Science Foundation Chapter 5
Appendix 5.1 – Case Study
Vernal Pools

Authors: Christina M. Sloop[1]

[1] *San Francisco Bay Joint Venture, 735 Center Blvd., Fairfax, CA 94930.*

DESCRIPTION OF THE HABITAT

Vernal pools are among California' s most sensitive and rare wetland habitats, with annual cycles of winter and spring inundation followed by summer desiccation (Keeley and Zedler 1998; Keeler-Wolf et al. 1998; Botkin et al. 1991). A diverse array of vernal pool complexes still exists within California grasslands, including some within the San Francisco Baylands (Holland 1998; Goals Project 2000). These seasonally precipitation-filled, shallow depressions are mainly found in more inland areas and are underlain by hardpan, clay pan or bedrock (Keeley and Zedler 1998; Goals Project 2000). Specialist species such as annual plants, crustaceans and other invertebrate taxa and some amphibians have evolved life histories specific to the extreme wet and dry conditions found in vernal pools (Keeley and Zedler 1998, King et al. 1996; Goals Project 2000).

Distribution of Baylands vernal pools has been reduced from their historic range (EcoAtlas 1998), with pools currently remaining north of San Pablo (Sears Point and lower Tolay Creek) and Suisun Bays (Solano County), and in southern San Francisco Bay at the Warm Springs complex in Fremont (Goals Project 2000, P. Baye, I. Loredo pers. com). Besides freshwater vernal pools, the San Francisco Baylands contain seasonal pans that lack the characteristic biota of upland pools because of elevated salinity, where salt diffusion from underlying soils causes them to be slightly brackish (Goals Project 2000).

CRITERIA FOR SELECTION OF THE HABITAT

Vernal pool systems throughout California have been relatively well studied (Keeley and Zedler 1998; Keeler-Wolf et al. 1998, Witham et al 1998), and they represent a threatened, and potentially climate-sensitive wetland type harboring high biodiversity. Specifically, many specialist endemic vernal pool species are naturally rare, and have as part of their life histories adapted to a fluctuating system with very extreme conditions making them vulnerable to changes (Keeley and Zedler 1998; Witham et al. 1998).

In the past century, land use change associated with urban development and agriculture have caused the loss of 90% of historic vernal pool ecosystems in California resulting in the endangerment of many species associated with vernal pools throughout the State, including the San Francisco Baylands (Holland, 1978; Griggs and Jain, 1983; Keeler-Wolf et al., 1998; EcoAtlas 1998). This is mainly due to habitat loss, degradation and associated isolation and genetic erosion of decreasing populations (Elam 1998; Ramp Neale et al. 2006, 2008; Sloop et al. 2011; Gordon et al. 2011; Sloop and Ayres 2012; Aguilar 2012, Sloop et al. 2012). Vernal pools and their specialist species are also rare and threatened in the San Francisco Baylands with current distribution severely reduced from historic (Goals Project 2000). This case study addresses the vulnerability of the few remaining San Francisco Baylands seasonal wetland systems and provides ideas for potential climate adaptation strategies.

REVIEW OF CLIMATE CHANGE EFFECTS ON THE HABITAT

Vernal pools as non-persistent emergent wetlands could be affected by a number of climate change impacts, including *changing precipitation and temperature* affecting evapo-transpiration rates that change inundation periods. This will influence annual plant, amphibian and invertebrate life cycles and reproductive success. Shallow pools may be lost due to decreased rainfall and increased temperatures, and deeper pools may decrease in size changing the community composition (Botkin et al 1991). Most vernal pool species are adapted to extreme and changing conditions, where boom reproductive years buffer relatively short periods of drought, and large numbers of long-lived invertebrate cysts and annual plant seeds are stored in the vernal pool soil for a decade or more (Nunney 2002, Aguilar 2012). Amphibians are also long-lived enough to survive drought years, also depending on boom years for successful recruitment (Paton and Crouch 2002). However, in case of severe changes in inundation period or phenology of wet and dry cycles for extended periods, over the long-term this could result in the extinction of species from the pools. Soil seed and cyst reserves may be used up as less and less reproductive propagules are deposited each year from decreasing population sizes. Also, if rainfall is not consistent and sufficient in the winter to keep pools inundated, amphibian larvae will not survive long enough to develop to the terrestrial adult stage (Paton and Crouch 2002). Within a vernal pool complex, inundation period is therefore the best indicator of whether a pool will support amphibians or vernal pool tadpole shrimp, for example, and an array of larger deeper pools among smaller and shallower pools is ideal to support a maximum array of varying species, buffering fluctuating conditions.

Sea level rise will also have a likely detrimental impact on the remaining San Francisco Baylands vernal pool complexes, especially those located adjacent to the Bay at low elevations (EcoAtlas 1998, I. Loredo pers. com.). The main Baylands vernal pool complexes occur behind levees, and are relict from lower sea levels of a century ago or more (Warm Springs complex, and Suisun - Scalley Road vicinity, Nurse Slough, Denverton, Miens Landing vicinity; P. Baye pers. com.). Vernal pool hydrology alterations that will negatively affect vernal pool systems include: 1) levee failure, introducing more saline water into complexes through overtopping or breaching; 2) increased terrestrial flooding in vernal pool-containing lowlands as an indirect effect of stormwater discharge constraints; and 3) backwater effects of high tides and rising groundwater tables relative to rising sea level (and possibly reversed groundwater gradients via artificial groundwater drawdown; P. Baye pers com). Hydrology will therefore change on both sides of levees when sea level rises, permanently changing the soil conditions, or convert the habitat to tidal marsh or subtidal (Botkin et al 1991, P. Baye, pers. com.). Even if not permanently inundated by brackish or saline water, increased salt intrusion to soils may have permanent effects on pool and pan biotic communities as most vernal pool species are not salt tolerant, with some notable exceptions.

FACTORS THAT MAY AFFECT RESILIENCE

Vernal pool specialists can overcome shorter inundation periods caused by changes in temperature and precipitation regimes via current adaptations (soil propagule bank and longevity) and metapopulation dynamics, where larger deeper pools may serve as propagule sources for smaller less resilient pools during boom years. Yet, if inundation regimes are subject to more consistent extreme fluctuations over the long-term (i.e. wet early in season, then drying as no additional rain falls during season, then wet again at end of season due to inconsistent yet extreme storm events) and become more consistently shortened even in larger pools, this will likely spell doom for vernal pool species persistence into the next century.

Dynamics affecting resilience to consider in the near term include the likely loss of adaptive capacity to changes in temperature, precipitation and associated phenology in specialist vernal pool species. This is especially of concern in species with restricted distribution that are isolated from other meta-populations in the area, and/or are surviving in degraded vernal pools, as they may be facing population declines and associated genetic erosion (Reed and Frankham 2003; Aguilar 2012; Sloop et al. 2012). Ultimately, these species may face more near-term extinction unless restoration activities that consider these dynamics in the context of current and future climate change impacts are implemented (Elam, 1998; Foin et al., 1998).

Unless directly managed for persistence in their current low elevation range, Bayland vernal pool complexes will likely be lost to the impacts from sea level rise and associated salinity changes by the end of the century. Some Baylands vernal pools, such as at the Fremont Warm Springs complex are found on natural, slightly saline, alkali soils, and non-native species biomass in these pools may be limited by salinity/alkalinity rather than herbivory. Some Baylands vernal pool plants also occurred in high tidal marsh edges, making them more salt tolerant, including *Lasthenia conjugens*, *L. glabrata* (still present), *Downingia pulchella*, *Castilleja ambigua*, *Plagiobothrys stipitatus*, *P. bracteata*, *Triphysaria versicolor*, *T. eriantha* (P. Baye pers. com.). Therefore, some specialist vernal pool species may be able to withstand at least lower levels of salinity intrusion and persist in more saline soils.

LIKELY CLIMATE CHANGE IMPACTS AND RISKS

- Precipitation and temperature extremes and/or changes will affect the timing of annual emergence and seed set success for plants and the completing of annual life cycles of invertebrates (i.e. vernal pool crustaceans) or amphibians (i.e. California tiger salamander) and decreased population sizes over the long-term may cause erosion of adaptive capacity and resilience of vernal pool species.
- Projected changes in climate conditions, hydrology and phenology will likely cause major shifts in community composition and the loss of biodiversity, especially of narrowly specialized endemic species that may decline and ultimately go extinct.
- Many rare vernal pool annual plants have coevolved specialist pollinators (Thorp and Leong 1998). Extreme weather events and changes in phenology may cause the disassociation of pollinators and plants and contribute to increased reproductive failure.
- Depending on the climate change scenario considered, sea-level rise will at least by 2100 likely cause the loss of low elevation vernal pool or pan systems to below-ground salt water intrusion or surface flooding as levees fail or overtop and groundwater and inland flooding regimes change. If not protected by levees, these low elevation systems will eventually undergo complete inundation and/or be replaced by the upward migration of marshlands. This may also affect slightly higher elevation inland vernal pools as sea level rise progresses upward over the coming century.
- Higher salinity levels in vernal pool complexes associated with sea level rise will be detrimental to amphibians (reduced viability of eggs and tadpoles – depends on species) and to most endemic saline-sensitive vernal pool plants and invertebrates, causing loss of biodiversity.

MANAGEMENT ACTIONS TO BE CONSIDERED

1. To maintain resilience of the vernal pool biotic communities manage for a *heterogeneous pool system* and *large populations* as much as possible (Gilpin and Soulé 1986). This means focusing on supporting an array of pools of varying depths and sizes that help support meta-population dynamics (Hanski 1994),

non-saline conditions and minimizing non-native competitors within pools and surrounding uplands as much as possible to allow for large population sizes of vernal pool native species.

2. Continue to *protect vernal pool complexes from projected tidal inundation* as sea level rises via maintenance of levees or other anthropogenic means. Also address potential issues regarding rising groundwater, impounded floodwaters with no outlet during high tides

3. *Manage all remnant vernal pools and pans in the San Francisco Baylands as high priority conservation targets.* Conserve, enhance, restore all microhabitats to maintain the highest possible level meta-population dynamics to maximize biodiversity and maintain community resilience to changing inundation patterns that might be negatively influenced by non-native annual competitors.

4. *Utilize grazing as a management tool where appropriate* to minimize negative impacts to native pool communities such as lowered pool inundation periods and competitive exclusion from non-native annual plants (Marty 2005). If implemented, grazing regimes must be appropriately designed utilizing suitable grazers and time lines to minimize potential adverse effects. Grazing may not be appropriate in saline/alkaline pools where non-native plants are naturally inhibited by high alkalinity and grazers may in fact cause more harmful impacts than benefits (P. Baye pers. com.). For example, Warm Springs pools are alkali sink, with uncommon subshrubs (*Suaeda moquinii, Arthrocnemum subterminale*), that may be damaged by grazing and soils are clay, very soft when wet and may be poached by cattle trampling (P. Baye pers. com.)

5. *Conduct vernal pool surveys within an adaptive management framework* to gain a better understanding of the status of the system over time, so appropriate management actions can be implemented in the face of projected and realized climate change impacts.

6. *Collect seed material/invertebrate cysts from all extant populations for long-term* ex situ *storage* and potential future reintroduction to higher elevation natural sites or restoration sites. To maximize adaptive capacity via long-term genetic resilience, genetic diversity collections and *ex situ* storage should occur throughout each reproductive season (early, mid and late season) and over several years.

7. *Protect any remaining vernal pools that are at higher elevations/farther from the Bay.* Target vernal pools in Baylands that extend above 21st century sea level rise projections topographically for conservation in concert with sea level rise, and reconnect upland transition zone pool complexes with tidal marsh edges where possible (P. Baye, pers. com).

8. *Evaluate the possibility of translocation of sensitive species and low elevation pool communities*. For pools that are problematic to conserve *in situ* in the face of sea level rise, preserve some component populations individualistically by accommodating them in re-expanded modified estuarine-terrestrial transition zones.

9. *Investigate potential for vernal pool creation/restoration on higher elevation grasslands.* If feasible, restore vernal pool habitat by perching depressional pools in constructed clay pans in more upland transition zones (P. Baye, pers. com).

10. If appropriate, *inoculate depressional clay pan pools in upland transition zone with soil propagules from low elevation pools* (by moving top vernal pool soil layer as appropriate). Incorporate brackish tolerant species reintroductions to terrestrial transition zones with constructed claypan to limit perennial dominance

UNCERTAINTY AND KNOWLEDGE GAPS

- The lack of specific data on San Francisco Baylands vernal pool systems is a major uncertainty in evaluating vulnerability and prioritizing and identifying effective management recommendations.

- The adaptive capacity of highly specialist species living in vernal pool systems is unclear. Since most vernal pool species are already adapted to extremes in inundation and other stochasticities that might affect their persistence and reproductive success in any given year, perhaps they will be able to remain resilient to the changes in temperature and precipitation that are projected.

- The feasibility of vernal pool recreation/restoration in higher elevation transition zones has not been tested, and its potential success is unclear, making these created habitats potential population sinks.

Data Gaps

- San Francisco Baylands vernal pool community composition and distribution. We need a current accounting of the plant and animal species that are found in these pools and determine their conservation status and vulnerability to projected impacts.

- There are no current evaluations of the specific localized threats to these remaining Baylands vernal pool systems, so devising specific management recommendations depend on the attainment of relevant baseline data.

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