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# Influences of annual weather variability on vernal pool plant abundance and community composition

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ABSTRACT

Vernal pools, also termed temporary wetlands, promote key ecosystem services such as floodwater retention and provide unique habitat for many organisms. Despite their ecological value, vernal pools are declining worldwide. Because vernal pools are strongly influenced by variation in annual precipitation that fills the pools, climate change and alterations in precipitation regimes could drastically alter these fragile communities. To understand how annual variation in precipitation and temperature affect vernal pool plant community composition, we examined vernal pool vegetation data collected over a 10 year period. We used native and non-native plant frequencies to explore the dynamics between species frequency and weather variability. We further analyzed fine-scale site topography to explore the effects of spatial variability on ponding. We identified key differences between native and non-native plant species' responses to weather variability and ponding. Over all, most native species tended to respond positively to precipitation accumulations in the early growing season, but some native species frequencies were negatively associated with precipitation accumulations in the late growing season. Some non-native species were negatively associated with increases in precipitation in either the early or late growing season. Inundation appears to act as an ecological filter, impairing the establishment of some non-native species. In addition, elevation was a predictor of ponding—lower elevation pools tended to have higher clay concentrations and promote greater ponding depths, which could enhance the effects of the inundation filter. Together, these findings will assist conservation and management efforts in understanding the climatic and physical factors that influence vernal pool plant community ecology.



## 1. Introduction

Vernal pools, which are also referred to as temporary ponds or ephemeral wetlands, are seasonal wetlands commonly found in Mediterranean climates throughout the world (Keeley and Zedler, 1998; Deil, 2005; Williams, 2006; Collinge and Ray, 2009; Fraga i Arguimbau, 2009). These ecosystems typically experience distinct and reoccurring wet and dry phases, often on an annual cycle. The flora in vernal pools consists largely of annual plant species that germinate during the wet phase and reproduce during the dry phase (Deil, 2005). For example, during the wet winter months, vernal pools in California fill with precipitation and flood. The winter rains cue seeds to germinate and produce seedlings that grow and develop under inundation (Keeley and Zedler, 1998; Collinge and Ray, 2009). As winter rains gradually subside and temperatures begin to increase, water evaporates from the pools in the spring and the predominately annual plants quickly develop, flower, and disperse their seeds prior to or during the summer-autumn dry phase (Collinge and Ray, 2009). The seeds remain in the seed bank throughout the dry months, a mechanism which facilitates propagule survival during unfavorable conditions (Zedler, 2003; Faist et al., 2013), and the vegetative life cycle begins anew with the onset of the winter rains.

Vernal pools provide an array of ecosystem services (McGreavy et al., 2012). Vernal pools act as basins for retaining floodwaters, help recycle nutrients while sequestering toxins, and promote the renewal of ground water (Rhazi et al., 2012). Vernal pools are also home to and support a wide range of endemic flora and fauna. For instance, California's vernal pool communities are made up of over 60 endemic taxa of animals and plants—many of which are rare or in danger of extinction (Croel and Kneitel, 2011).

Despite their ecological value, vernal pools are declining across the globe (Rhazi et al., 2012). In the Central Valley of California in particular, 60–85% of the vernal pools have been destroyed since

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the mid to late 1800s (King, 1998). Two major threats linked to the degradation of vernal pools are well documented: habitat loss and species invasions. In recent years, agricultural development in the Central Valley has surpassed urbanization as the lead cause of vernal pool habitat loss. Much of this development is due to agricultural shifts from traditional field crops like grains to higher priced crops produced in orchards and vineyards (Sleeter, 2008; AECOM, 2009). Of the remaining vernal pools, invasion by non-native species has resulted in significant declines in vernal pool native plant communities. Reports indicate that invasive plants have been observed encroaching into Central Valley vernal pools (Pollak and Kan, 1998; Collinge et al., 2011).

The third, often overlooked, factor that may contribute to shifts in vernal pool plant abundance and composition is increased annual weather variability, potentially resulting from climate change. Plant species around the world are responding to climate change by undergoing range shifts (changes in distribution) and phenological shifts (Walther et al., 2002; Parmesan and Yohe, 2003). Yet despite these general trends, little is known about how plant species found within vernal pools may respond to the changes brought about by climate change. Climate change is projected to result in temperature and precipitation shifts in the Central Valley (Hayhoea et al., 2004; Cayan et al., 2009). Water is a vital element to vernal pool communities and many vernal pools are entirely dependent upon precipitation as the sole source of water (Jokerst, 1990). Year to year precipitation fluctuations often result in different plant community compositions (Bauder, 2005). Because vernal pool plant communities depend upon inundation, climate change may act as a threat to their persistence (Pyke, 2005) and may increase the risk of extinction for many threatened or endangered vernal pool obligate plant species (Bauder, 2005).

In an effort to restore native plant communities and ecosystem function in degraded vernal pool communities, 256 experimental vernal pools were constructed on Travis Air Force Base (TAFB) near Fairfield, CA (38° 15′ 00″ N, 122° 00′ 00″ W, 6 m elevation) in 1999 as part of a mitigation effort (Collinge and Ray, 2009). The constructed pools were designed to mimic naturally occurring vernal pools found on TAFB (Collinge and Ray, 2009). Despite the protected habitat on TAFB, native plant abundance has dropped dramatically over the last seven years and non-native species have encroached upon native species within the constructed vernal pools (Collinge et al., 2013). Data suggest that the decline in native plant abundance may be partially explained by extreme weather events in 2006 and 2007. Climate projections for this region suggest that such extreme weather events may become more frequent and intense in the future. Our aim in this study was to better understand how weather variability and spatial variability affect the composition of vernal pool flora. We set out to answer the following two questions: (1) Do changes in annual temperature and precipitation affect the frequency of native and non-native species found in vernal pools? and (2) Does site specific topography, specifically pool elevation and soil type, affect ponding and contribute to changes in community composition within individual vernal pools in the research area?

## 2. Methods

### 2.1. Field data collection

We examined plant species frequency data collected for native and non-native plant species found within the 256 constructed vernal pools on TAFB from 2002 to 2012. We excluded the 2000–2001 frequency data because a portion of the constructed pools were still undergoing seeding treatment during this time period. All seeding treatments were completed by the 2002 growing season.

**Table 1**
A summary of the eleven focal species used in this study (Collinge et al., 2013; plants.usda.gov).

| Species Name | Family | Type | Common Name |
|---|---|---|---|
| Native species | | | |
| *Deschampsia danthonioides* | Poaceae | Grass | Annual hairgrass |
| *Downingia concolor* | Campanulaceae | Forb | Maroonspot calicoflower |
| *Hemizonia pungens* | Asteraceae | Forb | Common spikeweed |
| *Lasthenia conjugens* | Asteraceae | Forb | Contra Costa goldfields |
| *Plagiobothrys stipitatus var. micranthus* | Boraginaceae | Forb | Stalked popcornflower |
| Non-native species | | | |
| *Bromus hordeaceus* | Poaceae | Grass | Soft brome |
| *Erodium botrys* | Geraniaceae | Forb | Longbeak stork's bill |
| *Hordeum marinum* | Poaceae | Grass | Mediterranean barley |
| *Lolium multiflorum* | Poaceae | Grass | Italian ryegrass |
| *Vicia villosa* | Fabaceae | Forb | Winter vetch |
| *Vulpia bromoides* | Poaceae | Grass | Brome fescue |

Species frequency data were collected every spring (April–May) under similar conditions; after water had evaporated from the pools and during peak flowering. Frequency data were collected by positioning a 0.5 × 0.5 m grid frame divided into 100 cells over a permanently marked plot found within each of the 256 constructed vernal pools. All the occurring plant species found within the perimeter of the frame were identified using Hickman (1993) and their frequency (the total number of cells out of 100 in which a species was present) was recorded (Collinge and Ray, 2009).

We selected 11 focal plant species for this study. We selected only annual species to allow for a meaningful comparison of germination and life cycle patterns between native and non-native species. The other potential focal native species in the study area (*Eryngium vaseyi* J.M. Coult. & Rose) was excluded because it is a perennial. These focal species were present in the greatest number of constructed pools over the duration of the study and include 5 native species: *Deschampsia danthonioides* Munro, *Downingia concolor* Greene, *Hemizonia pungens* Gray, *Lasthenia conjugens* Greene, and *Plagiobothrys stipitatus var. micranthus* Greene and six non-native species: *Bromus hordeaceus* Kerguélen, *Erodium botrys* Bertol, *Hordeum marinum* Thell, *Lolium multiflorum* Lam, *Vicia villosa* Roth, *Vulpia bromoides* Gray (Table 1). We compiled frequency data for all eleven focal species. We then calculated annual arithmetic mean frequency values for the focal plant species by averaging the frequency of each species across all 256 constructed pools for each year.

### 2.2. Growing season data

We initially used the entire annual growing season (October–March) precipitation and temperature data to examine the effects of these abiotic factors on the annual focal species frequency data. This process proved uninformative and so we considered the results of a previous greenhouse study (Gerhardt and Collinge, 2007) that examined the effects of inundation on vernal pool plant communities, to help identify key annual growing season time intervals that were most appropriate to use for this study. These results suggested that inundation affects the different life stages of the vernal pool vegetative communities. Two stages were particularly affected: (1) plant development and survival and (2) plant growth and reproduction. The first half of the growing season is characteristic of vegetative development and survival at the study site, whereas plants typically grow and reproduce during the second half of the growing season. Thus,