended to begin by controlling newer patches of pepperweed and working inward towards the original source population. Younger plants are more susceptible to control methods, and eradicating them helps prevent further spread (Renz et al. 2002). Possible control methods are explored below:

- Mowing or clipping plants and coating basal leaves with glyphosate or 2,4-D is an effective control, but multiple applications may be needed to combat resprouting. Chlorosulfuron has been found to be more effective, but cannot be used near water (Renz et al. 2002). A combination of mowing and herbicide application has been found to be most effective in dense stands (Renz and Blank 2004). Mowing should occur early in the season when flower buds are present, and herbicide should be applied when plants regrow and return to flower bud stage (Renz and DiTomaso, 2006).
- Grazing can be an alternative to mowing, but must occur before pepperweed sets seed, or seed could be transported to uninvaded areas (Renz et al. 2002). Ruminal incubation of pepperweed

seed has been shown to increase germination rates as well (Carpinelli et al. 2005). If used, grazing should be followed by herbicide application.

- In dense stands, abundance of litter may inhibit recolonization by native plants, and mowing or removing litter may be necessary as well.
- Long-term inundation of pepperweed for two or more growth seasons is also an effective control but is often not practical for implementation, especially within vernal pool systems.
- Burning has not been found to be effective, as perenniating roots remain in the soil (Renz 2002, Renz et al. 2002). However, it may be used as an alternative to mowing prior to herbicide application, and may be used to remove dead litter.
- Disking and tilling alone are unadvisable because these activities can lead to the unwanted consequence of spreading root segments over a larger area, which can then resprout (Renz et al. 2002).

The presence of rare plants and aquatic systems also makes control of pepperweed more difficult in vernal pool regions, as it is imperative to not damage the native community in the process. Herbicides such as glyphosate (Rodeo©) can be used near aquatic systems, and if applied directly to severed pepperweed stalks will do minimal damage to surrounding plants (Renz et al. 2002). Care should always be used when using herbicides to minimize drift and impact on non-target species.

Depending on the goal of the restoration project, the focus may be on reducing vegetative spread or seed dispersal. Pepperweed spreads mainly through vegetative means at a local scale, but seeds may be responsible for longer-distance dispersal and colonization of new areas. To control a new local invasion in a region which is already heavily invaded by pepperweed, the focus might be on only controlling vegetative growth. However, when controlling an invasion in a relatively uninvaded region, it may be very important to minimize seed set and dispersal (by repeated mowing, etc.) as well.

Past management successes and failures

At the Cosumnes River Preserve, about 20 miles south of Sacramento, several methods have been evaluated for effectiveness in controlling pepperweed and effects on non-target native species (Hutchinson et al. 2007). They found that mowing and disking followed by tarp cover for two seasons was an effective measure against pepperweed, but mowing alone followed by tarping was not.

However, Renz (2002) found that disking can be potentially problematic due to the fragmentation and spreading of root parts, which then regenerate new individuals of pepperweed. The Cosumnes River Preserve project also used adaptive management to derive different recommendations for dry and wet years. In wet years, they suggest focusing control efforts on upstream or source populations to minimize seed spread, while newer satellite populations should be addressed during dry years (Hutchinson et al. 2008). On the Cosumnes river floodplain, periodic inundation and erosion due to flooding (scour) was found to reduce pepperweed growth and establishment as well.

Further research needs

It is unknown whether allelochemicals significantly contribute to the invasiveness of pepperweed; allelochemistry of this species has not been investigated though it is likely that it produces phytoactive chemicals, as many members of the Brassicaceae family do (Renz and Blank 2004, Muller 2009). Additionally, assessment of the plant-soil feedbacks between pepperweed and soil salinity (and other soil chemical characteristics) over longer time scales could provide new insights.

Funding sources specific to control

Several funding sources are available to assist with the control of high-priority weeds in California. Examples include the CALFED Bay Delta Program (at calwater.ca.gov), administered by several agencies, provides funding through the Ecosystem Restoration Program. EQIP, the Environmental Quality Incentives Program, is administered by the USDA Natural Resources Conservation Service and focuses on education and funding to farmers and ranchers (see "Noxious Times (1999)" for more information).

IV. Summary & Conclusion

Pepperweed, *Lepidium latifolium*, is an invasive species which can be extremely disruptive to both abiotic processes and ecological communities. It affects abiotic conditions by increasing soil salinity by redistributing ions within the soil profile, and forming dense layers of aboveground organic matter. The dense growth for crowds out native species and reduces habitat for wildlife. Pepperweed is capable of very rapid vegetative growth, so early detection and management are of the utmost importance. The best methods for controlling pepperweed are mowing followed by herbicide application, which may need to be repeated. Activities which cause the fragmentation and spread of root parts are to be avoided, as these can resprout and form new stands. Continual monitoring is recommended to prevent infestations before they result in long-term effects, as larger infestations can lead to soil feedbacks which are much more difficult to recover from.

Part II: Goals and management plans

I. Introduction

Perennial pepperweed (*Lepidium latifolium*) invasion is a top concern for vernal pools in Yolo Country Grasslands Regional Park. Invasion by pepperweed degrades vernal pool systems by altering soil chemistry and directly threatens rare vernal pool species. A management plan for the eradication of pepperweed from Grasslands Regional Park including goals, control methods, monitoring, and potential for research is discussed in this report.

II. Goals

A. Short-term goals (0-3 years)

- To eradicate sparse, newly-formed stands of pepperweed
- To minimize the potential for spread and development of new infestations of pepperweed in Grasslands Regional Park

B. Long-term goals (>3 years)

- To eradicate dense, well-established populations of pepperweed
- To eliminate all populations of pepperweed from Grasslands Regional Park
- To monitor Grasslands Regional Park over the long-term and prevent future invasions by pepperweed

III. Management plan

In the Grasslands Regional Park CALFED Conservation and Management Plan, the recommended action is to clip or mow plants and immediately apply herbicide; however, it would be more effective to clip the plants, wait until they have returned to the flower-bud stage, then treat the basal leaves with herbicide, and lastly remove or burn any aboveground litter that remains (Renz and DiTomaso 2006, Renz 2005). It is thought that the budding stage is the time when the maximum mass flow from the shoot to the roots occurs in pepperweed, providing the highest dose of herbicide to the roots (Renz and DiTomaso 2006). If applied directly after clipping, mass flow may instead be reversed, as plants devote resources to regrowing shoots.

Numerous herbicides are available for control of pepperweed, with varying success rates, and the choice of which herbicide to use is determined by the site conditions (see Tables 1 and 2 for more details about effectiveness of various herbicides on pepperweed at the flower-bud stage with and without previous mowing). Specific recommendations are detailed below for large/dense and small/sparse populations of pepperweed within vernal pools or upland areas. In all cases, repeated treatment each year for 2 to 3 years may be necessary to fully eradicate pepperweed. After each treatment, pools should be examined in the fall to note any resprouting which will need re-treating in spring.

A. Pepperweed within vernal pool or other seasonally wet areas

Since vernal pools are sensitive aquatic systems containing plant and animal species of concern, it is imperative to minimize the effects of chemical herbicides on these ecosystems. Many herbicides cannot be used in or near aquatic systems. Rodeo©, Aquamaster © (glyphosate) and Weedar© (2,4-D) can be used in aquatic systems, and are recommended for use on pepperweed in pools with standing water present late into spring. Glyphosate is non-selective, but more effective, and is generally not toxic to non-plant organisms; 2,4-D is somewhat less effective and can be toxic to wildlife, but will not damage monocots and has a shorter soil half-life (Renz et al. 2002, NCSU 2010). Products combining glyphosate and 2,4-D are also available (Renz 2005). 2,4-D is recommended for pools where rare vernal pool monocot species such as Colusa grass (*Neostapfia colusana*) and Crampton's tuctoria (*Tuctoria mucronata*) are a major concern.

Sparse populations within vernal pools:

Newly colonized vernal pools with only a small number of pepperweed individuals should be the top priority for immediate management, because pepperweed spreads at an extremely fast rate and can severely alter the ecosystem once well-established (Renz and Blank 2002). Sparse populations of pepperweed within vernal pools should be hand-clipped when pepperweed is at the budding stage, or as close to that stage as possible when pools have dried out. Since herbicides are mainly absorbed through basal broadleaves, pepperweed stems should be clipped just above these in case resprouting does not occur – pepperweed may or may not resprout soon after clipping, depending on water availability and root mass (Renz 2005). If resprouting occurs, herbicide should be applied when pepperweed reaches the flower-bud stage painting directly onto the basal leaves. If resprouting does not occur, herbicide should still be applied, but may not be as effective as herbicide applied during the budding phase. The recommended herbicide for these areas is Weedar© at a rate of 0.5 gallons/acre (Renz 2005) if damage to monocot species is a main concern, or Rodeo© at a rate of 0.75gallons/acre if damage to wildlife is of greater concern.

Dense populations within vernal pools:

In pools where dense stands of pepperweed dominate and species of concern are not present, pepperweed should be mowed or clipped once pools become dry, preferably when plants are budding or in early flowering. Again, once plants resprout to the budding stage, herbicide should be applied. Rodeo© applied at a rate of 0.75 gallons/acre is recommended for dense pepperweed populations where risk of herbicide damage to native plant species is minimal, and may be sprayed or painted onto the basal leaves.

B. Pepperweed in upland or mesic-dry areas

Managing upland infestations of pepperweed is necessary to control potential sources of future invasions into vernal pools and elsewhere. During dry periods when the potential for herbicide runoff into vernal pools is minimal, more effective herbicides such as Telar© (chlorsulfuron) may be applied at a rate of 1-2 oz./acre following removal of aboveground biomass.

Sparse populations in upland areas:

As in vernal pools, sparse populations should be addressed before large populations, since small colonies can more easily be eradicated before they form dense stands. Sparse populations should be hand-clipped at the budding stage, and herbicide painted onto basal leaves once plants reach budding again.

Dense populations in upland areas:

Management recommendation is the same as that of sparse populations, except that mowing and spray application of herbicide may be used instead of hand-clipping and painting in large infestations. See also “Incorporating research and management” for an alternative control method.

C. Risks and uncertainties

With herbicide use, there is always the risk of damaging native plant populations. However, harm to these populations can be minimized by using broadleaf-selective herbicides and the hand-clipping/painting method whenever possible.

Fluctuations in weather patterns from year to year can make the success rates of treatment variable and thus are a source of uncertainty; however, monitoring that includes correlating effectiveness of treatment with different weather patterns can provide insight for the future and reduce uncertainty.

D. Monitoring

Monitoring is an essential part of efforts to control pepperweed, and must be ongoing to prevent future invasions. During the first 0-3 years monitoring should occur in both fall (to identify resprouting of treated areas) and late spring (to look for pepperweed during its more apparent growth form, and to apply treatment when necessary). After management efforts have effectively eradicated most populations, monitoring can decrease to only in the spring with treatments as needed. A pepperweed monitoring plan should include the following components (time of the year that monitoring should be conducted is in parantheses):

- Mapping the current distribution of pepperweed within Grasslands Regional Park and ranking these as “small/sparse” populations or “large/dense” populations to establish a baseline for comparison
- Identifying new individuals of pepperweed, and prioritizing these for eradication efforts (Fall and Spring)
- Identifying rapidly growing stands of existing pepperweed and addressing these secondly
- Quantifying “before treatment” sizes of populations which are being treated (Spring, immediately before treatment)
- Monitoring treated populations and quantifying resprouting to determine success rate and to determine if further treatment is necessary (both Fall and Spring)
- Monitoring special status species to ensure they experience minimal adverse effects of pepperweed control methods

E. Incorporating research and management

By taking quantitative measurements of pepperweed populations before and after treatment (such as area, density, cover, and/or biomass), a success rate can be determined for the method of control being used. Other data that would be useful to incorporate is noting site characteristics (e.g., wet versus dry site, age of population if known, etc.) as well as environmental data (e.g., wet versus dry year, temporal pattern of precipitation, climate). If there are populations which are not going to be treated due to other constraints, they can be quantified as well and used as “control” plots to compare treated populations to untreated populations in addition to before and after treatment comparisons.

Another management option for dense upland populations that has been documented to have some degree of success is a combination of mowing and disking followed by covering with a tarp for two or more seasons (Hutchinson et al. 2007 and 2008). Establishing replicated “test plots” where combinations such as mowing+tarping, mowing+disking+tarping, mowing+herbicide+tarping, etc., can allow for the comparison of effectiveness of these treatments compared to one another and to the mowing+herbicide treatment. However, any disking treatments should be conducted with extreme caution so as not to spread root fragments to new areas (see Part 1 for more information).

While many examples of management plans for pepperweed are available, there are few specific to vernal pool systems. Documenting successes and failures at Yolo County Grasslands Regional Park would contribute to the knowledge base and allow other managers to make informed decisions.

IV. Summary

The recommended management plan for perennial pepperweed in Grasslands Regional Park is mowing followed by herbicide application, with specific recommendations for timing and herbicide choice based on location and density of the pepperweed population. This treatment may need to be applied in 2-3 successive years to be effective. Monitoring of new invasions by pepperweed and regeneration of treated populations is essential to effective control. Research-oriented monitoring in combination with alternative control means can provide insight on the most effective methods of controlling pepperweed and can be incorporated into future management.

Part III: Synthesis of management goals

Management of pepperweed is essential to the conservation and restoration efforts at Yolo County Grasslands Regional Park. Pepperweed threatens the persistence of special status species such as Crampton's tuctoria (*Tuctoria mucronata*), alkali milk vetch (*Astragalus tener* var. *tener*), and Colusa grass (*Neostapfia colusana*) (Yolo County Planning and Public Works Dept. 2005), as well as indirect threats to pool species through alteration of soil and water chemistry. Unfortunately, the successful eradication of pepperweed has thus far been dependent on herbicide use, which may also harm native species. However, by using proper management and monitoring, and incorporated research, harm to native species can be minimized and improved management methods can be developed.

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Appendix

Table 1. Effectiveness of herbicides after mowing at reducing pepperweed cover, biomass, and density.

From Renz 2005.

MOWED AT THE FLOWERBUD STAGE
TREATMENTS MADE WHEN STEMS
RECOVERED TO THE FLOWERBUD STAGE

Active Ingredient & Rate	Product & Rate	% Reduction in Biomass*	% Reduction in Density*
2,4-D 1.9 lbs. a.e./A (2.13 kg a.e./ha)	Weedar® 64 0.5 gal/A Weedone® LV4 0.5 gal/A	19-48[1]	16-57[1]
Triclopyr 2.25 lbs. a.e./A (2.52 kg a.e./ha)	Garlon 3A 0.75 gal/A Garlon 4A 0.56 gal/A	34	44
Chlorsulfuron 0.75-1.5 oz/A (0.053-0.105 kg /ha)	Telar® 1.0-2.0 oz/A	99-100	95-100
Imazapyr 1.5-6 oz a.e./A (0.11-0.42 kg a.e./ha)	Arsenal® (2 lbs. a.e./gal) 6-24 fl. oz/A	89-100	89-100
Imazethapyr 1.5 oz/A (0.11 kg /A)	Pursuit® 6 fl. oz/A	96[1]	88[1]
Glyphosate 3 lbs. a.e./A (3.33 kg a.e./A)	Roundup® 1 gal/A Rodeo® 0.75 gal/A	73-99[1]	61-93[1]

* Data is from unpublished results from Renz & DiTomaso.
[1] Renz & DiTomaso, 1998 a & b

Table 2. Effectiveness of herbicides at reducing pepperweed cover, biomass, and density.

From Renz 2005.

TREATMENTS MADE AT THE FLOWERBUD STAGE

Active Ingredient & Rate	Product & Rate	% Control or % Cover*	% Reduction in Biomass*	% Reduction in Density*
2,4-D 1.9 lbs. a.e./A (2.13 kg a.e./ha)	Weedar® 64 0.5 gal/A Weedone® LV4 0.5 gal/A	14-73% control[4,5] 63.2% cover	13-70	29-65
Triclopyr 2.25 lbs. a.e./A (2.52 kg a.e./ha)	Garlon 3A 0.75 gal/A Garlon 4A 0.56 gal/A	65.2% cover	35	38
Chlorsulfuron 1.5 oz/A (0.105 kg /ha)	Telar® 2.0 oz/A	0.0% cover	100	100
Imazapyr 6 oz a.e./A (0.42 kg a.e./ha)	Arsenal® (2 lbs. a.e./gal) 6-24 fl. oz/A	2.5% cover	98	88
Metsulfuron methyl 0.3-0.6 oz/A (21-42 g /ha)	Escort® 0.5-1.0 oz/A	76-85% control[1,2,3]	-	-
Glyphosate 0.38 lbs. a.e./A and 2,4-D 0.63 lbs. a.e./gal	Landmaster® 54 fl. oz/A Campaign® 54 fl. oz/A	72% control[1]	-	-
Imazethapyr 1.5 oz/A (0.11 kg /A)	Pursuit® 6 fl. oz/A	27% control[4]	9	10
Glyphosate 3 lbs. a.e./A (3.33 kg a.e. a.e./A)	Roundup® 1 gal/A Rodeo® 0.75 gal/A	20% control[5] 77% cover	32	0-27

[1] Crockett 1997, [2] Reid et al., 1999, [3] Beck 1999, [4] Renz et al., 1997 CWSS
[5] Renz & DiTomaso, 1998 a & b
* Data is from unpublished results from Renz & DiTomaso.

Perennial Pepperweed (*Lepidium latifolium*) Fact Sheet

Taraneh Emam

Biological characteristics of pepperweed

- Perennial forb; aboveground growth senesces but roots remain alive and resprout
- Late-season flowering with variable phenology (highly dependent on water availability), all phenological stages may be present simultaneously
- Produces abundant seed set, but reproduction via seed usually does not occur in established stands (may be more important for long-distance dispersal)
- Reproduces vegetatively from root fragments as small as 2.5cm, most local spread is vegetative
- Produces very dense stands of growth, colonies spread outward very rapidly (measured at up to 129% increase in stand area over two years)
- Highly flood tolerant; colonizes wet areas and saline/alkaline soils, including vernal pools, riparian corridors, wetlands, irrigation and runoff ditches
- Deep rooted (has been shown to grow roots deeper than 3m)

Within vernal pools systems, pepperweed has been documented colonizing:

- Saline/alkaline vernal pools
- Playas, alkali sinks, alkali meadows
- Short-inundated, shallow pools AND Long-inundated pools

Effects of pepperweed invasion

Abiotic effects:

- Dead stalks create thick layer of organic matter on the soil surface which decomposes slowly and inhibits growth of native plants
- Relocates phosphorus from deeper in the soil profile to the organic matter layer
- "Salt pump" - Relocates calcium and magnesium from deeper soil to surface layer, this displaces sodium in surface soils which could possibly increase salinity of adjacent vernal pools

Biotic effects:

- Promotes salt-tolerant species through increasing soil salinity
- Dense growth of pepperweed displaces and outcompetes native plants; is named a direct threat to Crampton's tuctoria and alkali milk vetch
- Degrades habitat for wildlife such as small mammals and migrating waterfowl

Management of pepperweed

- Early detection and eradication in combination with monitoring is very important since spread can be rapid and well-established stands are much harder to control; good candidate for remote sensing monitoring program
- Most effective technique: mowing followed by herbicide application (such as glyphosate)
- Grazing can be used in place of mowing, but only before any plants have set seed – ingestion of seed by animals can spread pepperweed to new sites and increases germination success
- Mowing or burning alone (without herbicide) are ineffective as roots will resprout
- Inundation for two full seasons can also be effective, but difficult to implement
- Disking or tilling alone spreads root fragments which resprout and cause new infestations

(See Renz 2002, Renz and Blank 2004, and UC WEEDS booklet on Pepperweed for more information.)

Andrew Ma

Field Bindweed (*Convolvulus arvensis*)

Part I

Background

Field bindweed is a native of Europe and western Asia and was first documented in the United States in 1739 in Virginia. It most likely arrived as a contaminant in farm and garden seeds. Field bindweed has become a serious weed problem in all parts of the United States except the southeastern states. It is particularly a problem in dryland farming areas of the Great Plains and western states. It is found in temperate, tropical, and Mediterranean climates but is most troublesome in cereals, beans, and potatoes. Field bindweed occurs in dry or moderately moist soils but can tolerate long periods of drought. (NDDA)

Field bindweed is invasive primarily in agricultural areas, but can also be invasive in moist natural areas. In California, field bindweed is established in vernal pools in Sacramento County and large pools in Tehama County. These habitats also support endangered grass species like the hairy Orcutt grass and Hoover's spurge that the growth of bindweed can be a threat to. (Zouhar 2004)

Literature Review

Field bindweed is a persistent species that is difficult to control. It grows best in dry or moderately moist soils, but persists on poor, gravelly soils as well. Field bindweed has been found at elevations of 10,000 feet in the Himalayas, but in California, the weed persists at generally less than 5,000 feet.

Field bindweed can reproduce in two ways. Field bindweed produces seed approximately two weeks after pollination. The seeds are variably shaped, and each plant can produce up to three hundred seeds under favorable conditions. The seeds germinate throughout the growing season when there is adequate moisture available. However, peak germination occurs during late spring or early summer. Field bindweed can also germinate as rhizomes that develop from root buds on vertical roots. Plants that grow this way emerge as early as May and begin flowering in June (NDDA).

Germination can occur under various temperatures, but is highest and most rapid when temperatures fluctuate from twenty to thirty-five degrees Celsius. Dry, sunny conditions and calcareous soils favor seed production (NDDA).

Field bindweed produces impermeable seed, which may be associated with seed longevity. The weed's seed coat may be broken down by mechanical abrasion during cultivations, by passage through the digestive tract of animals, or by high temperatures due to fires. (Zouhar 2004) Seeds of field bindweed can remain viable in the soil for a number of years, ranging from twenty to fifty years, so control methods would need to span at least a decade-long of consecutive growing seasons to prevent field bindweed from growing. Laboratory results have indicated that as much as 62% of 50-year-old field bindweed seeds stored were viable. The weed seeds can be dispersed by water, as contaminants in crop seed, by machinery and vehicles, or even by animals after ingestion. (Zouhar 2004)

Differences in percent germination, impermeability, and viability have been observed in seeds of bindweed collected in different years and from different sites. These differences could be explained by different exposure temperatures and differences in chemical and mechanical scarification of the seed coats of bindweed. (Zouhar 2004)

Control Methods Available

The most important method of control is prevention, which entails planting with clean seed and controlling new infestations while they are small. (UCIPM 2003)

One control method involves hand pulling field bindweed. This method is only effective when the plant is a seedling, because hand pulling an adult weed would leave behind roots that could resprout. Tilling for eight to twelve days after each emergence will control the field bindweed, but it could be necessary for up to five years to be fully rid of the roots. Mowing is not successful because the plant grows too close to the ground, while burning will only remove above ground growth and leave the root systems. Black plastic can also help control weed growth, but may take up to five years. (NDDA) Burn control has been found to be ineffective by itself, since fire provides a suitable seedbed for field bindweed by removing shade and exposing mineral soil. (Zouhar 2004)

Another control method uses crop rotations with tall, shade-producing crops that reduce bindweed problems, since the bindweed is not competitive under shady conditions. Forage sorghum and sudangrass are good competitors with bindweed. For example, in 1985, a farmer said in the *New Farm* magazine that he stimulated the growth of his pumpkin crop, which shaded and strangled the bindweed. (Sullivan 2004) Alfalfa has also been shown to shade out bindweed. A rotation between rye and vetch with buckwheat and oats is used to control many weeds like bindweed.

There are many chemical herbicides that are used for field bindweed control. Dicamba is applied in the fall to crops and is an excellent control for bindweed. Glyphosate can also control the field bindweed when it is still growing. Other herbicides like picloram, 2,4-D, and quinclorac can also effectively control field bindweed. (NDDA) However, many of these herbicides cannot be used efficiently in cropland, and are restricted to use only in pastrues and non-cropland. (Zollinger 2000) Although the herbicides are available, application to a large area could be costly. Acetic acid herbicides, for example, can cost anywhere from seventy dollars per acre to eight hundred dollars per acre. Costly herbicides are mainly used for spot spraying. (Sullivan 2004)

Other methods of control involve biological controls. *Tyta luctuosa*, or European moth, has been used to defoliate field bindweed as a caterpillar, and *Chelymorpha cassidea*, a tortoise beetle, feeds on leaves of the plant. However, biological control of field bindweed has not been successful. (NDDA)

Despite bindweed's persistence in much of the agricultural United States, there are still knowledge gaps. It is unclear which vegetations types may be susceptible to invasion by field bindweed in the absence of disturbance. There is also no information on fire regimes in areas where field bindweed is native, and no information on the effects of fire regimes where the weed is invasive. There is also little information available on the immediate effects of fire on field bindweed. More information is also needed regarding the use of field bindweed by livestock and wildlife, including its nutritional values and the effectiveness of using livestock as a means of control for bindweed. (Zouhar 2004)

Part II

Goals

Goals for control of field bindweed in the vernal pool habitat would include the following:

1. In the short term, reducing its population to fewer than 14 stems per square meter where it does not crowd out native species such as the hairy Orcutt and Hoover's spurge that it often grows in high frequency with. (This density was chosen because it is the economic injury threshold for field bindweed regarding agricultural plants (Jacobs 2007), and is the best available reference for target density).
2. In longer term, removing its extensive root systems so that vegetative growth through rhizomes is unable to repopulate the field bindweed after other treatment programs.
3. Continuing observation after its removal and other treatment programs, since its seeds maintain viability and can germinate for up to fifty years.

These goals will be difficult to achieve due to the limited number of control methods that are viable for use in the vernal pool habitat. Methods that would be considered for agricultural use such as the pesticide 2,4-D will have limited value in vernal pool field bindweed control because of its potential harm to other plant species. Other similarly limited methods like crop rotation with alfalfa (NDDA) would also have to be ruled out for vernal pool use. Use of black plastic or some other means to simply cover the infested area and prevent sunlight from reaching the field bindweed would be effective but would also have negative consequences on surrounding native plant species that need to be kept alive. Grazing will also be limited because of the tropane alkaloid content of field bindweed, making it toxic in larger amounts to horses and sheep (California Department of Food and Agriculture).

Other methods like burning and mowing are not effective because they would only remove the aboveground parts of the field bindweed, leaving the root systems to provide potential for regrowth under favorable conditions (NDDA). A biological method such as introducing the caterpillar of a European moth that is meant to eat the field bindweed above ground has not proven successful thus far (NDDA). A method that could have some success would be pulling the weed by hand. Although this method would not remove the root system if the taproot has already grown too deep, it would have the least negative impact on surrounding native plant species. However, the timing of hand pulling would have to be carefully regulated, since there could be the presence of native grasses with similar phonologies to field bindweed. Human carelessness and disturbance could also negatively impact native plant species, so the method is not without risk.

Control

Taking all of the limitations of various control methods into account, a combination of light grazing and hand pulling the field bindweed would be the most effective method in achieving both the short term and long term goals proposed. Hand pulling during the beginning of the growing season for the field bindweed and native plant species, once the invasive bindweed is distinguishable from native grasses, would give a growing advantage to the native species. Allowing the native species a growing advantage could discourage establishment of field bindweed since it is not very competitive under shady conditions (Van Vleet 2007).

In conjunction with hand pulling, limited grazing by hogs and chickens could be effective in controlling field bindweed growth. Unlike horses and sheep, hogs and chickens not only eat the leaves and stems of field bindweed, but also expose the roots and crowns, which would help deplete root reserves (Sullivan 2004).

Also, upland sites would fall under the same managerial plan as pool sites because of the potential. There is some freedom to allow more aggressive grazing, both in terms of number of grazers and length of grazing, but the limitations of chemicals still stand. Pesticides could leach into the soil and eventually contaminate the pool sites. Also, more effective agricultural methods like prescribed burning and mowing would pose a threat to native species that are in the upland areas, and could deplete nutrient sources like nitrogen that would cause damage to a sensitive pool system (Clinton 2003).

Although this combination of methods would not immediately eliminate potential field bindweed growth, it would give native plant species a chance to grow. Also, by eliminating flowers before they set seed, growth area of the field bindweed could be brought under control. Moreover, removing the above-ground part of the weed repeatedly could deplete the carbohydrate reserves stored in the roots, eventually causing the plant to die (Dockstader 2005).

Monitoring would need to be done throughout the growing season, which could start in late March, and last until temperatures are not suitable for field bindweed growth. Monitoring would be especially essential during the beginning of the growing season, since presence of field bindweed early could prevent native plant species from flourishing that season, even if treatment were to be applied later. Monitoring of treated areas would have to continue for at least twenty years, since field bindweed seeds remain viable for that length of time, and laboratory tests have shown that field bindweed seeds kept for fifty years were still capable of germination (Zouhar 2004).

Although this method seems to be the best approach to controlling and eliminating field bindweed from vernal pool areas, it is not foolproof. Chemical application in agricultural fields provides thorough treatment methods that are dependable. However, since this method is based on human monitoring and animal grazing, there are spots that can be “missed.” Since root fragments as small as 5 cm can generate new shoots, this non-thorough control method would need to be made thorough (NDDA). Because the root system is the most difficult part of the bindweed to remove, and because rhizomes can germinate from roots that are left behind, grazing regimes will have to be thorough. Also, since field bindweed is so persistent and capable at finding light sources, extreme care is necessary in implementing this method so that it is effective.

Other issues such as the cost of employing people to hand pull the field bindweed could be important if the budget of a vernal pool restoration site were limited. Costs of constant monitoring of grazing animals and monitoring after treatment could also come into play.

Additional information from research would be useful in implementing this method of hand-pulling and grazing. Information such as the number of years it would take to deplete carbohydrate sources in the roots after removal of above ground plant parts as well as the amount of field bindweed animals like hogs and chickens could safely ingest would help the control plan be more specific.

Part III

Goal Synthesis

According to the class presentations and group discussion, my goal for eradication of field bindweed through hand-pulling and light grazing fits in with many other project goals. Other projects attempting to minimize the impact of exotic plant species also recognized the delicate nature of the vernal pool habitat, and opted against harsh control methods like chemical application and prescribed burning. Species like the Manna grass were also recommended for hand-pulling, while the control of *Hordeum marinum* also called for grazing. Although the animals required for grazing were different, because of the similarities in management plans, a compromise or synergy between the plans is possible. Many of the plans for other invasive species, including the pepperweed, also advocated monitoring, which is crucial for management of field bindweed. Also, according to many of the restoration plans for native species, such as the Alkali milk-vetch and Hedge hyssop, minimal disturbance that hand-pulling would cause and light grazing would either be manageable or beneficial. However, special care needs to be taken for native species that cannot adapt to disturbances. An example would be during the mating season for organisms like the Fairy Shrimp, whose eggs cannot be disturbed before they hatch.

Fact Sheet - Field Bindweed (*Convolvulus arvensis*)

Species Characteristics:

- Field bindweed is a perennial vine that grows best in dry or moderately moist soils
- Most likely arrived in America as a contaminant in farm and garden seeds from Europe and western Asia
- Could also be transported through the digestive tract of animals – seeds can survive up to 144 hours in the stomach of migrating birds
- Stems twine around other plants – up to 6 feet long; roots can grow to a depth of 4 feet
- One plant can produce 500 seeds – seed is produced over 3 months within a population
- It produces impermeable seed, which may be associated with the seed's longevity – seeds can remain viable for up to fifty years
- Has regenerative properties – A 5 cm section of a lateral root with buds could produce as many as 25 shoots four months after planting up to 120 cm from original plant; bindweed seedlings cut 1 cm below the soil surface regrow between 1 and 4 weeks

Distribution:

- On California's list of noxious weeds
- Found in most counties in California
- Established in vernal pools in Yolo/Sacramento County and large pools in Tehama County

Justification:

- Field bindweed is a threat to associated endangered grass species like hairy Orcutt and Hoover's spurge – On the Vina Plains Preserve in 1995, the pools with Hoover's spurge also had the highest frequency of field bindweed
- Its extensive root systems are capable of extracting available moisture from the upper soil layers so that it is not available to other species
- Competition from invasive species like bindweed can contribute to changes in hydrology and livestock grazing practices
- Changes in hydrology can result in a change of the timing, frequency, and duration of inundation in vernal pools, making it unsuitable for native vernal pool species

Control & Management:

- Higher rainfall and longer inundation periods limit field bindweed and benefited native species under observations
- Grazing can remove the weed, leaving open area for growth of native plants
- However, cattle are traditionally removed from vernal pool landscapes before the pools are dry, and field bindweed can begin regrowth from its extensive root system
- Field bindweed contains tropane alkaloids, which is toxic to horses and sheep
- Use of chemicals to control field bindweed requires extreme care because of herbicide breakdown products

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Matthew Dumlao

Spring 2010

Manna Grass

Introduction

Exotic plant invasions pose a serious threat to the long-term sustainability of vernal pool systems in California. Manna grass (*Glyceria declinata*), a native of ephemeral wetlands in Europe, has invaded many vernal pools and the California Invasive Plant Council has assigned an invasive species rating of “moderate”, meaning it has “substantial and apparent…ecological impacts on the physical processes, plant and animal communities, and vegetation structure” (Cal IPC 2006). Some reports also indicate that it is spreading rapidly through vernal pool systems with one pool experiencing an increase from 2% cover to over 90% cover within 5 years (2001-2006) (Gerlach 2006). Unlike other invasive species that invade pools from the upland areas, manna grass is adapted to temporarily inundated environments and grows very well at all pool depths (Molina 1996; Gerlach 2006). Manna grass can create dense – often monoclonal – stands that prevent seed germination and out-compete native vegetation. Also, it can alter important factors that are necessary for many invertebrate species leading to a reduction in invertebrate diversity within the pool (see discussion below). Furthermore, manna grass is particularly difficult to eradicate because the only effective strategy identified thus far is to remove the plants by hand from the pools (Carol Witham, personal communication).

This report attempts to summarize the information available on the ecology of manna grass, including a detailed description of the plant and its ecology, its impact on vernal pool structure and function, and a summary of management efforts. Throughout the report, gaps in our understanding are identified.

The Ecology of *Glyceria declinata*

General Description:

Glyceria declinata (Poaceae) is a perennial grass commonly referred to as manna grass or waxy manna grass. In the past, it has also been labeled *Glyceria plicata* var. *declinata* and *Glyceria plicata* subsp. *declinata* (Barkworth and Anderton 2007). Mature plants are highly branched and generally decumbent, creating dense clumps that can spread into a thick mat (Gerlach 2006). The root system is rhizomatous and adventitious roots can develop along the prostrate stems (Hickman 1993). According to the second edition of the Jepson Manual (Rosatti, *in preparation*), the leaves are primarily short (3-12 cm) and somewhat wide (1.5-6 mm) with prominent midribs and the inflorescences are composed of a group of appressed spikelets with 5-14 florets. The most distinctive features of the inflorescences are the lemmas (the lower bract of the floret) that have three lobes and dark-tipped veins when mature.

In California, there are 5 native species from the genus *Glyceria*, and it is not known if *Glyceria declinata* can hybridize with any of them, although hybrids do exist between other species in the genus (Whipple 2007).

Organism-level Ecology:

In its native habitat in Europe, manna grass is adapted to areas with still or slow moving water, such as along the shores of lakes and ponds, in freshwater marshes, and in disturbed, seasonally inundated environments (e.g. ditches, cow ponds). Following introduction into California in the mid 20th century, it spread to rice paddies (Munz and Keck 1968), ditches, and ultimately vernal pools. In vernal pool systems, most invasive plants disrupt the system by encroaching into the pools from the upland areas, altering the hydrology of the system through increased evapotranspiration, and competing with native plants for space and nutrients (Bremer *et al*. 2001; Frank 2003; Marty 2005). In contrast, manna grass is adapted to the pool environment and grows in all levels of the pools. As it grows, it creates a layer of leaves that float on the surface of the pool and reduces the light available for photosynthesis below (Rogers 1998). The plant typically matures around April-May and the seeds shatter from the plant and drop onto the ground (Gerlach 2006). In addition to sexual reproduction, manna grass spreads vigorously through asexual reproduction. There is no information on the relative importance of sexual vs. asexual reproduction and we do not know how long manna grass seeds can survive in the seed bank.

Aside from a period of inundation, very little is known about the physiological requirements of manna grass, perhaps because manna grass has not spread to all vernal pool types. There is no evidence that manna grass requires specific nutrient levels or soil conditions (pH, cation exchange capacity, organic matter content, salinity, etc). It has been suggested that manna grass prefers deep pools (Rogers 1998), and Barbour *et al.* (2007) found manna grass in long-inundated pools. However, there is little empirical evidence to support the claim and other observations imply manna grass can grow at all water depths (Cal IPC 2006 and references therein). Overall, manna grass appears tolerant of a wide range of abiotic conditions. Further research is needed to determine the physiological constraints of manna grass.

Population and Community Dynamics

Because it grows directly in the pool, manna grass competes with many native forbs and grasses for space, nutrients, and sunlight. At the edge of the pond, it competes with *Lolium multiflorum*, and upland species, and can be found competing with species from the genera *Eleocharis*, *Eryngium*, *Psilocarphus*, and *Downingia* at lower depths (Gerlach 2006). Also, it is reported to threaten the endangered Sacramento orcutt grass (*Orcuttia viscida*) (Cal IPC 2006). Based on individual observations, pools invaded by manna grass have fewer native species (Cal IPC 2006 Carol Witham, personal communication).

Dispersal to new vernal pools appears to be largely mediated by waterfowl. Seeds stick to the legs and beaks of birds and drop off as the birds move from pool to pool (Cal IPC 2006)

Evidence also suggests that manna grass invasions alter invertebrate biodiversity as well. One report saw an increase in opportunistic invertebrate species (e.g. mosquito larvae) and it was speculated that the floating leaves provided greater protection from predation (Rogers 1998). Detailed studies on multitrophic-level interactions are lacking and should be conducted to shed light on the broader impacts of manna grass invasions.

Landscape and Ecosystem Ecology

Relatively little is known about the broader impacts of manna grass on ecosystem processes. One study found that manna grass increased denitrification by promoting soil oxidation (Matheson 2002). That study, however, was conducted in a wetland in New Zealand that most likely has different characteristics than the vernal pools in California. Due to the close proximity of vernal pools to sources of nutrient inputs, further studies should be conducted to determine the effects of changes in nutrient levels on manna grass populations within vernal pool systems.

Current Status and Management Options

Manna grass is currently found in Alameda, Butte, Fresno, Mendocino, Placer, Sacramento, San Joaquin, Shasta, Sonoma, Stanislaus, Tehama, and Yuba counties (Gerlach 2006; Dean *et al.* 2008). Also, herbarium samples are found in Amador, Calaveras, Contra Costa, Humboldt, Lake, Marin, Mariposa, Merced, Monterery, Nevada, Riverside, and Sutter counties, indicating manna grass might be widely distributed throughout the state. According to personal observations made by vernal pool experts, manna grass distribution has increased dramatically and it is even found in relatively undisturbed pools (Cal IPC 2006).

Manna grass is especially difficult to control because it grows within the pool. To combat manna grass invasions in rice paddies, various herbicides can effectively reduce biomass by up to 90% (Braverman 1996). In vernal pool systems, very little is known about the effectiveness of different management options. Thus far, removing plants by hand before the seeds are dispersed appears to be the most effective eradication method available (Carol Witham, personal communication). Unfortunately that method is labor and time intensive and may only be possible on small scales. The potential effectiveness of grazing efforts are likely to be limited because manna grass grows in the pools and grazing is typically performed prior to drydown (Marty 2005). More research is needed to determine the most effective time to remove manna grass by hand and to explore the possibility of other non-herbicide control measures.

Funding to address the challenges posed by manna grass and other invasive species can come from a wide range of sources ranging from the federal government to local organizations. To help facilitate the efforts of several federal departments and agencies, the National Invasive Species Council was created in 1999. The NISC contains members of 13 federal departments and agencies, including the Departments of Agriculture, Interior, and Commerce. The USDA Grant and Partnership Program and agencies within the USDA (e.g. National Institute of Food and Agriculture and National Resource

Conservation Service) actively support invasive species research, prevention and control through a number of programs. For example, the NIFA recently awarded $4 million to address invasive species research with nearly $1 million going to researchers at UC Davis and UC Berkeley. The US Fish and Wildlife Service provides many services as well as financial assistance (e.g. grants through the North America Wetlands Conservation Act) to help local governments, organizations and individuals manage invasive species. Within California, the Department of Fish and Game concentrates primarily on preventing invasions while also providing assistance to help control and eradicate invasive species. For a detailed review of laws and regulations regarding invasive species in California, please refer to the California Aquatic Invasive Species Management Plan (addresses both aquatic and terrestrial species despite its nam) (Department of Fish and Game 2008). On a local level, some county and local governments administer programs housed under state or federal agencies. Also, some counties have conservation programs (e.g. Solano Habitat Conservation Program) that provide management plans for non-native species invasions with particular emphasis on those that threaten endangered species.

Controlling Manna Grass – Goals and Management Approaches

Overview of Goals:

Manna grass (*Glyceria declinata*) invasions in vernal pool systems pose a serious threat to the native biodiversity and a comprehensive management plan is necessary to create a successful campaign to eradicate existing populations and prevent the spread and reestablishment of populations in the future. At Yolo County Grasslands Regional Park, the extent of manna grass invasion is not known and it is possible that manna grass has not yet invaded the pools. According to the most recent management plan (CalFed At-Risk Plant Species, Habitat Restoration and Recovery, and Non-Native Species

Management; 2005), manna grass was not present in the vernal pools; the non-native invasive species that received the greatest attention were perennial pepperweed (*Lepidium latifolium*), medusahead (*Taeniatherum caput-medusae*), yellow starthistle (*Centaurea solstitialis*), swamp grass (*Crypsis shoenoides*), and barbed goatgrass (*Aegilops triuncialis*). Therefore, the goals for Grasslands Park are simply to prevent the establishment of manna grass in the vernal pools. In the short-term, that can be divided into two separate goals: (1) determine the current status of manna grass in the vernal pools in the park and (2) remove existing populations, if present.

Over the long-term, the objective should be to prevent the introduction or establishment of manna grass. Manna grass can quickly take over a pool once it is introduced, as evidenced by the increase from 5% cover to over 90% cover in a 5 year span for one vernal pool (Gerlach 2006). Thus, preventing the establishment of manna grass populations is paramount to the success of the restoration efforts at Grasslands Park. To achieve this long-term goal, a combination of sustained monitoring efforts and targeted eradication efforts (when necessary) should keep manna grass from negatively affecting the vernal pools (see details below). Furthermore, preventing new populations of manna grass from invading the pools can be helped by reducing the nearby sources of manna grass seeds. It would be beneficial, therefore, to reduce/eradicate manna grass populations from the non-vernal pool water bodies (i.e., ditches, ponds, cow ponds, etc) that may be found in the agricultural fields near Grasslands Park.

If manna grass has not invaded Grasslands Park, resources can be allocated to the prevention of future invasions. Identifying and removing new populations of manna grass are likely to be easier and cheaper to remove than more entrenched populations, which have more extensive root systems and a larger seed bank. However, if that is not the case, eradication efforts could be tied with efforts to eradicate other invasive species found in the pools, including swamp grass and perennial pepperweed.

Monitoring efforts can be conducted after the pools have dried for the year, corresponding to when manna grass flowers are clearly visible and the seeds have not set. If monitoring efforts discover manna grass in a pool, only hand weeding can be conducted in the pool and all efforts will have to be carried out once the pools have dried down.

Restoration and Management Plan:

As stated above, the primary objective of the management plan is to prevent the establishment of manna grass in the vernal pools. To achieve this goal, the first step is to perform a detailed survey of all the vernal pools found at Grasslands Park to determine the extent of infestation with manna grass, if at all. This should be performed as soon as possible, preferably when the pools dry down and the presence of inflorescences makes identification easy. Damage to populations of special status native plants (i.e., Crampton's tuctoria and Colusa Grass) can be avoided by surveying the pools once they have dropped their seeds or by limiting the foot traffic in areas that might have rare native plants and using binoculars to scan the areas of the pool that cannot be accessed (the latter approach would require a botanist with strong identification skills). Furthermore, surveys should be scheduled when other invasive species like perennial pepperweed and swamp grass can also be identified. If the survey finds that manna grass is not present in the park, future surveys should be conducted each year to monitor the situation and they should be coordinated with all other monitoring efforts to limit the disturbance in the pools. However, if manna grass is found in the pools, the surveys should document the location and density of the populations.

Ideally manna grass will not be found in the vernal pools; however, if it is, the following plan will outline the recommended management steps. Once it is safe to enter the pool (i.e., native plants have set seed), manna grass populations should be removed by hand, the only proven method of eradication suitable for vernal pool habitats. If the seeds have already set and/or shattered from the plant, future eradication efforts will have to be conducted, possibly over several years. Unfortunately, we know very little about manna grass seeds, e.g., how long they can remain dormant and the optimum conditions for germination, and future research should be conducted to shed light on these topics and shape future eradication efforts. If the labor is available, it is recommended that a second round of surveying and weeding be performed a couple weeks after the first round, in order to remove plants that were missed and/or regrew. The following year, at least two more rounds of weeding will need to be conducted to remove the plants that germinated from seeds produced during the previous year. Because manna grass can only be weeded by hand, the management approach will not change much depending on the size of the infestation. All efforts should be made to eradicate manna grass from the most sensitive and most important pools first (such as pools 9A and 9B, the two largest pools in the park).

Furthermore, it should be pointed out that once manna grass is discovered in a vernal pool, all surveys should be even more meticulous. Prevention is the best hope for controlling manna grass. Also, by monitoring the location and density of manna grass in the pools, eradication efforts can focus first on the areas where manna grass has the largest potential to damage the pool.

Like any management approach, there are a number of risks and uncertainties. For example, the potential for manna grass to regenerate following weeding is largely unknown. Since it spreads asexually, manna grass populations will likely regenerate if the plants are not removed completely. If that becomes a major problem, weeding might have to be more frequent that two times a year. Furthermore, all material weeded from the pools should be carefully removed to the upland region and burned. Also, entering the pools for any reason runs the risk of damaging the native vegetation. Thus, there may be significant legal barriers to working in the pools, even after they had dried down.

Research Topics:

Unlike other invasive species, relatively little is known about manna grass, and management efforts will provide opportunities to shed light on the ecology of manna grass. Currently, removing by hand is the only proven method of control. However, that has not been formally documented and the results of eradication efforts in Grasslands Park can provide a definitive answer. Furthermore, weeding trials can help us determine how easily manna grass can resprout if segments are left in the soil.

Other invasive plant species have been successfully combated using grazing, mowing, burning, or chemical applications (or a combination of approaches) and trials could be conducted to determine the effects of those treatments on manna grass populations. Due to the sensitive nature of the pools, all chemicals will have to be carefully "painted" on the individual plants, possibly in conjunction with mowing efforts. Burning will not likely have much of an impact on manna grass populations because burning should ideally be conducted prior to seed set at that corresponds to when the pools are still inundated. Grazing might suppress manna grass populations if the animals are allowed to enter the pools while they are still inundated. However, that might not be possible if rare plant species are present. Moreover, grazing and mowing are two of the most common management approaches employed at Grasslands Park and setting up trials to see their effects on manna grass should be easy to incorporate into existing management efforts.

The surveys conducted to monitor the status of manna grass in the pools could also be used to address questions regarding the community dynamics between manna grass and other pool species. For example, which species are most sensitive to manna grass invasions?

Furthermore, it is often suggested that manna grass outcompetes natives by producing a thick thatch layer. That, however, has never been empirically verified and management efforts at Grasslands

Park could address that claim. The optimum time to manually remove the thatch layer is the fall (prior to germination).

Finally, it is important to point out that any advances in methods to control manna grass should be incorporated into future management efforts at Grasslands Park. Since we know relatively little about manna grass ecology, the management plan must be flexible and allow for adjustments (e.g., in the frequency or timing of removing the plants).

Synthesis With Other Goals

Combating manna grass invasions provides a major challenge for park managers. While it has not yet invaded the pools in Grasslands Park, it is found in nearby vernal pool systems and other inundated environments and it is likely to be a major problem in the near future.

Due to the ecology of manna grass, efforts to eradicate it from vernal pools can potentially disturb populations of native plants, including special-status plants and rare invertebrates. Park managers might be faced with the unfortunate dilemma of proceeding with necessary eradication efforts at the expense of the native vegetation (which will likely be harmed if manna grass is *not* removed). It should also be noted that the lack of knowledge regarding the effects of manna grass on vernal pool ecosystems makes it difficult to identify other potential trade-offs and challenges. Therefore, the importance of studying the impacts of manna grass on vernal pools is critical to improving the management strategies.

Despite the challenges, a few win-win situations are possible. While most invasive species found in Grasslands Park are found in the upland areas around the pools, perennial pepperweed and swamp grass are commonly found in the pools. Thus, all management efforts aimed at manna grass (i.e.

monitoring and eradication) can be coordinated with similar activities targeting perennial pepperweed and swamp grass. For example, perennial pepperweed can be effectively eradicated with a combination of mowing and herbicide applications and similar approaches might be useful for targeting manna grass populations. Both invasive species could be addressed at the same time, saving time and money.

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Manna Grass

Species: *Glyceria declinata* **Family:** Poaceae

General Description

- *Appearance:* Highly branched, decumbent growth habit. Leaves rather short (3-12 cm) and wide (1.5-6 mm). Inflorescences: appressed spikelets with 5-14 florets. Lemmas have three lobes and dark-tipped veins when mature.
- *Locations:* Grows in still or slow-moving water, including ditches, ponds, & vernal pools
- *Physiological requirements:* Grows at all pool depths. When submerged, leaves float on the surface. Apparently no specific soil/water conditions are necessary for survival (pH, CEC, organic matter, soil texture, etc).
- *Reproduction:* Can spread asexually, creating a dense monoclonal stand. Seeds germinate readily once soil wets. Typically seeds mature around April-May and shatter from the plant throughout the summer. Seeds germinate the following fall/winter or are dispersed by waterfowl.

Status of Manna Grass in California

- *Distribution*: Found in at least 12 counties, potentially found in 24 counties. Geographic distribution has increased dramatically in the last 10-15 years.
- *Classification*: assigned a rating of “moderate” by Cal IPC.

Impacts of Manna Grass Invasion

- *Vernal pool vegetation:* Invasion results in reduced pool diversity and can crowd out native plants, including key endangered species.
- *Vernal pool invertebrates:* It has been suggested that manna grass alters invertebrate diversity by making conditions better for opportunistic invertebrates while also reducing the microhabitats that are important for other invertebrates. More research is needed.
- Information is needed on the effects of manna grass invasion on vertebrates and ecosystem processes.

Management Strategies

- *Management strategies:*
    - Hand pulling is the only proven strategy. Waterfowl will eat the seeds.
    - Potential control through grazing, mowing, burning, and chemical treatments might be limited. Just removing inflorescences and/or seeds might not be sufficient because manna grass can spread asexually.
    - More research is needed to explore other options.
- Preventing new invasions is critical.
- Manna grass can be a pest in rice paddies, possibly creating common ground for partnerships between agriculturalists and vernal pool conservationists.

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Russian Thistle, *Salsola tragus*
Tracy Kelsch

Background:

Salsola tragus, Russian thistle, tumbleweed, or wind witch, has become an established invasive species throughout California. It belongs to the family Chenopodiaceae or the goosefoot family (Invasive Plant Atlas 2009). Russian thistle is native to Eurasia, specifically southeastern Russia and western Siberia. In the early 1870s Ukrainian and Russian immigrant farmers brought Russian thistle to the United States, specifically South Dakota, in contaminated flax seed (UC IPM Online 2008). In 1895 it was introduced to Lancaster, California in Antelope Valley from railway cars transporting cattle from the Midwest. Historically, Russian thistle was one of the first invasive plants to try to be eradicated or controlled by the U.S. government because it provides fuel for fire and outcompetes certain cereal crops.

Throughout the United States Russian thistle has invaded 100 million acres of land (UC IPM Online 2008). States where Russian thistle has been listed as invasive include: Washington, Oregon, California, Nevada, Utah, Colorado, Arizona, and South Dakota (Invasive Plant Atlas 2009). The largest invasion of Russian thistle in California is in the southern, more arid region (Richardson 2004). Russian thistle can also be found in coastal regions due to its ability to live in saline conditions. It lives in elevation range from below sea level up to 2,600 meters (Howard 1992). Other community types where Russian thistle is observed in are salt marshes. Within the salt marsh community "plant species typically found … were observed in roadside ditches, ponding areas upstream of road culverts, in agriculture ditches, in detention basins, and amongst riparian scrub and forest plant communities in natural stream channels" ("Affected Environment").

Identifying *Salsola tragus* specifically can be difficult because the taxonomy of is continually changing. *Salsola tragus* has also been variously referenced as *S. kali*, *S. iberica*, and *Salsola* sp. throughout different papers. It has also been found that different species can hybridize between each other. While the results are unknown about whether or not this is an invasive characteristic, it has the potential to make this plant very hard to manage especially for biological control. Some biological controls are only effective to a given species instead of a whole genus. The hybridization between different *Salsola* species makes it difficult to find a biological control because sometimes the exact species present at a site cannot be identified by morphology alone without gene sequencing (Ayres et al 2009). According to the California Department of Food and Agriculture, "recent taxonomic reconsideration of *Salsola tragus* and its possible biotypes or subspecies may bring further clarity to the effectiveness of this biocontrol agent." Once the plants have been appropriately classified, there may actually be an effective biological control for Russian thistle where needed.

Russian thistle is a successful invader due to its diverse characteristics. In general it is a summer, broadleaf, annual forb. At the end of its growing season Russian thistle senesces and then dies by the first frost. The entire plant breaks off the main stem and rolls over the landscape by the wind—a characteristic that gave it the name tumbleweed. A single plant travels 60-4069 meters in six weeks depending on the terrain. "When compared to stationary plant, wind-blown plants dispersed up to 50% more seed (Ghersa et al 2007)." An adult plant generates around 250,000 seeds that can survive up to one year and in rare cases three years. The seeds are winged, lack endoderm, and contain a coiled embryo with chlorophyll already present. After being separated from the parent plant the wings on the light weight seed aids it in further wind dispersal (Howard 1992). The seeds germinate in winter or early spring, usually before the crop plants or natives surrounding the Russian thistle. The seedlings tend to establish themselves in loose soil and germinate at temperatures between 52 to 90 degrees Fahrenheit (Ohlendorf). Because of the time of germination, it can impact later season seral species (Richardson 2004). Germination happens quickly, sometimes as fast as a few minutes, because of their lack of a hard shell and food reserve. This allows them to outcompete other slow germinating, possibly native, plants (UC IPM Online 2008). However, in crowded communities, Russian thistle seedlings are not good competitors because they cannot establish themselves well (Howard 1992). Flowers appear starting in July through to October. It is a wind pollinated plant and can outcross or self fertilize to create the new seed bank. Sometimes when the stem is cut, Russian thistle can reproduce asexually by resprouting (Richardson 2004). Overall Russian thistle has "pollen-mediated gene flow and efficient seed dispersal [which] aids both short- and long-distance spread" (Beckie and Ardath 2009).

Besides its life history creating advantages for colonization, it has morphological and physiological features which also contribute to Russian thistle being a successful invader. It has a long tap root, up to 1.5 meters, and an extensive lateral root system, sometimes spanning 1.8 meters. This feature allows Russian thistle to access water deep within the soil; however, it needs little soil or water to survive and can tolerate high heat and drought (Kaufman 2007). *Salsola,* from the Latin word for salt, indicates that Russian thistle has a high salt tolerance (Kaufman 2007). Russian thistle can also thrive in alkaline soils. It can also leach oxalate into the soil which makes phosphorus more available. This can provide an environment good for other invaders or it could possibly help certain native plants to establish themselves and grow (Richardson 2004). Russian thistle is a C_4 plant, which means it is adapted to grow more efficiently in dryer, high light intensity conditions (Beckie and Ardath 2009). This gives it a competitive advantage to C_3 plants especially in hot and dry summer months. It can also outcompete other C_4 plants because of its other advantages as an invader.

In general Russian thistle invades disturbed areas easily, especially ones that are dry, sandy, and stony (UC IPM Online 2008). It has mostly become an issue in crop systems and the semi-arid regions located in Western North America. In agriculture, Russian thistle can be a major weed in potato crops in the Columbia Basin and the Rocky Mountains because it attracts the beet leaf hopper, a vector of a bacteria pathogen (Integrated…2006). Russian thistle also hosts *Circulifer tenellus* which causes a curly top virus that can impact native plants or crops such as tomatoes, cucurbits, and sugar beets (Richardson 2004). Other crops it impacts negatively include alfalfa and other small grains, some of which are also C_4 plants (UC IPM Online 2008). There can be a 50% yield loss when Russian thistle is invading a wheat field (Pagad 2005). Because it is able to colonize degraded areas easily, Russian thistle becomes a problem post-harvest when the fields are cleared.

Besides being an agricultural pest, many people in Europe and North America are sensitive to Russian thistle pollen. It has been estimated that 5% of Spain's pollen is from Russian thistle and reported that 30% of their population who has undergone the allergy skin prick test is allergic to it as well. There have also been cases of contact dermitis from touching Russian thistle. Allergies provide another reason as to why it is a good idea to control Russian thistle (Pagad 2005).

There are other issues Russian thistle presents outside of being an invasive species and an allergen. Russian thistle can cause car accidents when tumbling across a road. When it builds up along fences or groves of trees dead Russian thistle plants create a fire hazard. In addition it can spread the fire by rolling across dry grasslands or other areas susceptible to fire. Russian thistle can invade after a disturbance well, including burned sites. Sometimes it accumulates in streams creating a dam and blocking the usual flow. In disturbed sagebrush, *Artemisia* sp., dominated areas it has also been found to be a problem. However, this is only for the first two years after which conditions become too crowded for Russian thistle to grow and mustards are able to take over (Howard 1992).

The California Department of Food and Agriculture consider Russian thistle to be a noxious weed list c: “control required in nurseries, not required elsewhere” (Calflora 2010). Within wetlands, specifically vernal pools, there is not much information about Russian thistle as a problematic invasive. However, in a report done by the U.S. Fish and Wildlife, Russian thistle was reported to be a competitor with *Astragalus tener* var. *tener*, the alkali milk-vetch in Yolo County at Grasslands Park, an ephemeral wetland with vernal pools. Alkali milk-vetch is a California Native Plant Society species of concern. Russian thistle is classified as a priority invasive species to investigate methods of control and it is assumed to take $15,000 per year to control over a five year period. A priority one action “must be taken to prevent extinction or prevent the species (alkali milk-vetch) from declining irreversibly in the foreseeable future.” No other literature was found on how Russian thistle competes with alkali milk-vetch or its impact on vernal pool ecosystems.

Management:

Chemical: Metsulfuron, triasulfuron, thifensulfuron + tribenuron, tribenuron, dicamba 2,4-D, or picloram plus 2,4-D are different herbicides that can be used effectively on Russian thistle (Bossard et al 2000). However, it has evolved an acetolactate synthase-inhibitor resistance to some of the herbicides used to control it (Beckie and Ardath 2009). Creating an integrated pest management plans can reduce the pesticide use and therefore the likelihood that the plant will adapt with resistance. Herbicides can be applied in different ways. An experiment in 2000 and 2001 in Washington compared whether a light activated, sensor control application method or broadcast spraying was more effective at controlling Russian thistle. The study concluded that the light activated, sensor control, LASC, was more effective at application because it required much less herbicide achieving the equivalent quality of work as a broadcast spray. “The use of the LASC for postharvest Russian thistle control can reduce growers' input costs, increase growers' profits, and improve environmental quality by reducing the amount and area of a restricted-use chemical (Young et al 2009).”

Mechanical: Tilling is recommended for crops after they have been harvested to control young and older plants. However, if the tilling creates too large of a disturbance it could lead to providing the right environment for the next Russian thistle generation to take over. Mowing over young seedlings is also effective. Timing of mowing, usually before late summer, is important so that it does not disperse seed and actually kills the plant (CDFA 2010). Fire is not recommended as a management tool for Russian thistle because it is a fire hazard.

Biological: Two moths, *Coleophora parthenica* and *Coleophora klimeschiella*, were released in an attempt to control Russian thistle in California. For various reasons such as predation and inability to prevent seed production, neither moth has been effective even though they established a sufficient enough population. Another biological control that has been released is *Aceria salsolae*. It is a blister mite that attacks the plant by killing the growing tips; however, a population in the wild has not been successfully established. *Colletotrichum gloeosporioides* f. sp. *salsolae* is a fungus that is currently under investigation for controlling Russian thistle. It has been tested to see its effects on 19 families besides the Chenopodiaceae. So far it has been most detrimental specifically to the *Salsola* genus (Berner et al 2009). Seed-feeding and stem-boring caterpillars and weevils are also potential biological controls that are currently being investigated (UC IPM Online 2008). Many other biological control agents are being researched to control Russian thistle; however, it is clear the there is no frontrunner for which has been found to be the most effective.

Restoration: When grassland has been restored successfully, Russian thistle populations tend to naturally decrease, due to the fact they prefer disturbed areas and the bacteria and fungi that come with a good organic soil are not ideal for the Russian thistle to grow (Kaufman 2007). In the process of restoring disturbed sites, Russian thistle can actually be used to more rapidly revegetate an area the still has its topsoil intact. This is because the mycorrhizae will quickly invade the root, killing it. This increases the populations of mycorrhizal fungi in the soil and decreases the Russian thistle population. The presence of these mycorrhizae can help plants establish themselves quicker in a degraded area. Dead Russian thistle plants can also provide a microenvironment for growing seedlings, providing enough shade for the plant to not get damage from high light intensity (Howard 1992).

Grazing: Russian thistle can be consumed from germination until it flowers, providing a fair forage for cattle and sheep. Dry Russian thistle, although not appealing to most livestock, is a good source of vitamin A and phosphorus (Howard 1992). However, if the levels of nitrates or soluble oxalates are too high in the plant, Russian thistle can be poisonous to sheep (Pagad 2005). Conditions that lead to the build-up of oxalates in Russian thistle is the use of too much nitrogen fertilizer (CDFA 2010). In the wild, pronghorn and prairie dogs especially like eating Russian thistle, sometimes through the whole year when it has been wet all year. The seeds can also be eaten by small mammals and birds (Howard 1992).

Generally, management of Russian thistle appears to be most important when invading agricultural areas and dry, unoccupied stretches, such as along the sides of highways, where they increase the probability of fire.

Funding:

Funding for the management of Russian thistle can be achieved through government funding sources, such as: the Environmental Protection Agency, U.S Department of Agriculture, U.S. Fish and Wildlife Service, and the National Oceanic and Atmospheric Administration. Private funding sources include: the William and Flora Hewlett Foundation, Clif Bar Family Foundation, Richard and Rhoda Goldman Fund, and S.D. Bechtel Jr. Foundation/Stephen Bechtel Fund. Local foundations such as the Yocha Dehe Community Fund, Teichert Foundation, Thornton S. Glide Jr. and Katrina Glide Foundation, Beneto Foundation, Irma Ceunis and Simone C. Wynant Foundation, Gumerlock Family Foundation, Yolo Community Foundation, Sacramento Community Foundation, and Yolo County Resource Conservation District are also likely candidates for funding support. Other funding strategies include sponsorships from local businesses and identifying philanthropists in Yolo Country for a major gift donation. Each organization approached should have a report tailored to the specific interest with a description of how this project deserves funding in regard to that interest. Because Russian thistle is a threat for a listed species, funding can also be received federally to control it. These funding sources have been identified for wetland management, restoration, or conservation and are not directed towards the specific management of Russian thistle.

Goals and Management Plan for *Salsola tragus* at Grasslands National Park

At Grasslands Park, Russian thistle, *Salsola tragus,* was reported by the U.S. Fish and Wildlife to be a potential competitor with alkali milk vetch, *Astralagus tener* var. *tener*. Because alkali milk vetch is listed as threatened by the California Native Plant Society, Russian thistle populations must be kept in check to prevent further decline in the alkali milk vetch population. At Grasslands Park, alkali milk vetch is found mostly at pool 9B. No literature was available on the actual methods of competition; however, it was indicated in a report by the City of Fremont that it is a successful post-disturbance competitor. Based on my knowledge of Russian thistle, I have identified a few known disturbances at the Grasslands Park site and why this might interfere with alkali milk vetch specifically. Analysis of how these disturbances might impact the two plants is purely speculation based on my reading.

The first major disturbance at Grasslands Park is the remnants from the air force base that used to occupy part of the area. Construction of the buildings involved in this operation and the subsequent shut-down with partial removal of the structures could have caused a disturbance. This disturbance is in the upland area close to the vernal pool where alkali milk vetch has been found ~~at~~. The second cause of disturbance is the roads close to the site that are frequently used to access the park. Russian thistle occupies roadside ditches easily because of high disturbance. In a California Fish and Game report, alkali milk vetch was identified by Crampton in 1956 in a roadside ditch in Yolo County. This is clear evidence that Russian thistle and alkali milk vetch have the potential to grow in the same niche. Because the roads are still in use, there is an ongoing threat of increased disturbance. This situation is potentially good for both species so it is important that alkali milk vetch is able to grow in this area without Russian thistle present to displace it.

In the same California Fish and Game report, alkali milk vetch was reported to be threatened by cattle that were overgrazing at a different site. Because this observation was a small comment in a large report, there was no information about what conditions the reporter considered to be overgrazing. However, the relationship between cattle grazing and alkali milk vetch is not clear because there has been contradicting evidence in some reports. Overgrazing is considered to be a high intensity disturbance, creating another possible reason why Russian thistle is present at the site. Grazing has also been a method of management at Grasslands Park. If the grazers, cattle or sheep, are not properly monitored and overgraze the site, it could create the right conditions for Russian thistle populations to thrive. More research should be done to know what the thresholds are for alkali milk vetch populations and grazing. Alkali milk vetch may benefit from the disturbance by cattle: however, it creates the right situation for Russian thistle to move in and outcompete.

Although I was unable to find literature on where Russian thistle is found in vernal pools, given a few key characteristics, I would identify it as an upland species. Most invasive plants are not adapted to cope with the period of inundation within the pools. Russian thistle is most commonly found in semi arid regions with high light intensity and low water availability. Russian thistle does not tolerate water well, thus, being located too close to a vernal pool would not be an ideal growing condition. Alkaline and saline soils can both be characteristics of vernal pools--two characteristics common for Russian thistle growth. Alkali milk vetch also prefers alkaline soil conditions, another overlap in their potential niches. Pool 9B, where alkali milk vetch is found, is surrounded by Pescadero silty clay and Marvin silty clay loam, both of which can be moderately alkaline. Alkali milk vetch is also an edge species, not growing in the middle of the pool. This creates another possible overlap between the more spatially close habitats of an edge and an upland species.

Russian thistle can be a major invader in agricultural fields, especially post-harvest. Grasslands Park is surrounded by agricultural fields. These fields could be a potential avenue to allow Russian thistle to enter the site. Because it rolls around flat areas pushed around by wind, the threat of Russian thistle may come from other potentially contaminated fields around Grasslands Park.

In addition, both plant species can be found in salt marshes, with alkali milk vetch occupying the edge of the marsh. While I could not find the distribution of Russian thistle in the marshes, it gives more evidence of overlapping niches especially in one form of a wetland. If their niches overlap too much, it is possible that Russian thistle can replace the alkali milk vetch population by outcompeting it for the area they are both in. This could be directly related to its ability to access most of the water within the soil in the area it is growing in. It is also possible that because Russian thistle seeds germinate and grow so quickly that they could outcompete alkali milk vetch seedlings. These competitive mechanisms have not been observed with alkali milk vetch, but knowing how Russian thistle outcompetes it could be important to a management plan if it ever becomes a problem.

The last plausible situation as to why Russian thistle is a threat to alkali milk vetch is that it is a fire hazard. Dried up Russian thistle plants pile up along fences and tree groves, creating a quick starting fire if ignited. There are many eucalyptus trees present at Grasslands Park which are also fire hazards. There are also many fences surrounding pools to protect the endangered species within them along which Russian thistle can build up. If an uncontrolled fire were to occur, it would create a large disturbance. This could increase the Russian thistle populations, which, in turn, could increase the possibility of fire at the site.

The ultimate goal I have set for Russian thistle is to ensure that it is not inhibiting the local alkali milk vetch growth. The largest concern of Russian thistle at the Grasslands park site was reported as a competitor with alkali milk vetch. I believe any funding related to Russian thistle control should go into research about the relationship between Russian thistle and alkali milk vetch. Furthermore, because there is so little information available about alkali milk vetch, research should additionally be done to fill the gaps in knowledge about its life history, such as germination requirements and pollinators.

If the managers decide to take an extremely cautious approach, there are a few methods I believe could control Russian thistle. Preventing the plant from getting into Grasslands Park from the surrounding agricultural fields will be imperative to ensure that Russian thistle never becomes a problem. An analysis of the weeds present in those fields should be done, searching for all potential threats, including Russian thistle, to the vernal pools. Also, an analysis of the connectivity between the agricultural fields and Grasslands Park to determine the ease of access by Russian thistle would be useful in determining what lengths of prevention must be taken. A simple management method would be surrounding the entire park with fencing to exclude Russian thistle plants from entering the park by wind if it is identified in the agricultural fields.

If there is a large Russian thistle population in the surrounding agriculture fields, then owners or keepers of the land should be educated about Russian thistle management practices. Tilling and herbicides have proven to be the most effective management methods of Russian thistle within an agricultural setting. Regular management within the agricultural fields around the site should prevent the Russian thistle from becoming a problem. While all the management techniques listed in part one can be used, I do not recommend them for this site. For example herbicides would contaminate the pools and tilling would damage the soil and shape of the pools. If Russian thistle becomes a problem at the vernal pools, I would recommend grazing before July which is the earliest it is usually seen flowering. Grazing effects on alkali milk vetch should be studied further to be sure that grazing will not negatively affect it.

When the land manager was asked about Russian thistle, he said it was not a problem at this particular wetland and that management for yellow star thistle and purple star thistle are far more important. Up to now there is no hard evidence that Russian thistle is a problem in the vernal pools within Grasslands Park. However, because Russian thistle has the potential to seriously threaten the alkali milk vetch's population, a watchful eye should be kept on its encroachment, particularly from the surrounding agricultural area. Once all the disturbances within the site have been addressed and populations of other plants have established themselves from other restoration implementations, Russian thistle populations should naturally decrease, if it is present at all.

Synthesis of Goal

Preventing Russian thistle from entering or becoming a problem at Grasslands National Park is still the goal. Because the original goal is to just make sure that Russian thistle does not become a problem, there are no changes needed to modify the original goal to accommodate other management plans. This goal fits with the goals of promoting alkali milk vetch and San Joaquin spearscale populations. One difficulty is that all three of these plants need a little disturbance to have a healthy population. Because Russian thistle has the potential to compete with them, it is important to know how much Russian thistle is present in the vernal pools or the surrounding areas. While monitoring Russian thistle populations, research on the other two plant species can be done to fill in the gaps in knowledge which creates a win-win situation. There are no trade-offs currently involved in Russian thistle management at the site, but if it becomes a large problem there may eventually have to be some.

***Salsola tragus*, Russian Thistle**

I. History
   a. Introduced to the United States in early 1870s via immigrants
   b. Introduced to California in 1895 via railroad
   c. Native to Eurasia
   d. Family: Chenopodiaceae

II. Distribution
   a. Washington, Oregon, California, Nevada, Utah, Colorado, Arizona, and South Dakota
   b. In California it invades the southern arid region, some coastal communities, and salt marsh communities

III. Morphology
   a. Highly branched
   b. Summer annual forb
   c. Axillary apetalous flowers with showy sepals
   d. Pine-like seedling
   e. Hard to identify on the species level because it can hybridize with other species in the *Salsola* genus

IV. General Areas Russian Thistle Invades
   a. It is a post-disturbance invader
   b. Disturbed areas
   c. Roadside ditches
   d. Agricultural fields

V. Invasive characteristics
   a. Rapidly germinating seed
      i. Sometimes in a matter of minutes
      ii. Lacks a hard shell, has no endosperm, and embryo is already photosynthetic
   b. Can disperse up to 250,000 seeds over 4069 meters in six weeks
   c. Extensive root system
      i. Deep tap root- up to 1.5 meters deep
      ii. Many lateral roots- up to 1.8 meters wide
   d. Grows well in saline and alkaline soils

VI. Reasons for Control
   a. Causes yield loss in important crops, especially cereal grains
   b. Major fire hazard
   c. Can cause car accidents
   d. Allergies
   e. Competes with CNPS listed species *Astralagus tener* var. *tener* which is also typical in disturbed sites
      i. Reported to be a potential competitor of *A. tener* var. *tener* in Yolo County because it is a post-disturbance invader
   f. Assumptions as to why this is a potential problem at Grasslands National Park

i. Disturbance from overgrazing
ii. Fire hazard
iii. Disturbance from air force
iv. Disturbance from roads
v. Saline and alkaline conditions
vi. Edge species competing with a possible upland species

VII. Management

a. Mechanical: tilling and mowing
b. Chemical: herbicides
c. Biological: moths, blister-mites, and possibly fungi
d. Restoration: aids in areas with a topsoil
e. Grazing: Cattle and Sheep
f. Recommendation for Grassland Park: nothing until more is known about its actual impact on *Astralagus tener* var. *tener*

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Morgan McMahon

June 3, 2010

Project Final draft

ENH 160

Hordeum marinum

Mediterranean barley

Project Goal

The goal for the species, *Hordeum marinum,* on Yolo County's Grasslands Park should be to reduce the occurrence of this invasive exotic wild barley and to reduce its establishment in the vernal pools in the park as well as its ability to compete with the native endemic and endangered species present on our project site.

Background

Hordeum marinum was probably first brought to the western United States by Spanish colonists in the 16th and 17th century as forage for grazers. By the 19th century it had expanded through the central valley of California with the help of cattle grazing (Hoopes et al. 2002, Brusati et al. 2003). Originally from the Mediterranean region of Europe, *H. marinum*, also commonly known as Mediterranean barely, wild barley, seaside barley or simply grouped into the set of grasses called "foxtail", has become an invasive exotic annual in grasslands stretching from Mexico to British

Columbia (Brusati et al. 2003). The very extreme abiotic changes that occur within a vernal pool system throughout the seasons in a year usually ensure the pools are rather safe from many exotic species invasion, since going from a flooded environment to a completely dry environment in a relatively short time takes specific evolutionary traits. It is now thought that 93-97 percent of California's vernal pools have been destroyed by agricultural and urban development, thus greatly diminishing the endemic species to the pools (Brusati et al. 2003). *H. marinum* is one of the few exotic grass species that can colonize successfully in vernal pools and so should be looked at carefully and extra precaution should be taken when creating management plans for vernal pool areas.

Literature Review:

Important morphological and physiological characteristics, distribution, threat to vernal pools and management techniques

H. marinum is a member of the Poaceae family and is generally 1-5 dm tall. The leaf blade is 1-6mm wide with a slightly hairy basal sheath and leaf. *H. marinum* forms an inflorescence 1.5-7cm, green to purple, and made up of spikelets of 3 florets that have stiff, barbed awns later in development (Jepson 1993, Brusati et al. 2003). The seeds generally fall close to the parent plant and will sometimes be dispersed by a strong wind or an animal. The awns on the spikelets make the seeds easily dispersed far from the parent plant by attaching to human clothing or equipment, as a contaminant of hay, or on wild and domestic animals (Brusati et al. 2003). The barbed awns present a potential problem as they only allow movement of the spikelets in one direction. They get caught in hair of animals, especially longer haired domestics, and with continued movement from the animal they work their way into skin, eyes and nasal passages causing irritation and infection (Brusati et al 2003).

According to the California Invasive Plant Council, *H. marinum* is a moderately rated invasive species, with moderate invasiveness and moderate impacts on the California landscape along with a relatively high distribution throughout the state (California 2006). Impacts include, but are not limited to, unpalatable forage for grazers in rangelands and competition with native species. In some sources, *H. marinum* is grouped with *H. murinum*, another species of wild barley that has similar characteristics but dominates generally more moist habitats and wetlands, while *H. marinum* is more characteristic of drier upland areas (California 2006). The California Invasive Plant Council Inventory groups these two species and their various sub species together in one group as they are so close in relationship and similar in appearance and function as seen by the supposedly dry land preferring *H. marinum* also being able to withstand the wetland-like winter vernal pool habitat.

Hordeum marinum can be found distributed throughout both moist and dry grassland areas (Jepson 1993). New establishments are generally in disturbed sites but can also be found establishing in many non disturbed grasslands of California (Brusati et al. 2003). *H. marinum* is distributed fairly evenly throughout the state except in mountainous areas greater than 1500 meters above sea level, favoring the foothills and central valley (Brusati et al. 2003). Its rate of spread is fairly slow and static since *H. marinum* has been established in California for so long with the exception of spreading quickly over newly disturbed areas of grassland (Brusati et al. 2003). Because of its ability to withstand inundation, unlike other invasive annual grasses, *H. marinum* is able to establish in vernal pools, posing a threat by competing with native and rare vernal pool species (Brusati et al. 2003, Gerhardt et al. 2007).

In an experiment by Gerhardt et al. in 2007, that compared different exotic species' response to inundation, it was found that *H. marinum* was hardly affected. Most species of exotic grasses find the vernal pool environment to stressful as multiple extreme abiotic fluctuations from flooded to dry, changes in nutrient availability, pH and salinity limit growth and act as a natural weed control. *H. marinum* has a relatively high tolerance for salinity and stressful environments and has a physiological response to high levels of water. During inundation, *H. marinum* develops traits to enhance growth in the anaerobic environment of the vernal pool with higher root porosity and less oxygen loss. These traits are specific to *H. marinum* and no other exotic annuals tested in this experiment were found to have this characteristic. The results of the experiment showed *H. marinum* had fewer flowers and had less leaves compared to what height each individual reached when grown in a simulated vernal pool environment, so growth and reproduction were slightly harmed by the water and anaerobic soil conditions. However, overall inundation of the plant did not affect survival of the species. This study also found that in vernal pool areas, *H. marinum* is more frequent in the pool itself than on the upland areas, most likely from the fact that it is more harmed by the competition of other neighboring annuals then by inundation (Gerhardt et al. 2007). Although it can survive in the middle and deepest parts of pools, it is more commonly found at the edges of pools, where competition from upland species is less but there is also less time covered by water (Hoopes et al. 2002). This species is, however, very prevalent in other areas where no vernal pools exist (Hoopes et al. 2002) and so can adapt to a wide variety of conditions and compete with a wide variety of native speices. Because of the specific traits of *H. marinum,* this species is more likely to be a threat to vernal pools which commonly have rare and endemic species (Gerhardt et al. 2007).

H. marinum, like most species within the wild barley grasses, germinates all its seeds rapidly after the first rains in the fall (Popay 1981). It is a cool season annual and though seeds can continue to germinate throughout winter and spring, few last that long and rarely do seeds remain in the seed bank after the first year (Brusati et al. 2003). Less than one percent are said to stay dormant until the next growing season, and this is actually more likely caused by lack of moisture contact than actual dormancy (Popay 1981). If the plants are kept from seeding every year, no seeds will be found left in the seed back after 3 years (Brusati et al. 2003). This is a benefit for controlled management of the species as experiments show 2 consecutive years of keeping the *H. marinum* and other species of the *Hordeum* genus from setting seed is often all it takes to eradicate the species from the area (Popay 1981).

Another means of control and potential benefit of the species, *H. marinum*, is its use as forage in rangelands. Although the mature spikelets with retrorse barbs are problematic when combined with domestic animals, the species can be grazed early in the season, winter to spring, before maturation when the spikes are still green and edible. This provides a good source of nutrition for the animals as well as diminishes the seed bank and lessening the chance of *H. marinum* taking over a threatened area (Brusati et al. 2003).

There are other potential problems associated with *H. marinum.* Being an introduced annual exotic grass, increased thatch can increase fire frequency in areas dominated by the species. However, levels this high are rarely seen with *H. marinum. H. marinum* also has advantage over native perennial grasses as it can have a higher tolerance to high salinity levels and outcompete the natives (Brusati et al. 2003).

There are still many areas of *H. marinum's* life cycle in relation to management that could be possible new research areas. What species of grazer is the most successful at suppressing *H. marinum* and at what time of the wet season was never specifically stated in my research. A more specific time table of when *H. marinum* becomes unpalatable in relation to grazing intensity needed and perhaps amount of rainfall during the season could aid in site managers.

Hordeum marinum can potentially be a threat to vernal pool complexes in the Central Valley because even though it is an exotic species and did not evolve in vernal pools it has the ability to thrive there and compete with endemic and endangered species. For adequate control of the species, keeping the plant from setting seeds will stop its spread as the seeds are not viable after one year. Grazing, at the right time of year, can also reduce the spread of *H. marinum* and related species as well as careful procedures to reduce the amount of seeds traveling in and out of the area by attaching on animals, machinery and humans.

Part II

Project Goal Summary

The goal for this portion of our management project is to eradicate the invasive European grass *Hordeum marinum* from Yolo County's Grasslands Park, especially from all vernal pools on site where *H. marinum's* ability to physiologically adapt to inundation poses a threat to fragile vernal pool species.

Short term

- Reduce current season's growth with high intensity grazing to immediately reduce maturing *Hordeum marinum* on site in upland areas and pools and reduce seed bank for future years.

Long term

- Annual low intensity grazing early in *H. marinum*, a cool season annual's life cycle as a maintenance tool to maintain low levels of this exotic invasive
- Reduce chance of competition with fragile vernal pools species as well as upland natives.

Timing

- Grazing for *H. marinum* control is best done in winter and/or early spring while spikelets are still green and palatable.

Spatial Distribution

- *H. marinum* is a threat to both upland areas and vernal pools and is present in most of the park. Control measures must be taken on a large scale over the whole site. More specific and careful measures should be taken when dealing with pools with special status species, especially in the wet season, than need to be taken on the upland areas.

Restoration Plan

In theory, to restore Grasslands Park to its natural state requires eradication of all *Hordeum marinum.* However, the seeds of *H. marinum* are easily transported and invasive so a more realistic goal is to try to reduce and control the *H. marinum* population on our site. In managing this invasive species, we can take advantage of the fact *H. marinum* does not maintain a supply of seeds in the seed bank year after year (Brusati et al. 2003, Popay 1981). By destroying the new seed heads before maturity, we are able to drastically reduce the percentage of *H. marinum* present in the park.

Monitoring the *H. marinum* population should be done on a yearly basis. Preferably in winter after germination and before any grazing has depleted the population. Overall population size and distribution should be measured to see the change from year to year to see progress of control over the species with current management plan. Special concern should be give to populations residing in the vernal pools on the site. Timing of seed maturation should also be monitored on a yearly basis to better judge correct time of grazing management.

The intensity of grazing and number of animals present will depend on the time of year grazers are able to access the site. Early on in the life cycle of the plant, the spikes make good forage before awns with retrorse barbs mature and cause damage to animal's mouths, eyes, and skin (Brusati et al. 2003, Jepson 1993). To encourage animals to consume mature *H. marinum* over other forage present on site, animals must be grazed at higher densities to ensure the less desirable "foxtails" of *H. marinum* are destroyed.

High intensity grazing does not pose as great a risk in the upland areas as for the pools. Sensitive pool species can be trampled by grazing animals and soil can be compacted affecting the species in the pools. This poses a potential conflict as the optimal time of year for grazing *H. marinum* is the wet season, when the pools are still fully inundated (Brusati et al. 2003). Pools can be grazed later in the year, but the higher density of grazers required to guarantee consumption of *H. marinum* will also cause damage to vernal pools.

For pools that are too fragile to be grazed, especially pools with rare species such as the Crampton's tuctoria or Colusa grass, hand pulling of *H. marinum* might be necessary to remove the invasive. This technique is more labor intensive but should be implemented to increase the chance of survival of the endangered vernal pool species as *H. marinum* can compete with natives for water and space as well as reduce inundation time like many other invasive annuals on the outskirts of vernal pools (CALFED 2005).

For pools that do not have invasions of *H. marinum*, careful monitoring of grazers entering areas near pools should be give priority as *H. marinum* seeds often disperse by attachment to the fur of animals. Equipment and clothing should be cleaned before and after working on the site to prevent further spread of seeds to unoccupied areas (Brusati et al. 2003).

Another potential problem is the availability of grazing animals for the site. Due to financial issues, access to water, fencing availability or other similar problems, grazing might not be possible when needed. Effective communication is necessary between site manager and animal supplier to make sure protected areas are maintained and no accidents occur.

Mowing could also be used to remove seed heads. This could be especially useful if grazing is not possible. However, mowing must also be carefully timed, as mowing too late could have the opposite effect and aid in dispersal. Another alternate method to grazing control would be to use an herbicide application to kill *H. marinum* plants before the seeds mature. This is an effective way to reduce the population, but not recommended as it also destroys all surrounding vegetation as well, leaving applied area bare of many species (CALFED 2005).

Though many variations of grazing patterns could be used to control *H. marinum*, the most important aspect of this restoration plan for Grasslands Park is that some kind of control measure must be taken before this invasive becomes a real threat to the vernal pools located there.

Part III

Synthesis of *Hordeum marinum* Goal Within Class Project

Overall my individual goals for managing *Hordeum marinum* on the Grasslands Park site can fit well with the overall goals for the class. The main management tool for controlling *H. marinum* is grazing, and it was agreed upon by most species representatives in class discussion that grazing must be an essential part of the management plan at Grasslands Park. However, there are multiple potential tradeoffs when dealing with grazing a vernal pool system. The main issues addressed were compaction caused by grazing during wet season in vernal pools and intensity of grazing and grazer type to insure complete suppression of the invasive species. Both have positive tradeoffs. Though hooves cause compaction that can affect pool species, as well as upland species such as solitary bees and burrowing owls, also create micro depressions that support plants during drier years. It seems that the overall class impression was that cows were the best grazer type for the area, seeing as they are less selective and will eat the less appealing *H. marinum* and not prefer the forbs present.

Fact Sheet

Hordeum marinum

Common name: Mediterranean barley (also wild barley, seaside barley, or “foxtail”)

History:

- Originally from Mediterranean region of Europe
- Brought to North America by Spanish colonists, 16th and 17th century as forage
- Grazing expanded range throughout central valley (found from Mexico to British Columbia)
- California Invasive Plant Counsel- moderately invasive with high distribution
- Often grouped with *H. murinum,* species characteristically preferring moister habitats

Distribution

- Moist and dry grassland
- New establishment in disturbed areas (also found in non disturbed grasslands)
- Rate of spread relatively slow
- All of California except areas over 1500 meters above sea level, favors central valley
- Able to withstand inundation, threat to vernal pools

Characteristics

- Invasive, exotic annual grass, Poaceae
- Up to 50cm tall, slightly hairy leaf
- 1.5-7 cm inflorescence, green to purple, spikelets in threes, stiff barbed awns
  - awns only allow movement in one direction, irritation and infection in animals

- Dispersal by wind or more likely by attachment to animals, vehicles, clothing
- One of the few exotic grass species that can colonize vernal pools
  -high tolerance for salinity and stressful environments, physiological response to high levels of water

  - develops higher root porosity and less oxygen loss

  - growth and reproduction compromised, but not survival

  - can be more frequent in pools than upland areas

- Other problems: increased fire intensity, high tolerances outcompete native upland grasses

Life Cycle

- Cool season annual, germinates all seeds rapidly after first rain in fall
- Few last long enough to germinate through winter and spring
- Less than 1% stay dormant, no seeds left after 3 years

Management

- Keeping *H. marinum* from setting seed 2 consecutive years eradicates species from area
- Grazing
  - good source of nutrition before maturation

  - spikelets with retrorse barbs problematic with domestic animals

  - consumption before maturity lessens chance of *H. marinum* taking over threatened area

  - grazing pools can pose potential problems

Recommendations for Grasslands Park

- Grazing to reduce chance of establishment in pools

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Management tools

Ava Eitzen

ENH 160

June 2, 2010

Grazing in California Vernal Pools

Vernal pools are found in California's rangelands, specifically in the low lying grasslands. Rangelands are predominantly used for cattle grazing as well as horse and sheep. There is a need to sustain vernal pools while still being able to graze the land. It is important to know what management practices work best and have guidelines available for the public. Grazing can be harmful and detrimental to certain species and is a highly controversial. Many species, both plant and animal can benefit from grazing but only during certain seasons and under particular circumstances (Barry, 1995). Many of the remaining vernal pools in California are on private lands and are grazed. It is important to work with ranchers to preserve and protect the many endangered and threatened species that live in this habitat through monitoring and following proper grazing regimes (depending on the species present). Vernal pools have been grazed since the Spanish explorers arrived 150-200 years ago (Bauder, 2007). Vernal pool species have coevolved with grazers giving them an advantage to the exotic species (Barry). However, with land use conversion and increase in stocking rates, vernal pools are prone to overgrazing leading to the extinction of species within a pool. Grazing vernal pools can also protect and sustain the native species, control exotics, and enable vernal pools to thrive if done properly (Barry).

Grazing and its effects on vernal pool:

Hydrology

Hydrology is one of the most important aspects of vernal pools. It is necessary for water to stay in the pools for an extended period of time, long enough for the species that inhabit them to complete their life cycle, about four months. The two sources of the pool water are precipitation and runoff. Pool hydrology is altered when there is an absence of grazing causing problems. These include an accumulation of biomass is able to evaporate water, more roots are present creating more pores in the soil and less runoff down into the pools, deep tap roots from invasives are able to tap into the pool water supply and transpire the water. These different losses of water are very detrimental to the life of the plant and animal species that rely on the water to be present for an extended period of time. Grazing reduces total above and below ground biomass and invasives preventing the water loss from the pools (Barry, 1995).

Soil

The pools are created by a unique soil composition that consists of a shallow hard pan that restricts water from percolating down into the ground. These hard pans as well as the shallow depressions that fill up with water during the winter are critical to the survival of the pools. Cattle have a unique role in vernal pool soil/hydrology. When the livestock travel through the pools they leave deep hoof depressions which during the wet season are deeper than the pools (Barry). These provide a micro-depression thus creating a special microclimate that extends the life of the pool. This aids species such as Downingia bella which grow best in the deepest part of the pool as well as suitable habitat for fairy shrimp in low rainfall years (Barry).

Species Composition

Native species are specially adapted to the harsh environment of induation for a short period of time and the long dry period. There are less than 200 different native plant species that still predominate in the pools (Barry, 1995). This is unlike the surrounding grasslands where it is almost entirely exotic species which dominate. Exotic species are not able to survive in such harsh conditions of constant water logging for an extended dry period restricting their ability to grow in the pools. This is not true for all exotics, swamp grass for example thrives in vernal pools. However, generally this means that invasives can take over the outskirts of the pool and are them able to remove large amounts of water through evaporation, transpiration, and tap roots (Barry).

Grazing greatly reduces invasives and keeps them under control, reducing their ability of removing pool water and dominating along pool edges (Barry). In one field experiemnt done in the Sacramento area, grazing reduced the invasives by 88% and increased the natives by 47% as compared to ungrazed pools over a three year study. The study concluded that there is higher biodiversity, and increase in the number of species in grazed pools then ungrazed. The study also found that there was a decline in invertebrate diversity in ungrazed pools because the lack of disturbance changed the pool hydrology (Marty, 2005).

Grazing regimes and their effects on vernal pools:

Timing

The season and the duration of when pools are grazed is an important aspect of their sustainability. A field study done in Sacramento looked at the effects of dry season, wet season, continuously grazed and ungrazed regimes. It compared species composition, length of induation, and overall pool health. The continuously grazed regime is the control and is also the historical grazing season in this area (from October- June). This regime had the highest number of natives and the lowest number of non natives. The dry grazed pools (October-November and April-June) had the second highest cover by natives and second lowest cover from non natives. The wet grazed regime was third behind the continuously grazed and dry grazed in both natives and exotics. The ungrazed had the highest cover of non natives and throughout the study steadily increased over the three year period. It also had the lowest native cover in the four different grazing regimes and the highest amount of absolute cover. This means the diversity decreases in ungrazed pools and non natives can change the hydrology and function of the pools if left of a period of several years. The continuously grazed pools were the best grazing regime for this particular site. The ungrazed regime was counterproductive to conservation of vernal pools (Marty, 2005).

Stocking rate

Light and moderate grazing are identical and have much lower rates of infiltration (Barry).

Species

Cattle, horses, sheep, and goats are suitable grazers for vernal pools depending on why the pool is being grazed. There are differences in preference and ability to consume the plant matter between the species. Differences in plant palatability and disturbance potential should be taken into consideration when choosing the right grazer for a site (Barry).

Cattle and horse prefer grasses and horse can graze closer to the ground than cattle. This could be effective in reducing the exotics. Sheep prefer broad leaf plants and can graze closest to the ground. Sheep should then be closely monitored because the prefer the native forbs more than the other two species. Goats eat almost everything and should only be considered if the pools are over run by exotics. Cattle and horses should be monitored as the pools dry up and the grass turns brown because they are then likely to graze of the green vegetation in the pools. Cattle are also more adventurous and will travel more than horses, meaning that horses are likely to stay near the pools where cattle will wonder even if there is still water in the pools (Barry).

Differences from site to site are evident. Each set of vernal pools need to be individually evaluated. What works for on site may not work for another. It is imperative that more studies be done to fully understand the extent of which grazing has on vernal pools. There are many well documented observations and only a few long term studies that show the effects of grazing.

<u>Grazing Grasslands Park Vernal Pools</u>

Goals

1. To reduce the non native and/or invasive upland vegetation

2. To increase or sustain water in pools by increase runoff to pools and/or decrease transpiration of upland vegetation
3. To give natives a competing edge through disturbance
4. To create disturbance in created pools to change topography
5. To protect established vernal pools (natural pools)

In order to successfully complete the above goals it is necessary to have carefully management with the proper stocking rate and season of grazing. There are tradeoffs between controlling the exotic populations that are threatening the livelihood of the vernal pools and sustaining the native populations of plants and animals. The proper stocking rate of animals is necessary to obtain the desired effects of reducing invasives while not jeopardizing the overall health of the park. The reduction of upland species should allow more water to stay in the pools for a longer period of time which allows for species to complete their life cycles. However, with too much disturbance from these animals there can be detrimental effects; trammeling of plants or aniamlas leading to injury or death before complete life cycle, compaction of soil so seeds will not be able to germinate the following year, and contamination of water with feces causing unsuitable habitat for the animal species to survive (Barry). All of these concerns need to be carefully monitored to insure that the right numbers of animals are grazing the site. These goals are long term that will take several seasons of grazing to accomplish. To reach these goals it will take continuous and yearly grazing. To sustain the results some grazing will most likely be necessary during peak forage months, late spring into early summer (USFWS, 2004).

Restoration Plans

There are several species of grazers that can be used depending on the target species being managed for. Grazing during the winter in the pools and upland will be beneficial for most species because it will provide the right amount of disturbance. Dry season grazing is necessary for the uplands but should be avoided for the natural pool. The natural pools should be fenced off. The created pools would benefit from continuous grazing because they need a high level of disturbance. The number of exotics needs to be reduced before natives can establish in the pools and the sides of the pool need to be gradual, less steep than they currently are. April is traditionally considered the start of dry season grazing but will vary depending on annual rainfall. Below are a list of possible grazers with their benefits, drawbacks, and level of disturbance (Marty, 2005).

a. Cow/calf pair:

Pro:	Effective in controlling yellow star thistle, if grazed May and June after spring grass and before flowering. Consumes medusahead before awns become dry (April /May). Will eat Mediterranean barley before goes to seed.
Con:	Does not eat perennial pepper weed, does not prefer swamp grass but will eat if nothing else. Spreads seed of perennial pepper weed though feces. Possibly spread of other exotic in feces. Possibly toxic contamination of water with feces. Possibly eat/disturb native population of species. Cows with calves are very aggressive and will attack dogs if felt threatened.
Level of disturbance:	High level of disturbance with two animals but lower consumption of vegetation because only the cow will be eating vegetation.

b. Cow/heifer/steer

Pro:	Effective in controlling yellow star thistle, if grazed May and June after spring grass and before flowering. Consumes medusahead before awns become dry (April /May). Will eat Mediterranean barley before goes to seed.

Con:	Does not eat perennial pepper weed, does not prefer swamp grass but will eat if nothing else. Spreads seed of perennial pepper weed though feces. Possibly spread of other exotic in feces. Possibly toxic contamination of water with feces. Possibly eat/disturb native population of species.
Level of disturbance:	High level of disturbance with higher level of grazing than cow/calf pair.

c. Horses:

Pro:	Eat Mediterranean barley prior to seed set.
Con:	Do not eat perennial pepperweed or Mediterranean barley. Does not prefer swamp grass but will eat if nothing else. Yellow star thistle is toxic. Highly selective grazers. Able to eat closer to ground than cattle or sheep.
Level of disturbance:	High level of disturbance to pools. Less disturbance to vegetation than cattle, sheep, or goats.

d. Sheep:

Pro:	Eat perennial pepper weed and swamp grass. Only effective in decreasing density of yellow star thistle with late summer grazing. Will eat medusahead at every stage. Will eat Mediterranean barley before seed set. Less compaction of soil than cow or horses.
Con:	Spread seed of perennial pepperweed though feces. Less selective grazers that will eat grasses and forbs (more likely to forage on natives).
Level of disturbance:	Lower disturbance because of smaller body size. High level of disturbance to vegetation because not selective grazers.

e. Goats:

Pro:	Eat perennial pepperweed, swamp grass. Effective in eating yellow star thistle (best species eats at all stages). Will eat medusahead at every stage and Mediterranean barley. Less compaction of soil than cattle or horses.
Con:	Spread seed of perennial pepperweed though feces. Less selective grazers that will eat grasses and forbs (more likely to forage on natives). Able to eat closer to ground than sheep or cattle.
Level of disturbance:	Lower level of disturbance due to smaller body size. High level of disturbance to vegetation because not selective grazers.

For Grasslands Park cow/heifer/steer is most likely the best choice for the next grazing season because of the high level of disturbance and palatability of many of the exotics species. Cow/calf pairs are not ideal for this site due to the high activity of dogs in the area. Horses would not be ideal for this site because they will not be effective in controlling the main exotic species even though they have a high level of disturbance. Sheep would be a good candidate if cow/heifer/steers where not available. If cattle were not initially effective in decreasing exotic species than goats should be considered because they are not selective grazers and would consume the exotics but need to be carefully monitored to ensure there is minimal disturbance to natives (USFWS, 2004; Bauder, 2009; Rentner).

Managing the time of year and stocking rate is very important. The stocking rate will be different depending on the species. Cattle and horses will have a lower stocking rate than sheep and goats. Determining when to start grazing and when to stop is also very important. Careful monitoring is necessary in late spring or after the rains have subsided to determine if enough species have set seed before adding the livestock. Monitoring to make sure that overgrazing does not occur and animals are removed before damage to soil and/or plant/animal species occurs (Barry; Rentner; USFWS, 2004).

There are several concerns about having livestock in Grasslands Park. The pools need to be properly fenced off so animals are not able to break of push fence over. This is mainly a concern with cattle. Dogs should not be allowed in area and designated to the dog park only. They can chase the livestock and sometimes cattle can be aggressive towards them.

There are several risks and uncertainties that are related to grazing. There can be an increase or no change in exotics. There can be a decrease in natives. The relationship between the livestock and bird populations is uncertain. Overgrazing is always a concern and needs to be avoided. There can be undesirable changes in vernal pool chemistry or hydrology in the unfenced pools.

The effects of grazing on the different species in this habitat are not all known. Keeping careful records of the effects of the different species would be very important to improving the general knowledge of grazing in vernal pools.

Part III

Grazing is necessary for other management goals of certain plant species. Most species will benefit from winter grazing with cattle. This is because cattle leave mircodepressions that aid in the survival of species, they eat many of the exotics, and provide an adequate level of disturbance for this site. Coyote thistle would be a concern because it is not compatible with grazing, where most of the other species can tolerate light to moderate.

Gazing in Vernal Pools

History: Late 1700's to mid 20th century there was a large amount of grazing in California grasslands by sheep and cattle. Due to development and climate shifts there has been a large decrease in grazing. Currently it is considered a minor disturbance. 1992-1998 ~125,000 acres has been converted from grazing to agriculture.

Effects: consumption of vegetation, trampling, and nutrient output in feces and urine.

Pros: Maintain appropriate induation period by limiting vegetation accumulation. Sustain soil characteristics that create pool habitat. Control exotic grasses. Remove standing dead or dry vegetation. Produce micodepressions in pools with hoof prints.

Cons: Accelerate erosion and increase siltation into pools: reduces volume and alter soil profile. Heavy grazing promotes thick sheets of algae that smother plants. Inappropriate management leads to: overgrazing (decline in overall species, decrease in water quality), undergrazing (increase exotics), and incorrect timing (grazed during bloom/ seed set is detrimental). Trampling and grazing kills plants and animals.

Species	Response to grazing
Chamaesyce hooveri (Hoover's spurge)	(+) light/moderate grazing, (-) heavy. Cattle generally don't forage it is close to ground and toxic sap
Orcuttia tenuis (Orcutt grass)	(+) due to high density of stands
Tuctoria muncronata (Solano grass)	(-) heavy grazing, decrease germination rate
Elaphrus viridis (Delta green ground beetle)	(+) with effective management
Spea Hammondii (Spadefoot toad)	(+) moderate; cattle increase induation time, allowing more time for metamorphosis. (-) crush/consume eggs heavy; decrease water, increase metamorphosis time and decrease fitness. Sheep preferred
Neostapfia colusana (Colusa grass)	(+) moderate, generally better with sheep, before seedlings emerge. (-) water contamination
Astragalus tener var. tener (Alkali milk-vetch)	Either (+) or (-) depends on site
Gratiola sp (Hedge-Hyssop)	(+) moderate. (-) before seed set and overgrazing
Castilleja campestris ssp. succulenta (Fleshy owl's	(+) if monitored and adjusted

clover)	
Atriplex joaquiniana (San Joaquin spearscale)	(-) if overgrazed
Psilocarphus sp.(marbles)	(+) survive in microdepressions
Lasthenia sp. (goldfields)	(+) will decrease in population if livestock removed. (-) if overgrazed, reproduction decrease if not monitored
Eryngium sp (coyote thistle)	(-) if grazed
Downingia sp. (downingia)	(+) D. bella to microdepression
Plagiobothrys sp. (popcorn flower)	(+) survival in microdepression. (-) heavy grazing
Branchinecta sp (Fairy shrimp)	(+) survival in microdepression during low rainfall years

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Appendix- assignment outline

Spring 2010- Project for ENH 160

Project Scope

The focal experience of this class will be to develop a restoration handbook for Yolo County's Grasslands Park vernal pool complex. Grasslands Park is charged with multiple goals: some are legally required (conservation of a few key federal and state enlisted species), some are key management issues (e.g. managing visitor use of park, how to manage for upland requirements without negatively impacting the vernal pools), and other goals are not required, but highly desirable (e.g. diversity, ecosystem services, etc.). In order to manage for multiple goals, it is critical to bring together the latest information on various components, and to use this information to develop management plans that can achieve multiple goals. This is where you come in. Each student will rate their preferred topics from the list (separate handout), and based on these rankings, will be assigned a given topic. You will research this topic, summarize your key findings, and make a management plan based on that information (see details below). Each student will make a short presentation to the whole class, so that everyone is familiar with the broad scope of the overall project. As a class, we will then discuss management options that encompass as many of these goals as possible, and you will amend your management plan to encompass a broader array of goals. All individual projects, as well as a class synthesis, will be compiled and sent to the Grasslands Park, and be made available on the web for other managers.

General approach

The project will be divided into different stages, which will allow you to develop the project step-by-step, and get feedback from your teachers and peers before the final compilation is due. You will essentially be graded twice for each written section you turn in. The project has been designed this way to reflect actual restoration planning- where each step of the planning process is improved based on feedback from various stakeholders. Thus, the first version you turn in for each section should reflect a serious attempt to "get it right", and will be graded for overall quality. A high quality first draft will not only affect your grade, but will also minimize the work you will need to put into a final version. At the end of the quarter, you will submit a final version of all sections, where you have incorporated feedback from your teachers and peers. The grade of the final version will be based on overall quality and how well you address suggestions you received on your draft versions of each section. Details on each step are below.

Writing style- The project is intended to be a brief overview of the key issues involved in your selected restoration project. As such, it is entirely appropriate to touch on key points through the use of bullets and numbered lists, *as long as you are conveying enough information for the reader to follow along with your logic and story.* Remember, this is a professional document that will be used to inform managers—be sure your writing is clear, concise, and professional. Be sure to cite all reference sources, including websites, newspaper articles, journal articles, books, etc. Provide complete information for each reference at the end of each part (for most sources, that includes author, date of publication, article/chapter title, journal/book title, publisher, city of publication, page numbers). (See the handout attached to the syllabus on avoiding plagiarism for more details on proper citations).

Specific requirements:
Below you will find *guidelines* for addressing your target restoration goal in each section of the project. Different goals will require some different information, or have different information available. If after a thorough search, you cannot find some of this information, make it clear that this is a current hole in our knowledge about the subject. The guidelines below will fit most projects, but feel free to expand on certain topics, add certain components that are critical for your goal, or briefly describe why a given topic is not relevant to your goal. You're encouraged to look at examples from previous years (available in the resources folder on smartsite) as examples of what is expected. The sections of their papers were not identical to this year's assignment, but most of the key information/approaches are still valid to your assignment. Strong examples include:
From 2008 report- medusahead, goatgrass, tiger salamander, erodium, burrowing owl
From 2009 report- California brome, gumplant, Himalayan blackberry, white-tailed kite

Part I: Project background and justification, literature review Due 4/22
Part I should focus on YOUR specific goal- providing the conceptual background that will be needed to make a management plan. In this part, you should NOT yet focus on our project site, but on your goal in general.
A. Background & Justification: View this as a brief proposal for funding of the restoration target.
- Why do we care about this goal? (e.g. this invader decreases native diversity and lowers the depth of the water table).
- Why is this restoration goal important and interesting? For example, what is your target goal's conservation value, its impact on agriculture and/or the environment?
- What is the current state of your target goal? (Not necessarily at our project site, but overall). For example, to what extent are populations in decline?
- What is the history of degradation of your goal? (e.g. it is estimated that 60-90% of California's vernal pools have been destroyed through agriculture and urbanization).
- What are the local to national laws/policies that constrain or provide opportunities for your target goal?
- What are some potential sources of funding for restoration of this goal?

B. Literature review
A comprehensive review of our existing knowledge on your topic—this requires considering multiple sources of information. This is particularly critical because it is common to draw very different conclusions about restoration effectiveness at different sites. It is critical that you base this review on trusted sources (e.g. peer reviewed literature and government reports) and emphasize specific facts—avoid citing opinions or propaganda that you may find on the web, and avoid speculation or vague comments. For example, rather than making a vague comment about an invader decreasing ecosystem health, describe how its increased evapotranspiration dries up vernal pools faster, thus not providing the period of inundation needed for a specific native species of interest.
- What are the main factors affecting your goal (both ecologically and major challenges to restoration)? (Biotic, abiotic, human land use, etc. Consider all topics covered in class- at the levels of physical site conditions, organism, population, community, ecosystem, landscape, socio-economic, global change, etc.) Some specific examples include: o specific characteristics of your species- germination controls, seed bank dynamics, environmental tolerances and preferences, key mutualists and competitors, etc.

  o specific to vernal pools- what are your species requirements in terms of vernal pool: depth, surface area, size, period of inundation, proximity to other vernal pools?

- o How does your goal respond to: climate change, grazing, fire, nearby plowing, herbicides/pesticides? other potential management actions?

- For all of the above information, focus on potential: constraints, non-linearities/thresholds, interactions, feedbacks
- What scale (spatial and temporal) do these controls operate over?
- What restoration/management options have been effective or ineffective? Do these change site-to-site or project-to-project?
- What are key gaps in our knowledge that limit effective restoration planning?
- Other relevant information

Part I should be approximately 6-8 double-spaced pages, and key information can be summarized in a bulleted form, if desired.

Part II: Goals and management plans- focused on your target Due 5/20
(At this time, turn in one copy of Part II for grading, and THREE copies of Parts I & II and your "fact sheet" for peer review—part I should be revised based on earlier comments!)
Part 2 again should focus on YOUR goal (not the overall class goal). Your goal(s), restoration plan, and monitoring plan should be specific, clear, and actionable. For example, rather than saying seed will be collected and spread on the site—you need to be specific about where it will be collected, and what seeding rate you will use. Similarly, if you suggest using grazing or fire as a management tool, you need to be specific about the timing of the fire, the frequency (every year?), and how much flexibility there might be in this plan.
A. Goals: Outline the key goal(s) relevant for the restoration of your focal target (a list or table is fine, as long as you have descriptive phrases about each goal). Be sure to be explicit about the spatial and temporal scale of these goals (and in many cases, it may be appropriate to have different goals focusing on short- vs. long-term, small- vs. large-scale). Discuss the potential for restoring these goals, giving careful consideration of tradeoffs, feedbacks, interactions, and thresholds.
B. Restoration plan: Describe your restoration plan(s), be sure to justify your choices. If possible, discuss a few different restoration options (which will really help fit your project into the broad, multiple goal plan), and the relative effectiveness of each. Points to include:
- specifics on methodologies (e.g. genetic sources of seeds, seeding in vs. transplanting, density and configuration of introductions, frequency and intensity of manipulated disturbance regimes)
- the temporal and spatial scale of your plan
- monitoring techniques (pre- and post-restoration) and "thresholds of action", justify the measurements and thresholds you have selected as indicators (For example, with complete failure of reestablishment of a population you plan to…….. versus with species establishment at only small, sporadic locations, you plan to ……). Be sure to be specific about when you will monitor, for how long monitoring must occur (and will it be of equal intensity the whole time, or change over the years?) Again, be sure there is enough detail to be actionable.
- potential problems you might encounter, and how you might adjust the plan along the way if you encounter those problems
- a description of the risks and uncertainties associated with your plan
- highlight research questions that need to be answered in order to improve the plan
- what research questions could be answered by this restoration project (or by comparing a suite of similar restoration projects?) How does your restoration design allow for those to be tested? (e.g. the presence of control plots, replicate treatments, etc.)

This section should be approximately 4-7 double-spaced pages.

Extra credit opportunity *(up to 10 points)*
Do a restoration budget for your goals, including factors such as: site preparation, labor hours, materials, monitoring costs, etc. (** Note: this can be handed in up to the last day of class).

Class presentation and fact sheet
You will be assigned a date to present- see class schedule
Briefly present the key facets of your project to the class. Presentations should be 6-8 minutes in duration (no longer!! To fit everyone in, I will need to cut you off if you go over), and 1-2 minutes will be allowed for questions. The point of this is for all classmates to be aware of the importance, constraints, and opportunities of your project, so that we can fit all of these goals together in a comprehensive management plan. Be sure to keep that in mind during your presentations. Remember, we're all part of the same broad restoration team, so we'd all like to see all of these things happen. We'll address tradeoffs and hard decisions in the group discussion following the talks. This talk should not be a reiteration of everything you've written & researched. Instead, briefly hit on the highlights (think about the brevity and clarity you'd like from your classmates' presentations). As we're managing for multiple goals in the class, it will be very important to have specifics about your goal's requirements (e.g. period of inundation required in vernal pools, proximity to other pools, timing of management practices needed for your goal, etc.)
Be sure to cover these previous points as well as:
- justification for your target goal
- key constraints/opportunities (Be sure to think about this broadly—e.g. if you're working on frogs, will your project be decimated by snakes, grazing, a certain % change in water availability, etc.)
- "proven" restoration techniques vs. uncertainties
- your restoration plan(s) and alternative options- paying particular attention to what management needs to occur, and over what spatial and temporal scales

You must present the class with a 1 page "fact sheet" (a summary of key facts needed for the overall class management plan), and can base your presentation on this fact sheet, and/or a powerpoint presentation.

All fact sheets and powerpoints MUST be placed in the smartsite dropbox (or emailed to Valerie) BEFORE 7am on the day of your presentation. (This gives me time to make photocopies of the factsheets, and compile the powerpoints for the day).

Peer assessment
You will get the assignments on 5/25, and your reviews are due on 5/27
You will be divided into groups of 3-4 students. On 5/25 you will receive the full draft (parts I&II) of each member of your group. Read and give both written and oral feedback on each project in your group. The goal of this is to provide *constructive* criticism, helpful hints, and to point out potential tools or problems that the writer may have missed. Your comments should be written- you will need 2 copies; you will turn in the first to the professor (these will be graded), and give the other copy to the project author. On 5/27, your group will spend the class discussing each other's projects and exploring ways to overcome any remaining hurdles in the projects.
Detailed guidelines on peer review are provided in an attached handout.
Peer reviews should be 1 page per project, and should include:
- label the top of the page with your name (the reviewer), and the name of the person's paper you've reviewed
- what the author did well
- general suggestions for what the author might have missed

- constructive criticism

For discussion (15 minutes per project):
- discuss suggestions you made as a reviewer
- as an author, bring up questions you'd like the groups help on
- 15 minute summary- comparison of projects' challenges, unknowns, tools, what you've learned from eachother's projects

Part III- Synthesis of your goal within class project
Due 6/3, along with final versions of Parts I & II
Based on your classmates' presentations and the group discussion of options for managing for multiple goals, discuss how your goals and restoration practices fit in with other key goals. Are there key tradeoffs and/or win-win situations? What are the potential feedbacks and interactions in managing for these multiple goals? How will you revise your original goals and management plan to accommodate these multiple goals?
Part 3 should be in the form of 1 short paragraph.

Final version - BOTH A PAPER COPY AND AN ELECTRONIC COPY IS DUE (electronic copy can placed in the dropbox on Smartsite or emailed to Dr. Eviner) Due 6/3
The final version should include Parts I-III and your fact sheet, merged as one document, and all citations should be grouped together at the end (both in paper and electronic form). Sections I&II and the fact sheet should incorporate the comments you received from the teachers and your peers. If you do not agree with some of the suggestions (we're not talking about grammar, but suggestions for shifts in management plans, etc.), you do not have to address every point. However, if there is a substantial conflict between some feedback and your project, you should note that in the final version and justify your reasons for not adjusting the project in response to reviewer comments.

Web posting of compiled papers. The overall class report will be compiled and placed on the web for wide access to managers. By handing in your final paper, you are permitting us to post your paper as part of the compiled class report. If you do not want your paper posted, you must email Dr. Eviner within a week of the end of spring quarter 2010, and we will keep your project out of the full class report.