

Plant Ecology of Arid-land Wetlands; a Watershed Moment for Ciénega Conservation

by

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## ABSTRACT

It's no secret that wetlands have dramatically declined in the arid and semiarid American West, yet the small number of wetlands that persist provide vital ecosystem services. Ciénega is a term that refers to a freshwater arid-land wetland. Today, even in areas where ciénegas are prominent they occupy less than 0.1% of the landscape. This investigation assesses the distribution of vascular plant species within and among ciénegas and address linkages between environmental factors and wetland plant communities. Specifically, I ask: 1) What is the range of variability among ciénegas, with respect to wetland area, soil organic matter, plant species richness, and species composition? 2) How is plant species richness influenced locally by soil moisture, soil salinity, and canopy cover, and regionally by elevation, flow gradient (percent slope), and temporally by season? And 3) Within ciénegas, how do soil moisture, soil salinity, and canopy cover influence plant species community composition? To answer these questions I measured environmental variables and quantified vegetation at six cienegas within the Santa Cruz Watershed in southern Arizona over one spring and two post-monsoon periods. Ciénegas are highly variable with respect to wetland area, soil organic matter, plant species richness, and species composition. Therefore, it is important to conserve the ciénega landscape as opposed to conserving a single ciénega. Plant species richness is influenced negatively by soil moisture, positively by soil salinity, elevation, and flow gradient (percent slope), and is greater during the post-monsoon season. Despite concerns about woody plant encroachment reducing biodiversity, my investigation suggests canopy cover has no significant influence on ciénega species richness. Plant species community composition is structured by water availability at all ciénegas, which is

consistent with the key role water availability plays in arid and semiarid regions. Effects of canopy and salinity structuring community composition are site specific. My investigation has laid the groundwork for ciénega conservation by providing baseline information of the ecology of these unique and threatened systems. The high variability of ciénega wetlands and the rare species they harbor combined with the numerous threats against them and their isolated occurrences makes these vanishing communities high priority for conservation.

## DEDICATION

Dedicated to Canyon Wolkis with profound gratefulness for understanding when his Dad had to stop playing – even when we were stacking blocks.

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## INTRODUCTION

Globally, half of all wetlands have vanished because of anthropocentric activities (Zedler & Kercher 2005), and 6% was lost from 1993 – 2007 (Prigent et al. 2012). In some regions of the arid and semiarid American West, meadows and wetlands have declined by 95% (Dilts et al. 2012). The remaining wetlands occupy only a small percentage of the landscape, yet provide vital ecosystem services (Zedler & Kercher 2005).

Niering (1985) defines wetlands as areas “where water is the primary factor controlling the environment and the associated plant and animal life.” The United States Fish and Wildlife Service (USFWS) define wetlands as “lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water.” They must have one or more of the following three attributes: “1) at least periodically, the land supports predominantly hydrophytes (plants that grow in water); 2) the substrate is predominantly undrained hydric soil (wet and periodically anaerobic); and 3) the substrate is nonsoil and is saturated with water or covered by shallow water at some time during the growing season of the year.” (Cowardin et al. 1979). Wetlands can be further classified based on factors including dominant water source (e.g. groundwater, surface water), position in the landscape (e.g., depression, lacustrine fringe, riverine fringe), and hydroperiod (percent of time inundated) (Detenbeck 2002).

Cowardin and Golet (1995) state, “no single system can accurately portray the diversity of wetland conditions world-wide. Some important ecological information inevitably will be lost through classification.” Ciénega is a term brought to the Americas

by Spanish explorers to refer to a freshwater marshland. While ciénegas have yet to be adequately classified as a wetland type, the landmark paper by Hendrickson and Minckley (1984) describes them as a regionally endangered type of freshwater wetland occurring between 1000-2000 meters in elevation, and they provide a host of attributes to parse ciénegas from alpine meadows and riverine marshlands (Table 1). Historically, these groundwater-fed wetlands were abundant within the Sky Island Region of southeastern Arizona, southwest New Mexico and northern Mexico (Hastings 1959). Today, even in areas where ciénegas are prominent, such as the Las Ciénegas National Conservation Area, they occupy less than 0.1% of the landscape (Salywon et al. 2012).

Minckley et al. (2013) mapped the historic and current distribution of ciénegas within Arizona, New Mexico and Northern Mexico, and documented substantial regional decline. Of 60 ciénegas studied, 46 were considered to be extant. Although they reportedly have low alpha diversity of plants, they sustain many imperiled plants, fish, amphibians, and mollusks (Minckley et al. 2013). La Cebadilla Ciénega, for example, may be a last refugium for ciénega plant species within Pima County (Pima County 2002).

### ***Factors Contributing to Decline and Alteration of Ciénegas***

Many factors have contributed to the decline of ciénegas. Historical land uses in the watersheds, including overgrazing, have converted many grass-covered slopes to eroded scrublands. These changes in soil and plant cover altered patterns of water infiltration and runoff, and the ensuing increase in flood intensity and reductions in stream base flows fundamentally changed the nature of many ciénegas. Groundwater

pumping, surface water diversion, stream channel incision, and extirpation of beavers have reduced the water available to many ciénegas, in some cases causing complete loss of the wetlands (Minckley et al. 2013). Recent drought conditions have exacerbated the problem. Much of the Southwest has been in a prolonged drought for the past decade, and climate change models predict that aridity will increase (Seager et al. 2012). Studies examining or predicting effects of increasing aridity exist for various wetland types globally (Werner et al. 2013), but not for Southwestern ciénegas.

Table 1. Attributes of three types of wetland habitats of the American Southwest.

<b>Attributes</b>	<b>Alpine Meadowlands</b>	<b>Ciénegas</b>	<b>Riverine Marshes</b>
<b>Altitude (m)</b>	> 2,000	1,000-2,000	<1,000
<b>Drainage position</b>	headwaters	headwaters and low-order streams	high order streams
<b>Climatic factors</b>	complete winter snow cover alternate freezing/thawing	brief hillslope snow cover only occasional insignificant freezing (brief edge ice only)	no snow no freezing
<b>Discharge characteristics</b>	no scouring floods	low probability of scouring floods	higher probability of scouring floods
<b>Channel structure control</b>	little	relatively tight by bounding ranges	little, bounding ranges distant
<b>Position in channel</b>	bank to bank	along edge, leaving channel or may cover channel	edge, backwaters, oxbows; substantial open water
<b>Surface water ephemerality</b>	perennial to briefly ephemeral	perennial	perennial
<b>Edaphic factors</b>	soils saturated, may dry seasonally	soils permanently saturated;soils perennially anoxic-reducing; generally high organic content in soils; low	soils permanently saturated lower levels soil anoxia-oxidizing lower organic

		percolation rates, but may be inter-bedding of coarser lenses	content in soils higher percolation rates
<b>Vegetation</b>	low, emergent sedges; grasses; riparian shrubs (Salix, Alnus)	low, emergent sedges; riparian trees (Salicaceae)	tall, emergent vegetation ( <i>Typha</i> spp.)
<b>Relative longevity</b>	long	intermediate	short

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**Reproduced from Hendrickson and Minckley (1984).**

Woody vegetation is increasing in many types of ecosystems historically vegetated by grasses or forbs (Villarreal et al. 2013). A synthesis of 20 years of research concluded that “Woody plant expansion is one of the greatest contemporary threats to mesic grasslands of the central United States” (Briggs et al. 2005) while a meta-analysis on 29 studies concluded that woody plant encroachment significantly decreases species richness (Ratajczak et al. 2012). For Bingham Ciénega in the San Pedro Valley of Arizona, comparison of 1879 General Land Office survey data with 1998 conditions revealed that grasslands and mesquite-savannas were replaced by agriculture and mesquite (*Prosopis*) woodlands, and that an ash (*Fraxinus*) woodland had established in the ciénega after 1879 (Fonseca 1998). The regional increases in woody vegetation have been variously attributed to increased CO<sub>2</sub> levels, increases in winter precipitation, high intensity grazing, and reduced fire frequency (Morgan et al. 2007; Munson et al. 2013; Brunelle et al. 2013). Within river floodplains, the changes have been linked with dam-related reduction in frequency and intensity of scouring floods (Shafroth et al. 2002; Stromberg et al. 2010).

Another factor contributing to wetland loss has been beaver management. In an effort to drain wetlands, beavers were killed and nearly extirpated from the San Pedro River by the 1900's (Tellman & Huckleberry 2009). Today, beaver populations are increasing (Martin et al. 2015) from near extirpation from commercial trapping and nuisance management (Carrillo et al. 2009), and Johnston (2015) suggests they are highly resilient after examining 150 years of beaver pond data. As a keystone species they play a strong role in structuring wetland plant communities by inhibiting woody plant regeneration, increasing sedimentation and areas of ponded water, and assisting in nutrient cycling (Martin et al. 2015; Gibson & Olden 2014).

### ***Environmental Influences on Wetland Plant Communities***

Keddy (2010) states, "...the number one priority of wetland ecologists has been and would be the development of quantitative models linking wetland community structure to hydrological variables." He suggests that hydrology is the most important environmental factor structuring wetland plant communities, followed by soil fertility, salinity, disturbance, competition, grazing, and burial (sediment covering a plant) (Table 2).

Table 2. The estimated relative importance of environmental factors that determine the properties of wetlands. These can be considered the key filters for assembling wetlands from species pools.

Environmental Factor	Relative Importance (%)
Hydrology	50
Fertility	15
Salinity	15
Disturbance	15
Competition	<5
Grazing	<5
Burial	<5

Reproduced from Keddy (2010).

Keddy's assessment of the importance of hydrology and soil moisture to wetland vegetation is echoed around the globe. Topography, as it regulated soil moisture, was the strongest driver of plant diversity patterns in wet and dry grasslands in Europe (Moeslund et al. 2013). Seasonal changes in soil moisture potential was the most influential factor influencing plant communities of vernal pools in western North America (Crowe et al. 1994). Water level had a strong influence on species composition in freshwater marshes, by differentially affecting species germination (Kellogg et al. 2003). In arid and semiarid Arizona, Stromberg et al. (1996) demonstrated that plant communities of river floodplains vary along gradients of depth to groundwater while herbaceous wetland communities along the channel vary in composition and diversity depending on the permanence of stream flow (Stromberg et al. 2005). Also in Arizona, Cross (1991)

demonstrated the importance of water availability as an influence on ciénega wetland plants, and also differentiated between groups of herbaceous species affiliated with wet, ciénega conditions (e.g. *Muhlenbergia asperifolia*) and those affiliated with wet streamside conditions (e.g., *Persicaria fusiforme*). Depth of standing water exerts control on vegetation in ciénegas, owing in part to difference in plant tolerance to anoxia (Yatskievych and Jenkins 1981).

The United States Department of Agriculture (USDA) and much of the world use an electrical conductivity (EC) threshold of 4 dS/m to classify saline soils, and a threshold of 15% for the exchangeable sodium percentage (ESP) to classify sodic soils (USDA 2015). Salinity can affect wetlands by decreasing plant growth rates and reducing species richness (Keddy 2010), and can increase in wetlands because of factors such as high evaporation and evapotranspiration rates, low flooding and scouring, and geologic formations. Bui (2013) argues that soil salinity is a major driver of plant community composition in arid and semiarid environments worldwide, and cites soil salinity as a contributing factor of woody encroachment into grasslands. Saline soils often occur in seasonally inundated lowlands and are often associated with wetlands. Ten percent of the Earth's lands may be affected by soil salinization (Schofield and Kirby 2003).

Salinity may have a significant influence on plants and plant communities. For example, in experiments by Howard and Mendelssohn (1999), increased salinity reduced growth in *Eleocharis palustris*, *Panicum hemitomon*, *Sagittaria lancifolia*, and *Schoenoplectus americanus*. Out of the four species, *Eleocharis palustris* and *Schoenoplectus americanus* had the highest salt tolerances. As salinity increases in salt marshes, the number of germinating species decreases (Baldwin et al. 1996). Twenty-

nine species of halophytes common in salt marsh plant communities of New Zealand were found to require no saline solution to survive and most species grew better under freshwater conditions (Partridge and Wilson 1987). Spring and summer electrical conductivity decreased with increasing dryness of soil (Crowe et al. 1994). Soil salinity is the driving factor that explains obligate salt marsh and federally listed species, *Helianthus paradoxus*' narrow endemism (Bush and Van Auken 2004).

Canopy cover influences understory vegetation by altering light levels, microclimate, and litter cover depth. In wetlands canopy cover has been shown to influence composition of the herbaceous understory: at Canelo Hills Ciénega, *Berula erecta* and *Nasturium officinale* were common under canopy while *Eleocharis macrostachya* and *Muhlenbergia asperifolia* were common in open areas (Cross 1991). Areas with dense canopy can be unfavorable to establishment and flowering of various types of plants, including some endangered species (Hammons et al. 2010).

### ***Influences on Plant Species Diversity***

A well-documented global pattern in biodiversity is that species richness increases with decreasing latitude (Gaston 2000). For example Junk et al. (2006) report that species of flood tolerant trees increase from 10 in northern Canadian peatlands to 100 in Mississippi River Wetlands, to 1000 in the Amazon, and Gentry (1988) finds significantly more plant species per 0.1 ha plot in lowland neotropical forests than in temperate forests. However, Crow (1993) suggested species richness in aquatic plants is higher in temperate zones compared to the tropics, and in the family Cyperaceae, Junk and Piedade (1994) find the same pattern (Keddy 2010). Richness also varies with

elevation: In the Santa Catalina Mountains of Arizona, Whittaker & Niering (1965) find that as elevations decrease, plant species diversity increases.

Species richness is also associated with area, topographical variation, and microtopography. For example, MacArthur and Wilson (1967) found that species richness increases with increasing area (MacArthur and Wilson 1967). Findlay and Houlihan (1997) determined that plant species richness increases with wetland area, and Keddy (2010) showed that species richness increases as topographical variation increases. A study examining factors that drive grassland diversity found topography to be an important determinant (Moeslund et al. 2013), and Zedler (2000) suggests wetland microtopography can significantly alter species richness.

Other key factors influencing diversity are resource availability and disturbance frequency (intermediate productivity hypothesis and intermediate disturbance hypothesis, respectively) (Huston et al. 2014). In arid regions, plant species diversity along rivers peaks at intermediate levels of water availability (Stromberg et al 2008; Katz et al. 2012), and flood disturbance in riverine wetlands typically serves to increase richness, as suggested by declines in species plant richness below flood-regulating dams.

### ***Questions***

More investigations into the ecology and floristics of ciénega ecosystems are needed. There have been a few studies of plant –environmental relationships within individual ciénegas (Yatskievych and Jenkins 1981; Titus and Titus 2008) but comparative ecological studies for multiple ciénegas within a watershed has not been undertaken. Sivinski and Tonne (2011) completed floristic surveys of many ciénegas in

New Mexico. Within Arizona, floras and plant lists have been compiled for approximately 15% of the known extant ciénegas (Collins et al. 1981; Fernald 1987; Cross 1991; McLaughlin 1992; Fonseca 1998; Makings 2013). There has been no regional synthesis of plant distribution patterns. Hendrickson and Minckley (1984) provide a regional list of plant species commonly found in ciénegas, but do not indicate which species have high fidelity to ciénegas and could serve as ciénega indicator species.

Efforts to conserve and restore ciénegas will be facilitated by studies which assess the distribution of biotic organisms within and among ciénegas and that address linkages between environmental factors and wetland plant communities. My overarching question is, how do environmental variables influence plant communities of ciénegas?

Specifically, I ask: 1) What is the range of variability among ciénegas with respect to wetland area, soil organic matter, plant species richness, and species composition (including beta diversity and dominant plant species)? 2) How is plant species richness influenced locally by soil moisture, soil salinity, and canopy cover, and regionally by elevation, flow gradient (percent slope), and temporally by season? And 3) Within ciénegas, how do soil moisture, soil salinity, and canopy cover influence plant species community composition? Given that plant diversity tends to peak at intermediate levels of water availability, I expect that species richness will be greater during the summer wet season (vs. dry season), and will increase with increasing soil moisture until a threshold is reached at which point diversity will begin to decrease. Because lower elevations tend to have higher species pools, and dense canopy cover may be unfavorable to many plant species, I predict decreasing elevation and canopy cover will increase plant diversity. I expect the most influential factor structuring plant community composition will be water

availability given that water is a primary limiting factor in arid and semiarid regions. Soil salinity, and canopy cover will have less influence on plant community composition.

By answering these questions, my investigation will produce several deliverables including 1) plant checklists for sampled ciénegas including museum quality herbarium voucher specimens with data uploaded to the regional database of herbarium specimens, the Southwest Environmental Information Network (SEINet, <http://www.swbiodiversity.org/seinet>) and, 2) a description of the range of reference conditions for restoration professionals to utilize in revegetation and restoration efforts. Additionally, this investigation has implications for restoring freshwater ecosystems in a changing climate: examination of sites that range from high water availability to drought impacted, allows me to draw inferences about effects of increasing aridity on plant species composition, and distribution.

## **STUDY SITES**

My study design can be viewed as a natural field experiment. Field sites consist of six ciénegas within the Santa Cruz watershed (5<sup>th</sup> level Hydrologic Unit Code) (Seaber et al. 1987) of southern Arizona, USA (Fig. 1). The sites span a range of physical conditions ranging in elevation from 825 to 1880 m and in mean annual temperature from 14 to 20°C.

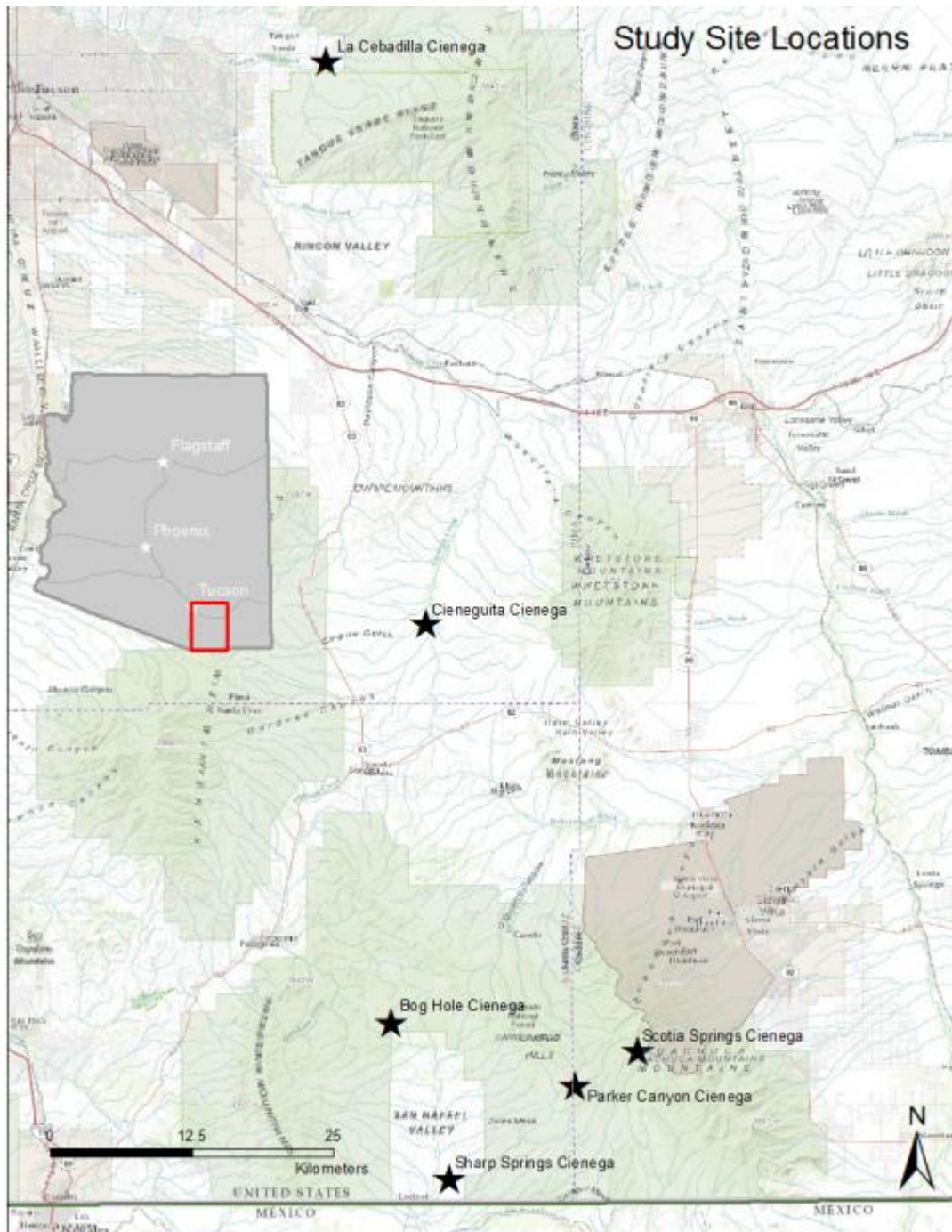


Figure 1. Map of study site locations.

### ***Bog Hole Ciénega***

Bog Hole Ciénega is located South of Patagonia in the San Raphael Valley, AZ (31.477440°, -110.629921°) (Figs. 2 & 3) on a headwater tributary to the Santa Cruz River. This tributary experiences an intermittent flow regime consisting of occasional completely dry periods in the spring, followed by large volumes of standing water in the fall as a result of monsoon precipitation run-off accumulating behind a large earthen berm which was installed at the southern end of the ciénega sometime prior to 1993 (The installation date and original purpose of the berm are unknown; Personal Communication, John Kraft, Coronado National Forest, Sierra Vista Ranger District 2015). The ciénega is 5.7 ha in area. On its downstream (southern end) it is bordered by the artificial berm and on its upper end by two stream channels. *Populus fremontii* and *Salix gooddingii* are common around the perimeter. Signs of a recent fire are evident from the charring patterns on the *Populus* trees and burnt organic matter found in the interior. Bog Hole is surrounded by Coronado National Forest, and is managed by Arizona Game and Fish Department as a protected wildlife area (Table 4). Bird abundance is high and the call of a willow flycatcher was heard in Fall 2013 (Personal Communication Julie Stromberg 2013).

Table 3. Special status species at Bog Hole Ciénega managed by Arizona Game and Fish Department. LE = Listed Endangered. LT = Listed Threatened. SC = Species of Concern. S = Sensitive. S1 = State critically imperiled. WSC = Wildlife of Special Concern in Arizona. Available from <http://azgfdportal.az.gov/wildlife/viewing/wheretogo/boghole>.

Common Name	Scientific Name	Status
<b>Amphibians</b>		
Chiricahua leopard frog	<i>Rana chiricahuensis</i>	LT, S, WSC
Lowland leopard frog	<i>Rana yavapaiensis</i>	SC, S, WSC
Sonoran tiger salamander	<i>Ambystoma tigrinum</i>	LE, WSC
<b>Birds</b>		
Baird's sparrow	<i>Ammodramus bairdii</i>	SC, WSC
Mexican spotted owl	<i>Strix occidentalis lucida</i>	LT, S, WSC
Sprague's pipit	<i>Anthus spragueii</i>	WSC
<b>Fish</b>		
Gila topminnow	<i>Poeciliopsis o. occidentalis</i>	LE, WSC
Longfin dace	<i>Agosia chrysogaster</i>	SC, S1
<b>Plants</b>		
Mock-pennyroyal	<i>Hedeoma dentata</i>	S
<b>Reptiles</b>		
Mexican Gartersnake	<i>Thamnophis eques</i>	SC, S, WSC



Figure 2. Bog Hole Ciénega facing north, Fall 2013. Large trees in background are *Populus fremontii*.



Figure 3. Aerial imagery (NAIP 2013) of Bog Hole Ciénega. Shown at 1:1,800 scale. Image captured 7 June 2013. Perimeter shown in white.

### *Cieneguita Ciénega*

Cieneguita Ciénega is located north of Sonoita, AZ in Las Ciénegas National Conservation Area managed by the Bureau of Land Management (BLM 2015) (31.796207°, -110.595668°) (Figs. 4 & 5). Elevation is ca. 1340 m and area is 4.4 ha. Three artificial ponds have been constructed and bullfrog exclosures erected to provide habitat to federally listed endangered amphibians. Excluding the artificial ponds, Cieneguita has only small areas with standing water throughout the year.



Figure 4. Cieneguita Ciénega facing west, Fall 2013.



Figure 5. Aerial imagery of Cieneguita Ciénega (NAIP 2013). Shown at 1:3,300 scale. Image captured 7 June 2013. Perimeter shown in white.

### ***La Cebadilla Ciénega***

La Cebadilla Ciénega is located east of Tucson, Arizona along Tanque Verde Wash in a private residential neighborhood making it possibly the most protected, yet unregulated of my field sites (32.244268°, -110.687974°) (Figs. 6 & 7). It is 1.3 ha in area, and elevation is ca. 825 m, making this site lowest in elevation and precipitation. Prior to 1987 an artificial berm running through the center of the site was installed. Its purpose is theorized to prevent water loss but the actual purpose is unknown (Julia Fonseca, Environmental Planning Manager, Pima County Office of Sustainability and Conservation; personal communication 2015). One small and one larger ephemeral pond dry during the spring and fill with water in the post-monsoon fall. A concrete spring box, a structure designed to utilize spring water, is located in the site and some water is diverted from the site to a large nearby artificial pond visible from the roadway. La Cebadilla harbors one of the only known locations of critically imperiled (Natureserve 2014) *Eryngium sparganophyllum*.



Figure 6. La Cebadilla Ciénega, Fall 2014



Figure 7. Aerial imagery (NAIP 2013) of La Cebadilla Ciénega. Shown at 1:700 scale. Image captured 7 June 2013. Perimeter shown in white.

### *Parker Canyon Ciénega*

Occupying the stream channel and flood plain directly below Parker Canyon Lake Dam, Parker Canyon Ciénega is located South of Canelo, Arizona in the Coronado National Forest (31.427319°, -110.458333°) (Figs. 8 & 9). Elevation is ca. 1620 m., and area is 0.8 ha. Water seeping from rock canyon walls is visible through out Parker Canyon Ciénega. *Salix bonplandiana* is prevalent in the site, and the southern border is comprised or an artificial berm creating a *Lemna minor* dominated pond.



Figure 8. Interior of Parker Canyon Ciénega, Fall 2013.



Figure 9. Aerial imagery (NAIP 2013) of Parker Canyon Ciénega. Shown at 1:1,100 scale. Image captured 7 June 2013. Perimeter shown in white.

### *Scotia Springs Ciénega*

Located on the south side of the Huachuca Mountains, Scotia Springs Ciénega is a series of three disjunct pools in Scotia Canyon (31.457101°, -110.397552°) (Figs. 10 & 11). Combined area is 0.1 ha, and elevation is ca. 1880 m, making this site the highest in elevation and precipitation. The federally endangered (USFWS 1997) *Lilaeopsis schaffneriana* var. *recurva* was found at this site in spring 2014. Water is perennial at the most upstream and largest pond, while water intermittently flows through the lower most pond. *Pinus cembroides* and *Juniperus deppeana*, are common around the outskirts of the site.



Figure 10. Scotia Springs Ciénega facing North at upstream pond, fall 2013.

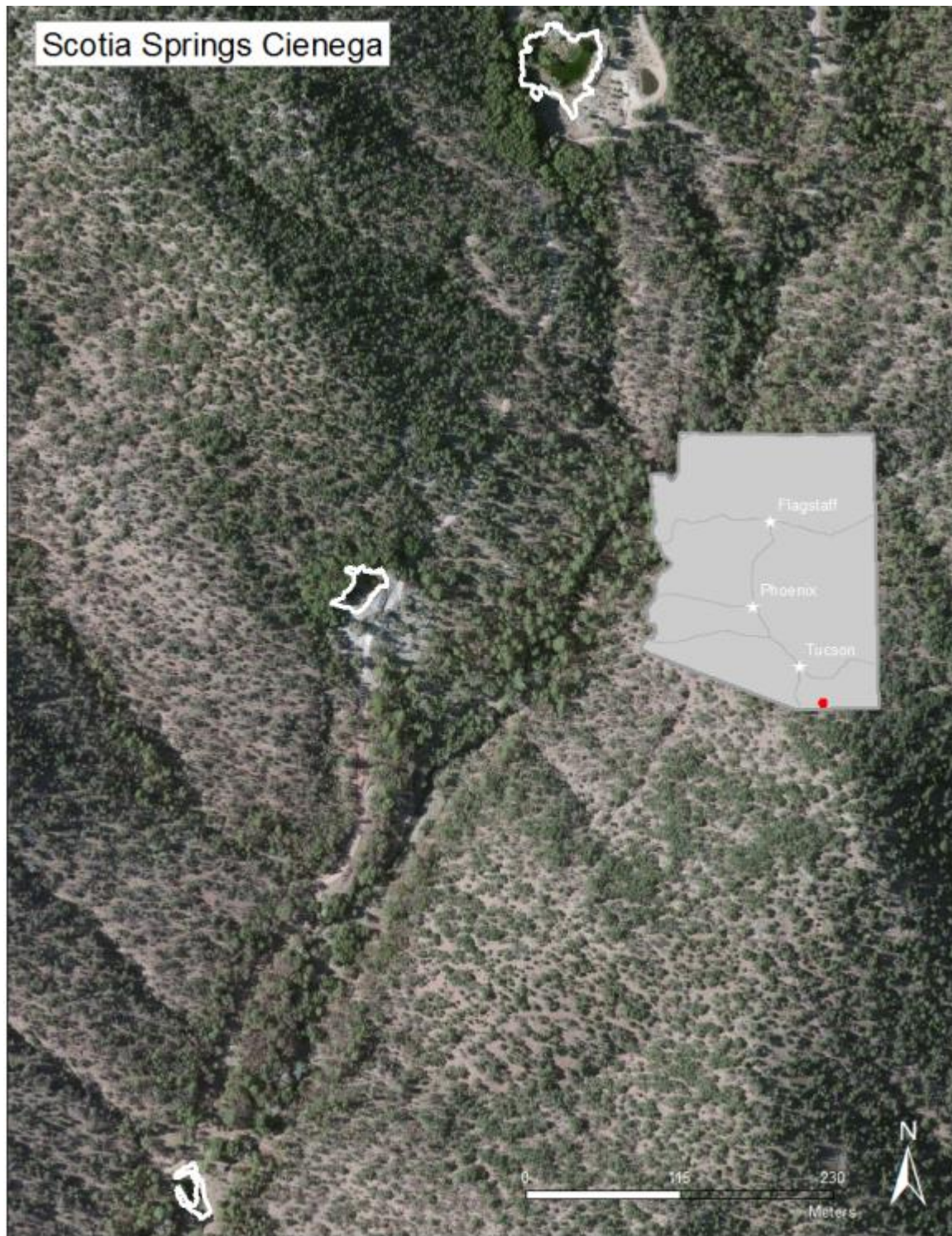


Figure 11. Aerial imagery (NAIP 2013) of Scotia Springs Ciénega. Shown at 1:3,300 scale. Image captured 7 June 2013. Perimeter shown in white.

### *Sharp Springs Ciénega*

East of Lochiel, AZ and 2000 m from the Arizona – Sonora border, Sharp Springs Ciénega is positioned at 31.352867°, -110.576261° (Figs. 12 & 13). It is 6.5 ha, making this the largest of my study sites. This ciénega is located in the San Raphael Valley and is managed by Arizona State Parks. Sharp Springs serves as a historic population for the federally endangered (USFWS 1997) *Lilaeopsis schaffneriana* var. *recurva*, though I was not able to relocate the plant. Elevation is ca. 1440 m. Surface water flows intermittently through the site, and cattle actively graze.



Figure 12. Sharp Springs Ciénega facing south, in Fall 2013.



Figure 13. Aerial imagery (NAIP 2013) of Sharp Springs Ciénega. Shown at 1:5,500 scale. Image captured 7 June 2013. Perimeter shown in white.

## METHODS

### *Field*

Field data were collected during one pre-monsoon and two post-monsoon seasons from August 2013 to October 2014. During this time annual average temperature in southern Arizona was 21.7°C, 1.4°C higher than the 100 year average (Fig. 14). Also during this time, southern Arizona was experiencing the fourth year of a continuous drought, and has been in a long-term drought for the past 20 years (Fig. 15)(NOAA 2015).

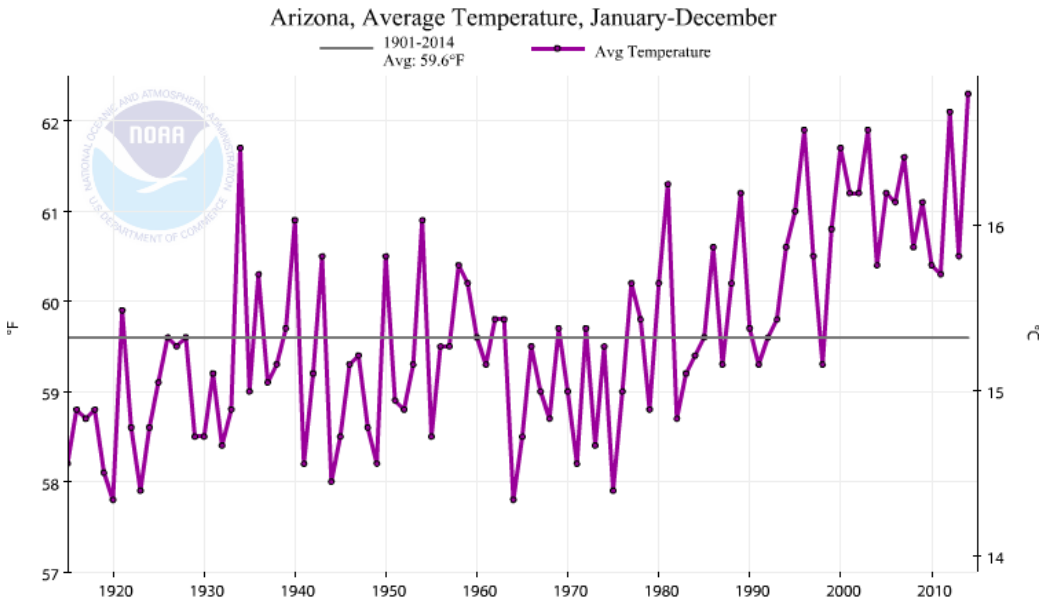


Figure 14. Average annual temperature for southern Arizona. Data from National Oceanic and Atmospheric Administration National Centers for Environmental Information (<https://www.ncdc.noaa.gov/cag/>).

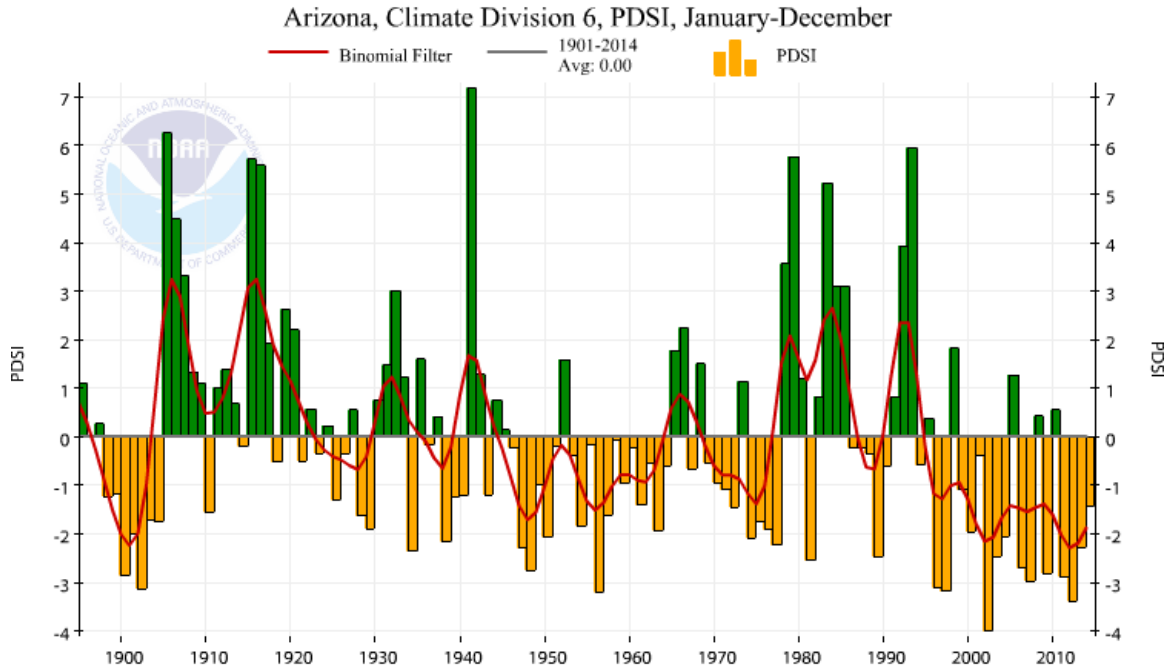


Figure 15. Palmers Drought Severity Index for southern Arizona. Data from National Oceanic and Atmospheric Administration National Centers for Environmental Information (<https://www.ncdc.noaa.gov/cag/>).

Within each ciénega, I quantified plant cover by species at 30 randomly selected 1x2 meter quadrats per sampling. I measured cover using a modified Braun-Blanquet scale (Table 4). To randomize the 30 quadrats, I first constructed polygons of study areas using a survey grade hand-held global positioning system (GPS) unit (Topcon GRS-1) and walked the boundary between upland and wetland vegetation. Once the polygons were entered into a geographic information system (GIS), I used ArcGIS to create a set of spatially balanced random points at each site. The point shapefiles were transferred to a consumer grade hand held GPS unit (Garmin eTrex 20) using the DNRGPS application available from Minnesota Department of Natural Resources. The consumer grade GPS unit was used to navigate to the pre-randomized points. The quadrats span a range of conditions from saturated soil to the mesic wetland fringe, and from full sun to shaded.

In each quadrat I measured soil moisture (General Digital Soil Moisture Meter DSMM500), soil salinity index (Hanna Soil/Liquid Conductivity Meter HI993310), depth of standing water, and percent canopy cover (Fig. 15). By sampling three times over a two-year period I capture annual and seasonal variations.

Table 4. Modified Braun-Blanquet scale (Braun-Blanquet 1932) for visual estimates of percent cover.

<b>Value</b>	<b>% Cover</b>
1	<1
2	1-5
3	6-25
4	26 - 50
5	>51

In post-monsoon 2013, I collected soil at a depth of 0-10 cm at five random points in one liter size zip lock bags, and I collected water from two to three locations per site in one liter plastic bottles. Soil and water samples were kept in a cooler and were sent to Motzz Laboratory Inc, Phoenix, AZ for analysis of chemical properties. Water was analyzed in parts per million (ppm) for Sodium, Calcium, Magnesium, Potassium, Carbonat, Bicarbonate, Chloride, Sulfate, Nitrate, Phosphate, and Boron, as well as pH, ECw (dS/m), cation/anion ratio, Sodium absorption ratio (SAR), adjusted RNa, hardness (mg equiv. CaCO<sub>3</sub>/L), leaching requirement (% additional irrigation for leaching salts), sulfuric acid requirement (~gallons conc. sulfuric acid / ac-ft to lower pH to 5.5), and United States Department of Agriculture (USDA) classification. Soil in ppm was analyzed for Calcium, Magnesium, Sodium, Potassium, Nitrate, Phosphate, as well as

pH, Electrical Conductivity (dS/m), free lime, exchangeable Sodium percentages (ESP) (%), and cation exchange capacity (CEC) (meq/100g).

### ***Floristic Analysis***

I inventoried vascular plants of each study area based on my field specimens and on SEInet for past collection records. Specimens were identified using a dissecting microscope, dichotomous keys (Gould 1940; Kearney and Peebles 1960; Correll and Correll 1975; Allred 2005), and ASU herbarium's collection. I used the nomenclature of the Arizona State University Herbarium taxonomic thesaurus, which mostly follows theplantlist.org. Two percent of the total cover was unable to be identified to the species level.

### ***Lab***

I determined total soil organic matter by drying soil samples at 60° C for a minimum of 4 days. Samples were sifted with a 2 cm soil sieve. Samples were then weighed to a tenth of a milligram, combusted at 500° C for 4 hours, then reweighed. The difference between dry and combusted soil was used to calculate percent organic matter. This method is based on Long Term Ecological Research (LTER) standard protocol (Robertson et al. 1999).

I analyzed soil texture using the hydrometer method (Bouyoucos 1962). Soil was sifted to 2 cm, and dried at 105° C for 24 hours. Forty grams of soil (+/- 0.5 g) was weighed into 250 ml Nalgene bottles and 100 mL of sodium hexametaphosphate solution (50g/L) was added. The bottles were placed on a shaker table overnight at a rate of 160 rotations per minute. The soil – sodium hexametaphosphate solution was transferred to a

1000 mL graduated cylinder, and filled to 1000 mL with distilled water and the temperature of solution was recorded. The solution was mixed and at 40 seconds, recorded the hydrometer's specific gravity. Isopropyl alcohol was added to every sample to remove foam from the top of the solution. The 40-second measurement was repeated three times. The solution was mixed a fourth time, and time of day recorded. After seven hours temperature and hydrometer readings were recorded. This procedure was repeated for three blank solutions containing only sodium hexametaphosphate and distilled water, to act as calibration samples.

### ***Statistics and Graphing***

R version 3.1.2 and R Studio version 0.98.1091 were used for all analyses and most graphs. ArcGIS (ESRI 2009) was used in GIS presentation and analysis. Polygons of field sites were smoothed by editing the shapefiles and redefining the edges. Interpolation of environmental variables was created using inverse distance weighting with a power of 1. Community weighted wetland score (CWWS) was calculated by assigning a numerical value to the wetland indicator status taken from the National Wetland Plant List (Lichvar et al. 2012) of each species (obligate wetland = 1, facultative wetland = 2, facultative = 3, facultative upland= 4, and obligate upland = 5) for the "Arid West" region. At the quadrat level, the sum of the percent cover was multiplied by this numerical value and divided by the total cover of each species in the quadrat. This was computed in order to gain a synthetic index of water availability. Slope calculated by dividing the upstream-downstream change in elevation by the upstream-downstream length of the site.

To address the question of how species richness is influenced by environmental variables, a linear model was employed with environmental factors including canopy cover, salinity, elevation, CWWS, slope, stream association, standing water, soil organic matter, and field soil moisture using data from the post-monsoon sampling period, and five outlying quadrats eliminated. Estimates S version 9.1.0 (Colwell 2013) was used to create species accumulation curves (sample-based rarefaction) using the Chao bias correction (Chao et al. 2005) because of my large sample size. Samples were combined across all sampling periods for a total of 90 samples per site.

To address question three regarding plant community composition, non-metric multidimensional scaling (NMDS) was used. Minchin (1987) sites NMDS as “commonly regarded as the most robust unconstrained ordination method in community ecology”. The “metaMDS” function in package “vegan” was used to construct the NMDS which tries to find a stable solution using several random starts (Oksanen et al. 2015). The data sets used in the NMDS analysis were post-monsoon 2014 data, by ciénega. Community weighted wetland score (CWWS) was calculated by assigning a numerical value to the wetland indicator status of each species (obligate wetland = 1, facultative wetland = 2, facultative = 3, facultative upland = 4, and obligate upland = 5).

## **RESULTS**

### ***Site Variability***

My ciénega sites span three levels of the de Martonne Aridity Index and are embedded within four different upland biotic communities (Table 5). La Cebadilla with the lowest elevation (825 m) also had the highest salinity (1.8 mS/cm) (Table 5, Fig. 19).

Ciénega size varied in area from 0.004 km<sup>2</sup> to 0.059 km<sup>2</sup> and length from 160 m to 1033 m (Table 7). The ciénegas which are long and linear are stream associated (Table 7, Figs. 16-18).

Ciénega sites range widely in canopy cover, from <1 percent of the area with canopy (Cieneguita) to >50% (Parker Canyon) (Table 6, Fig. 17). Sites with lower slope had less canopy cover (Tables 6 & 7, Fig. 18). All sites had high percent soil organic matter with Bog Hole having the lowest (13%), and Parker Canyon having the highest (29%) (Fig. 19). Results from a correlation matrix examining soil salinity, soil moisture, stream association, slope and canopy reveal very high correlations between salinity and moisture (0.93), salinity and stream association (-0.92), and stream association and moisture (-0.90) (Table 8).

Table 5. Climate variables and elevation at the study sites. All climate values are 30 year averages (1981-2010). Aridity calculated based on de Martonne Aridity Index (mean annual precipitation in mm divided by mean annual temperature in °C plus a constant of 10) (Quan et al., 2013). Matrix community based off Brown & Lowe (1994).

Site	Annual	Mean Annual	Elevation (m)	Aridity Index	Matrix Community
	Precip.(mm)	Temp.(°C)			
La Cebadilla	337	20	825	11.2	AZ upland subdivision – Sonoran desert scrub
Cieneguita	402	16	1340	15.5	Seimidesert grassland
Sharp Springs	456	16	1440	17.5	Plains and Great Basin grassland
Bog Hole	492	16	1525	18.9	Madrean evergreen woodland
Parker Canyon	498	15	1620	19.9	Madrean evergreen woodland
Scotia	588	14	1880	24.5	Madrean evergreen woodland

Table 6. Mean values (and standard deviation) for environmental variables measured in the field, ordered from low to high elevation.

Site	Soil Salinity Index	Field Soil Moisture (%)	Standing Water (class)*	Canopy cover(%)
La Cebadilla	1.8(1.4)	47(35)	1.2(1.1)	21(32)
Cieneguita	1.3(0.9)	44(34)	1.1(1.1)	1(8)
Sharp Springs	0.7(0.6)	34(27)	0.8(1.4)	22(33)
Bog Hole	0.9(0.7)	37(32)	1.0(1.0)	20(32)
Parker Canyon	0.3(0.4)	15(10)	1.7(1.5)	58(29)
Scotia	0.5(0.6)	25(19)	1.6(1.4)	11(24)

Table 7. Geomorphological site characteristics. Levels of stream association are as follows; 0 = none, 1= some, 2 = high association. Sites are in order from low to high elevation.

Site	Stream Association	Slope (%)	Area (km <sup>2</sup> )	Length (m)
La Cebadilla	0	2.5	0.0123	181
Cieneguita	1	1.4	0.0444	730
Sharp Springs	1	1.9	0.0589	1033
Bog Hole	1	1.0	0.0569	438
Parker Canyon	2	6.1	0.0081	293
Scotia	2	13.6	0.0041	160

Table 8. Correlation matrix for abiotic variables at the site level.

	Slope	Stream	Salinity	Moisture	Canopy
Slope	1.00	0.70	-0.65	-0.87	0.84
Stream		1.00	-0.92	-0.90	0.36
Salinity			1.00	0.93	-0.50
Moisture				1.00	-0.70
Canopy					1.00

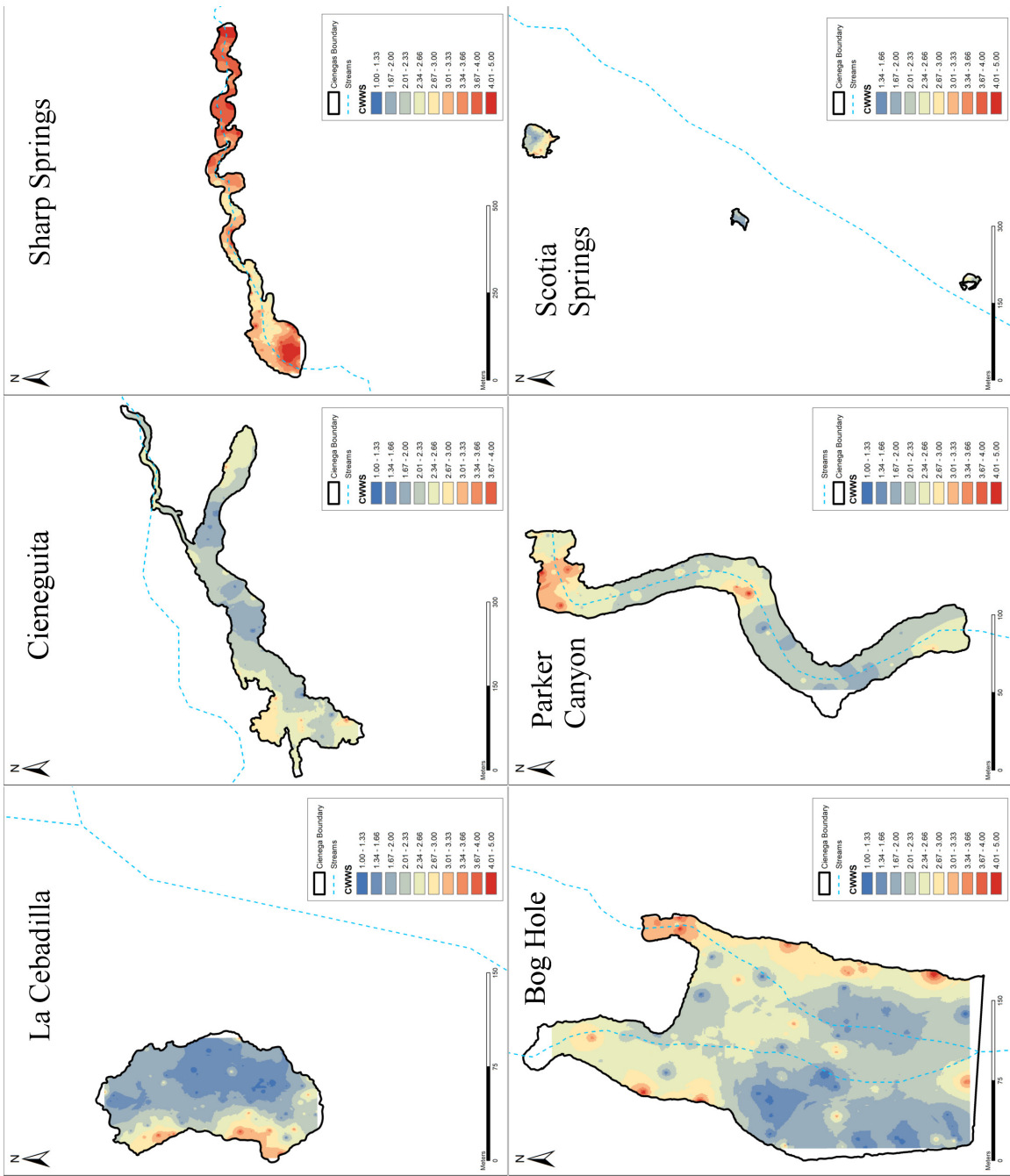


Figure 16. Inverse Distance Weighting of community weighted wetland score with a power of 1 interpolated at all sites. Warmer colors are dryer while cooler colors are wetter.

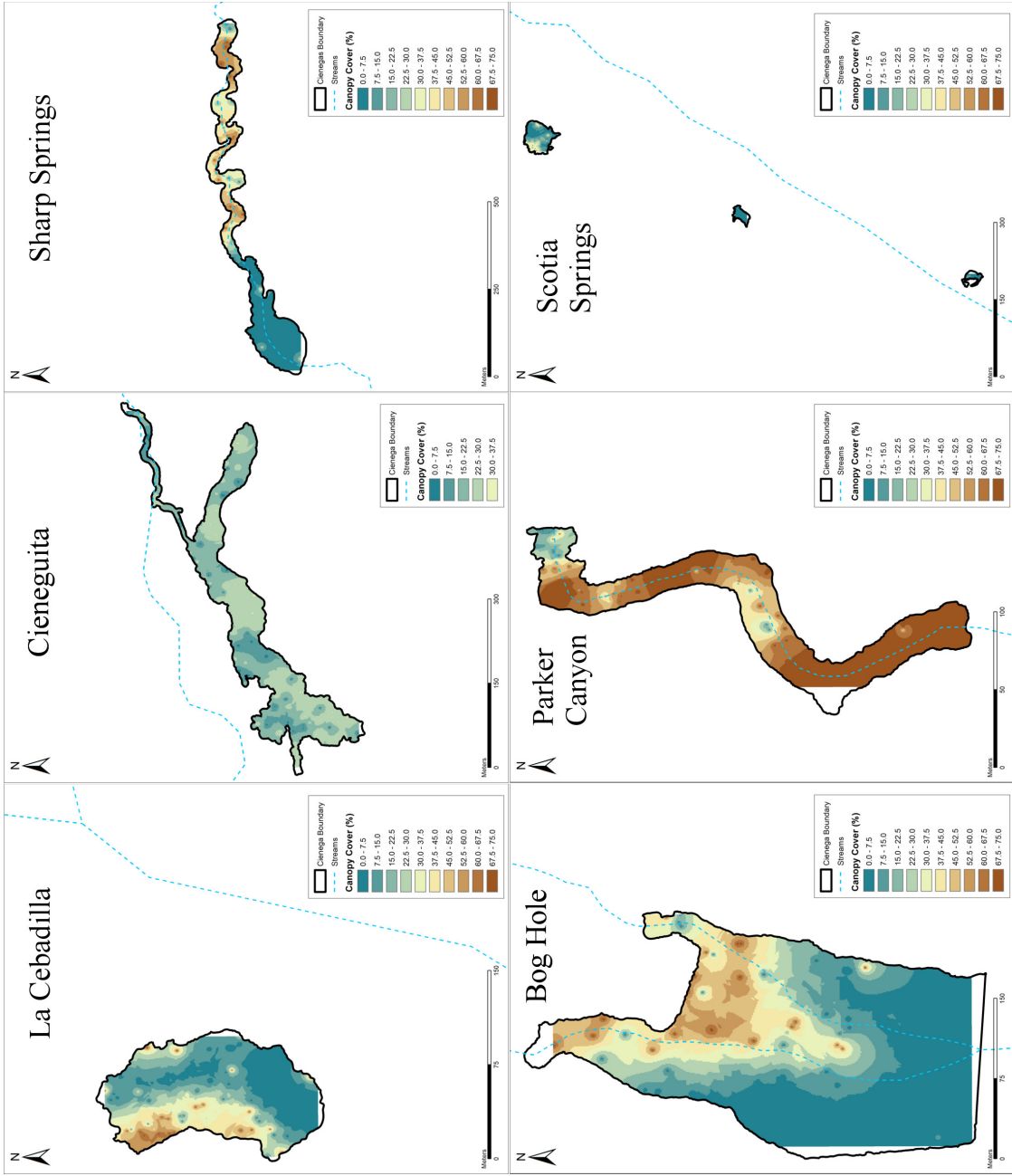


Figure 17. Inverse Distance Weighting of canopy cover (%) with a power of 1 interpolated at all sites. Greener is less canopy cover while browner is more canopy cover.

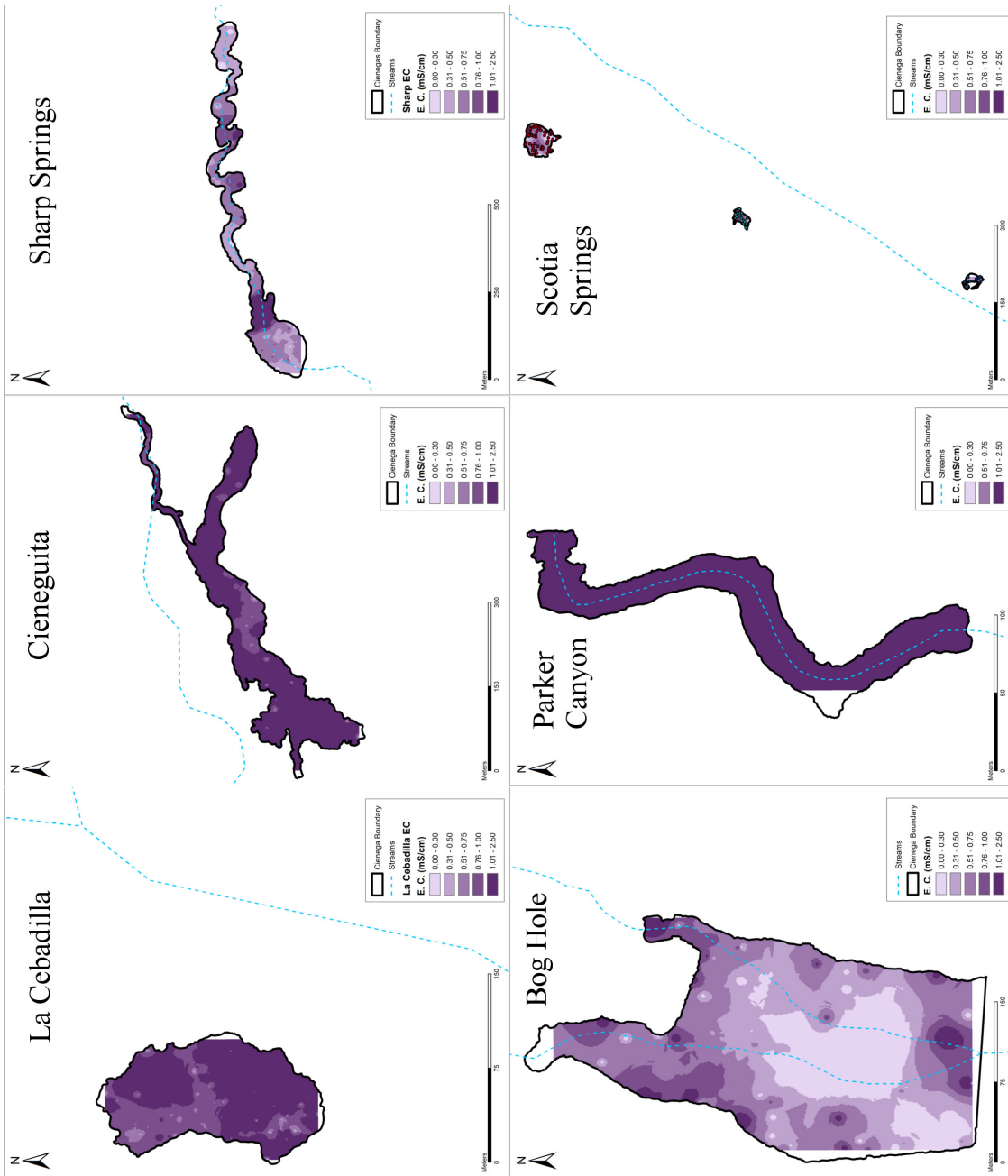


Figure 18. Inverse distance weighting of electrical conductivity (mS/cm) with a power of 1 interpolated at all sites. Darker purple is higher E. C.

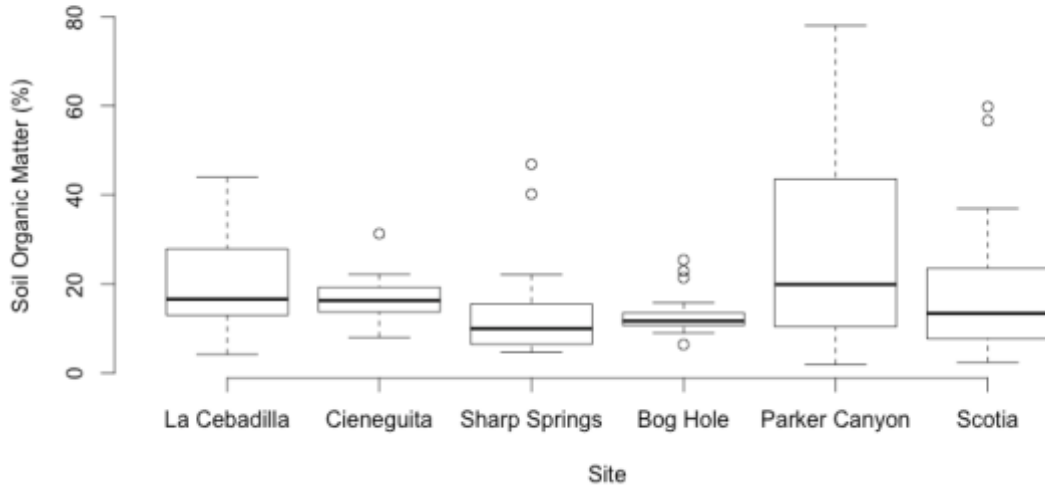


Figure 19. Percent soil organic matter. Box plots based on 30 samples per site. Lower whisker indicates minimum value, bottom box line indicates 1<sup>st</sup> quartile, bolded line within box indicates median, top box line indicates 3<sup>rd</sup> quartile, upper whisker indicates maximum value, and dots outside of this range indicate outliers. Sites are arranged from lowest to highest elevation.

### ***Species Richness***

Total species richness per site ranged more than three-fold from 40 (La Cebadilla, the lowest elevation and most saline site) to 138 (Scotia) (Table 9, Fig. 21). Total unique species ranges from 0 to 49 (Table 9). All sites had at least approximately 35 wetland species with the exception of La Cebadilla which has only 12. La Cebadilla had no unique wetland species while Bog Hole and Parker Canyon each had six. Most species at all sites were non-wetland species.

Mean quadrat level richness ranged from 4.1 (La Cebadilla) to 7.0 (Scotia) (Fig. 20). Site similarity using the Sorenson diversity index ranged from 0.08 to 0.51 (Table 10). Highest similarity was between sites closest in physical distance. La Cebadilla had the lowest similarity overall to other sites (0.08-0.25).

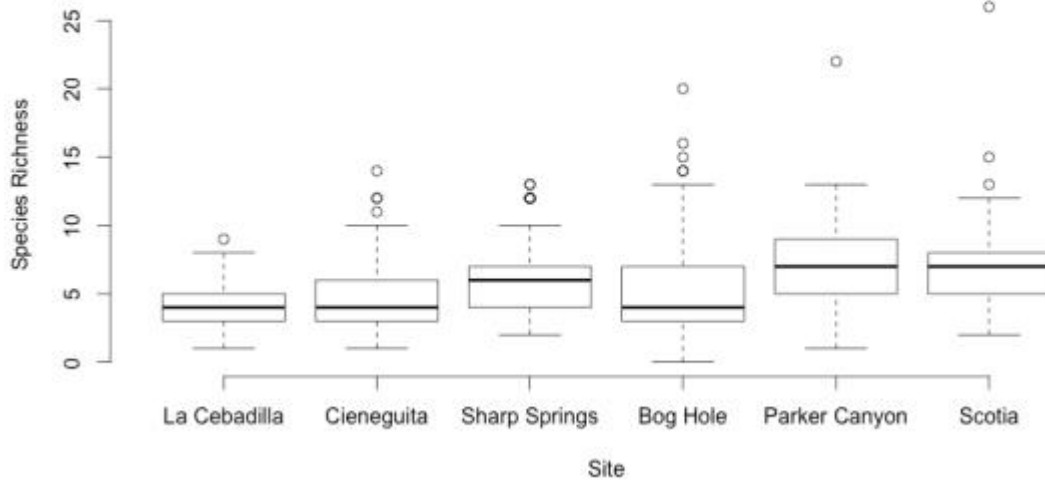


Figure 20. Box plot of species richness per site. Lower whisker indicates minimum value, bottom box line indicates 1<sup>st</sup> quartile, bolded line within box indicates median, top box line indicates 3<sup>rd</sup> quartile, upper whisker indicates maximum value, and dots outside of this range indicate outliers. Sites are arranged left to right from lowest to highest elevation.

Table 9. Unique species (i.e. species occurring only at that study site) and total species at each site parsed by wetland indicator score. Sites are listed from lowest to highest elevation. “Wetland “ includes obligate wetland and facultative wetland species; facultative includes facultative and facultative upland species.

	La Cebadi lla	Cieneg uita	Sharp Springs	Bog Hole	Parker Canyon	Scotia Springs
<b>Total species</b>	40	102	138	137	146	136
Wetland	12	33	34	33	36	36
Facultative	12	25	39	32	28	26
Other (upland)	16	44	65	72	82	74
<b>Unique species</b>	17	20	30	35	49	37
Wetland	2	1	4	6	6	2
Facultative	4	4	10	7	8	8
Other (upland)	11	15	16	22	35	27

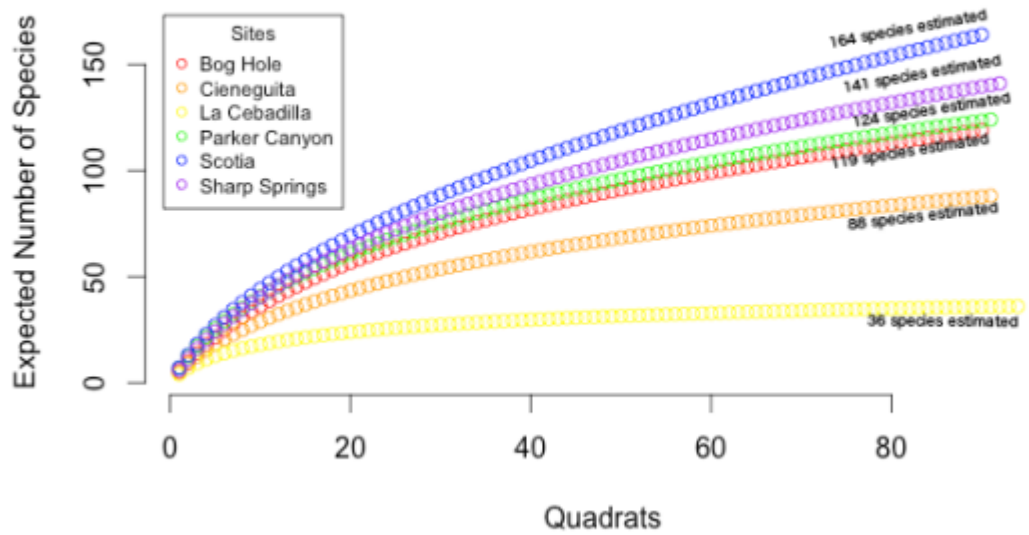


Figure 21. Species accumulation curves for all sites using the Chau method.

Table 10. Similarity summary table based on Sorenson measure.

	Bog Hole	Cieneguita	La Cebadilla	Parker Canyon	Scotia	Sharp Springs
Bog Hole	1.00					
Cieneguita	0.34	1.00				
La Cebadilla	0.10	0.25	1.00			
Parker Canyon	0.34	0.24	0.08	1.00		
Scotia	0.37	0.34	0.11	0.45	1.00	
Sharp Springs	0.51	0.43	0.12	0.34	0.37	1.00

Plants were categorized according to life history and habit. The most frequently occurring species at all sites belonged to the wetland category. The two most frequent species overall were in the rhizomatous perennial graminoids category (Table 12).

The only species to occur at all six of my study sites was *Eleocharis palustris*. The two most frequently observed species at each ciénega are *Muhlenbergia asperifolia* and *Schoenoplectus americanus* at La Cebadilla, *Carex praegracilis* and *Muhlenbergia asperifolia* at Cieneguita, *Ambrosia psilostachya* and *Carex praegracilis* at Sharp Springs, *Populus fremontii* and *Schoenoplectus californicus* at Bog Hole, *Salix bonplandiana* and *Muhlenbergia rigens* at Parker Canyon, and *Eleocharis palustris* and *Bidens palustris* at Scotia (Table 12). Globally rare species such as *Eryngium sparganophyllum* and *Carex spissa* were dominant where they occurred.

Post-monsoon 2014 plot-level richness (species per 2m<sup>2</sup>) varied significantly with several factors (Figs. 22-24). Although no factor individually explained the high variance given the overall low model adjusted R<sup>2</sup> (0.31), results of the linear model revealed community weighted wetland score (CWWS; a synthetic index of water availability), elevation, stream association and soil organic matter to be significant ( $\alpha=0.05$ ) ( $p = <0.001, 0.019, 0.045, \text{ and } 0.048$  respectively) (Table 11) (see Appendix F for residual plots). The most significant variable was CWWS ( $p = <0.001$ ). Elevation, CWWS, average soil organic matter, and stream association are all positively associated with species richness (Figs. 23-24). Although median quadrat level species richness remained consistent between sampling seasons, means were higher in the post-monsoon period (Fig. 25).

A correlation matrix and correlogram (Friendly 2002) indicated correlation between abiotic variables at the quadrat scale. With the exception of elevation and stream association (96%), no two variables were more than 71% correlated with each other (Fig 22).

Table 11. Results from linear model predicting quadrat level species richness from abiotic variables. Significance codes: ‘\*\*\*’ < 0.001; ‘\*’ < 0.05.  $R^2 = 0.31$ .

<b>Variable</b>	<b>p-value</b>	<b>Significance</b>
Canopy	0.9435	
Salinity	0.3035	
Elevation	0.0189	*
CWWS	2.14E-05	***
Slope	0.1933	
Stream Association	0.0452	*
Standing Water	0.2505	
Soil Organic Matter	0.0481	*
Field Soil Moisture	0.0693	

Table 12. Top ten most frequently encountered species at each site. Species are listed in order of decreasing frequency across all sites. Sites are listed from low to high elevation.

Species	Total Fre- quency	Bog Hole	Cien- eguita	La Cebadilla	Parker Cyn	Scotia	Sharp Springs
<i>Eleocharis palustris</i>	167	18	23	40	32	54	0
<i>Muhlenbergia asperifolia</i>	148	0	41	46	0	37	24
<i>Ambrosia psilostachya</i>	106	18	13	0	0	32	43
<i>Carex praegracilis</i>	101	0	61	0	0	0	40
<i>Muhlenbergia rigens</i>	91	13	0	0	40	38	0
<i>Juncus balticus</i>	84	11	0	19	0	20	34
<i>Schoenoplectus americanus</i>	66	20	0	46	0	0	0
<i>Salix bonplandiana</i>	62	0	0	0	62	0	0
<i>Anemopsis californica</i>	59	0	26	33	0	0	0
<i>Lythrum californicum</i>	47	0	0	0	20	27	0
<i>Populus fremontii</i>	47	26	0	0	0	0	21
<i>Bidens frondosa</i>	44	0	0	0	0	44	0
<i>Eryngium sparganophyllum</i>	43	0	0	43	0	0	0
<i>Solidago canadensis</i>	35	0	0	0	0	35	0
<i>Echinochloa crus-galli</i>	34	16	18	0	0	0	0
<i>Symphyotrichum falcatum</i> var. <i>commutatum</i>	33	0	0	0	0	17	16
<i>Lolium arundinaceum</i>	32	0	0	0	0	0	32
<i>Sorghum halepense</i>	30	0	15	0	0	0	15
<i>Ambrosia trifida</i>	27	0	27	0	0	0	0
<i>Fraxinus velutina</i>	26	0	0	0	26	0	0
<i>Prosopis juliflora</i>	23	0	0	23	0	0	0
<i>Berula erecta</i>	22	0	0	0	22	0	0
<i>Juncus mexicanus</i>	22	0	0	0	22	0	0
<i>Juncus saximontanus</i>	22	0	0	0	22	0	0
<i>Nasturtium officinale</i>	21	0	0	0	21	0	0
<i>Schoenoplectus californicus</i>	21	21	0	0	0	0	0
<i>Distichlis spicata</i>	18	0	0	18	0	0	0
<i>Polygonum punctatum</i>	18	0	0	0	18	0	0
<i>Bouteloua curtipendula</i>	17	0	0	0	0	0	17
<i>Sisyrinchium</i>	17	0	0	17	0	0	0

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<i>demissum</i>							
<i>Cynodon dactylon</i>	16	0	0	16	0	0	0
<i>Symphyotrichum subulatum</i>	15	0	15	0	0	0	0
<i>Bouteloua gracilis</i>	14	0	0	0	0	0	14
<i>Commelina dianthifolia</i>	14	14	0	0	0	0	0
<i>Almutaster pauciflorus</i>	13	0	13	0	0	0	0
<i>Carex spissa</i>	13	0	0	0	0	13	0
<i>Oxalis pilosa</i>	12	12	0	0	0	0	0

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### Correlogram

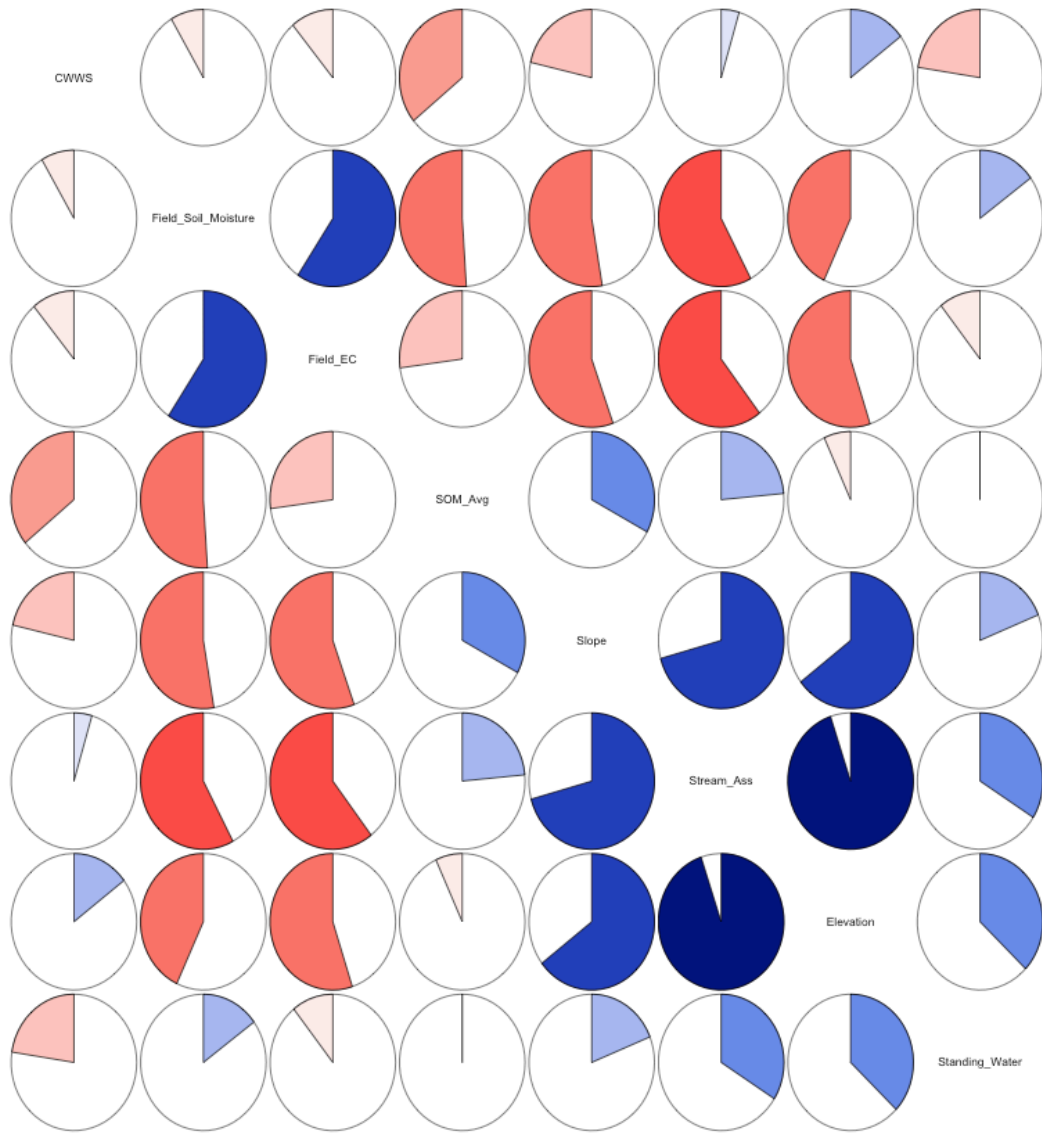


Figure 22. Visualization of similarity of abiotic variables. Red indicates negative values while blue indicates positive. Darker shades indicate stronger correlations.

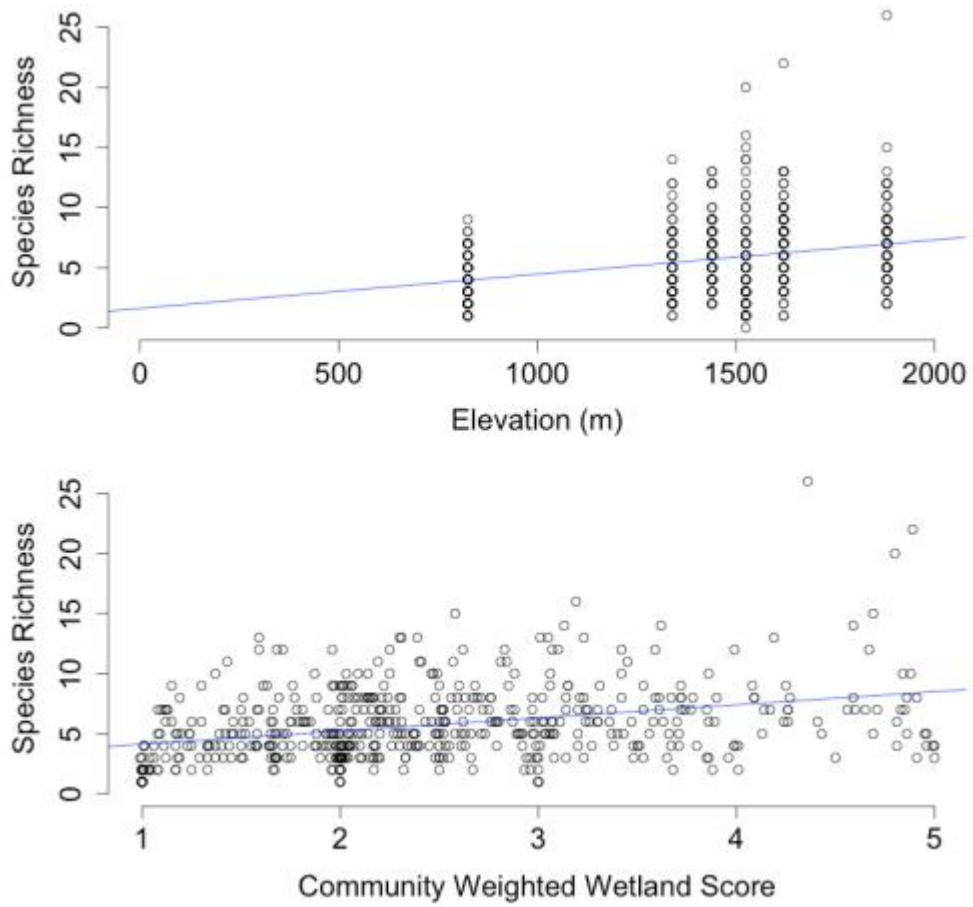


Figure 23. Quadrat level species richness plotted against elevation (top) and weighted wetland score (bottom). Blue line is linear regression line.

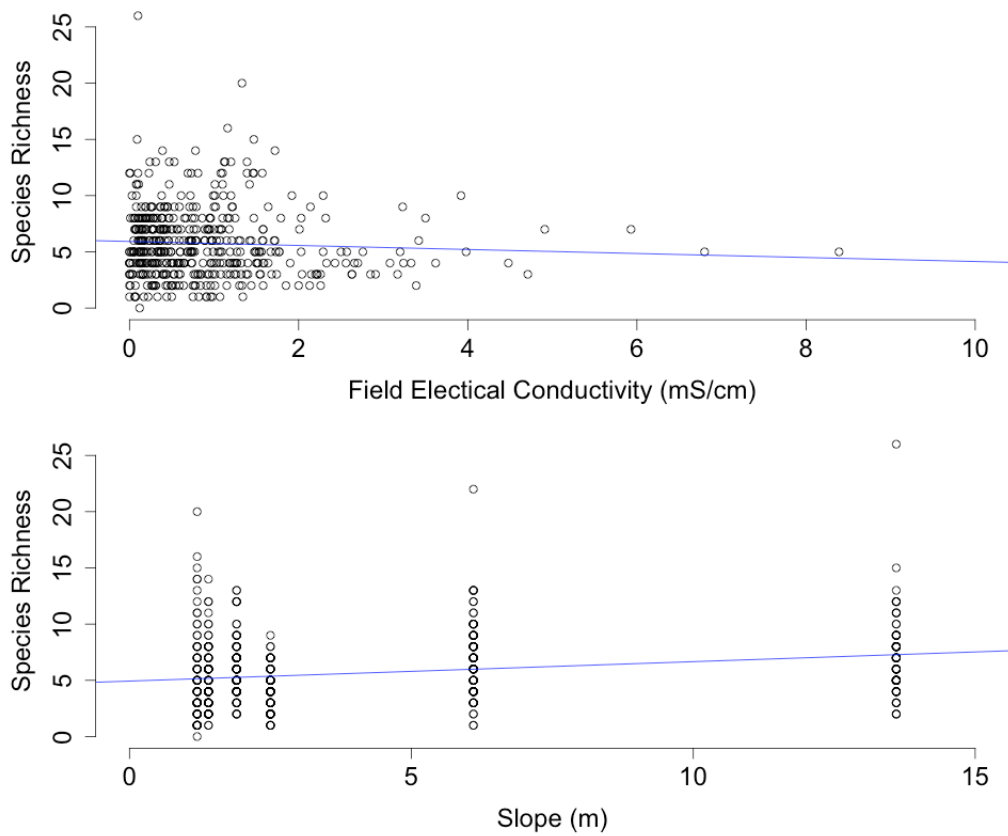


Figure 24. Quadrat level species richness plotted against field electrical conductivity (top) and slope in meters (bottom). Blue line is linear regression line.

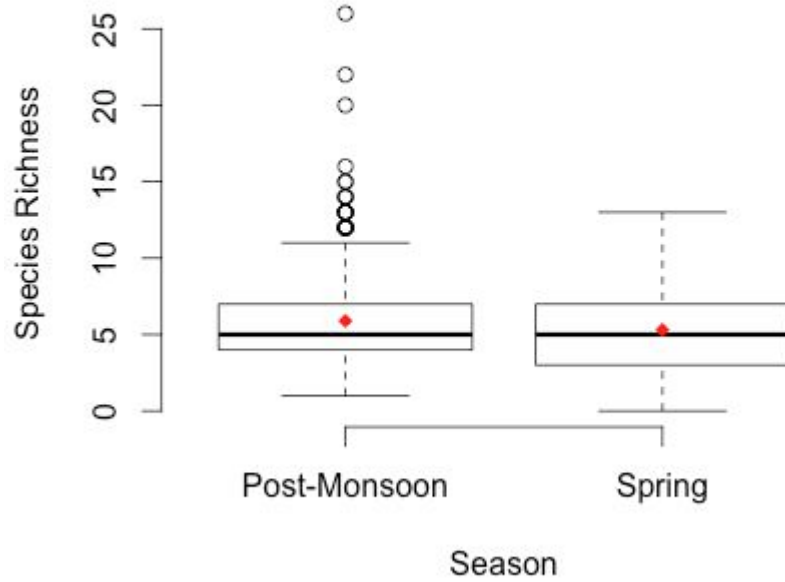


Figure 25. Box plots of species richness as it relates to seasons. Red diamonds indicate mean values. Lower whisker indicates minimum value, bottom box line indicates 1<sup>st</sup> quartile, bolded line within box indicates median, top box line indicates 3<sup>rd</sup> quartile, upper whisker indicates maximum value, and dots outside of this range indicate outliers.

### *Species Composition and Cover*

At every site, NMDS of post-monsoon data revealed the synthetic moisture index (CWWS; high values are indicative of dry conditions) to be a significant factor influencing plant species composition ( $p = 0.001-0.020$ ). At half of the sites, canopy cover was significant ( $p = 0.002-0.006$ ) and at half of the sites salinity was significant ( $p = 0.002-0.040$ ). At only Sharp Springs were CWWS, salinity, and canopy all significant ( $p = 0.020, 0.20, \text{ and } 0.006$  respectively) (Table 13, Figs. 26-31).

Canopy and CWWS were both significant in influencing species composition ( $p = 0.002$  and  $0.001$  respectively) and have the same relative directionality at La Cebadilla. Plant species on the wet end of those gradients include *Eleocharis palustris* and the globally critically imperiled, *Eryngium sparganophllum*. Species on the dry side of the gradient include *Baccharis sarothroides* and *Ziziphus obtusifolia*. Surprisingly, salinity is not significant at La Cebadilla ( $p = 0.450$ ) (Table 13, Fig 26).

At Cieneguita the only significant variable influencing species composition is CWWS ( $p = 0.002$ ). Plants on the extreme wet end of CWWS include *Cyperus odoratus*, *Juncus balticus*, and to a lesser extent, the ciénega obligate, *Almutaster pauciflorus*. *Ambrosia trifida*, *Heliomeris multiflora*, and *Sorghum halepense* compose the species on the other end of the CWWS gradient (Table 13, Fig. 27).

Salinity, canopy, and CWWS are all significant in influencing species composition at Sharp Springs ( $p = 0.020, 0.006, \text{ and } 0.020$  respectively). *Muhlenbergia rigens* and *Asclepias subverticillata* represent plants on one end of the E. C. and CWWS gradients while *Sorghum halepense*, *Bothriochloa laguroides*, and *Helianthus annuus* are representative of the other end (Table 13, Fig. 28).

At Bog Hole, *Schoenoplectus californicus* appears on the extreme wet end of the CWWS gradient while several species including *Physalis philadelphica*, *Portulaca suffrutescens*, and *Stacchys coccinea* appear on the dry end. As expected, *Populus fremontii* and *Salix gooddingii* fall out on the high side of the canopy gradient, but so do *Hopia obtusa*, *Bothriochloa laguroides* and *Muhlenbergia asperifolia* while *Melilotus officinalis*, *Eriochloa acuminata*, and *Chamaecrista nictitans* represent some of the species on the low side. Salinity is not significant at Bog Hole ( $p = 0.768$ ) (Table 13, Fig. 29).

Salinity and CWWS are both significant in influencing species composition at Parker Canyon ( $p = 0.040$ , and  $0.004$  respectively). The high side of the salinity gradient is represented by *Epilobium ciliatum*, *Hordeum jubatum*, and *Lythrum californicum*. *Tragia laciniata* is representative of the low side of the salinity gradient. *Verbascum thapsus* represents the dry end of the CWWS gradient. Canopy cover is not significant at Parker Canyon ( $p = 0.242$ ) (Table 13, Fig. 30).

At Scotia, salinity and CWWS are significant in influencing species composition ( $p = 0.002$  and  $0.001$  respectively). *Salix gooddingii* and *Solidago canadensis* are representative of higher salinity, as is *Carex spissa* to a lesser extent. Lower salinity is represented by *Vitis arizonica* and *Bidens pilosa*. *Nasturtium officinale* and *Salix gooddingii* appear on the wet end of the CWWS gradient, and *Heliomeris multiflora* appears on the drier end. Canopy is not significant at Scotia ( $p = 0.850$ ) (Table 13, Fig. 31).

Table 13. Summary table of environmental variables as they relate to plant species community composition and statistical significance for NMDS figures 28-33 arranged in order of ascending elevation. Significance codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05.

Site	Stress	Variable	NMDS1	NMDS2	r <sup>2</sup>	Pr(>r)	Significance
La Cebadilla	0.139	Salinity	0.599	0.801	0.060	0.450	
		Canopy	-0.253	-0.968	0.496	0.002	**
		CWWS	-0.402	-0.916	0.802	0.001	***
Cieneguita	0.126	Salinity	0.102	0.995	0.128	0.212	
		Canopy	-0.197	0.980	0.144	0.233	
		CWWS	-0.590	-0.807	0.476	0.002	**
Sharp Springs	0.151	Salinity	-0.747	0.664	0.241	0.020	*
		Canopy	-0.340	-0.940	0.331	0.006	**
		CWWS	0.850	-0.527	0.256	0.020	*
Bog Hole	0.173	Salinity	-0.135	0.991	0.018	0.768	
		Canopy	-0.006	1.000	0.368	0.004	**
		CWWS	1.000	0.017	0.785	0.001	***
Parker Canyon	0.194	Salinity	0.981	0.194	0.328	0.040	*
		Canopy	-0.994	0.109	0.150	0.242	
		CWWS	-0.808	0.589	0.586	0.004	**
Scotia	0.146	Salinity	0.633	0.774	0.392	0.002	**
		Canopy	-0.605	-0.796	0.015	0.850	
		CWWS	-0.991	-0.135	0.716	0.001	***

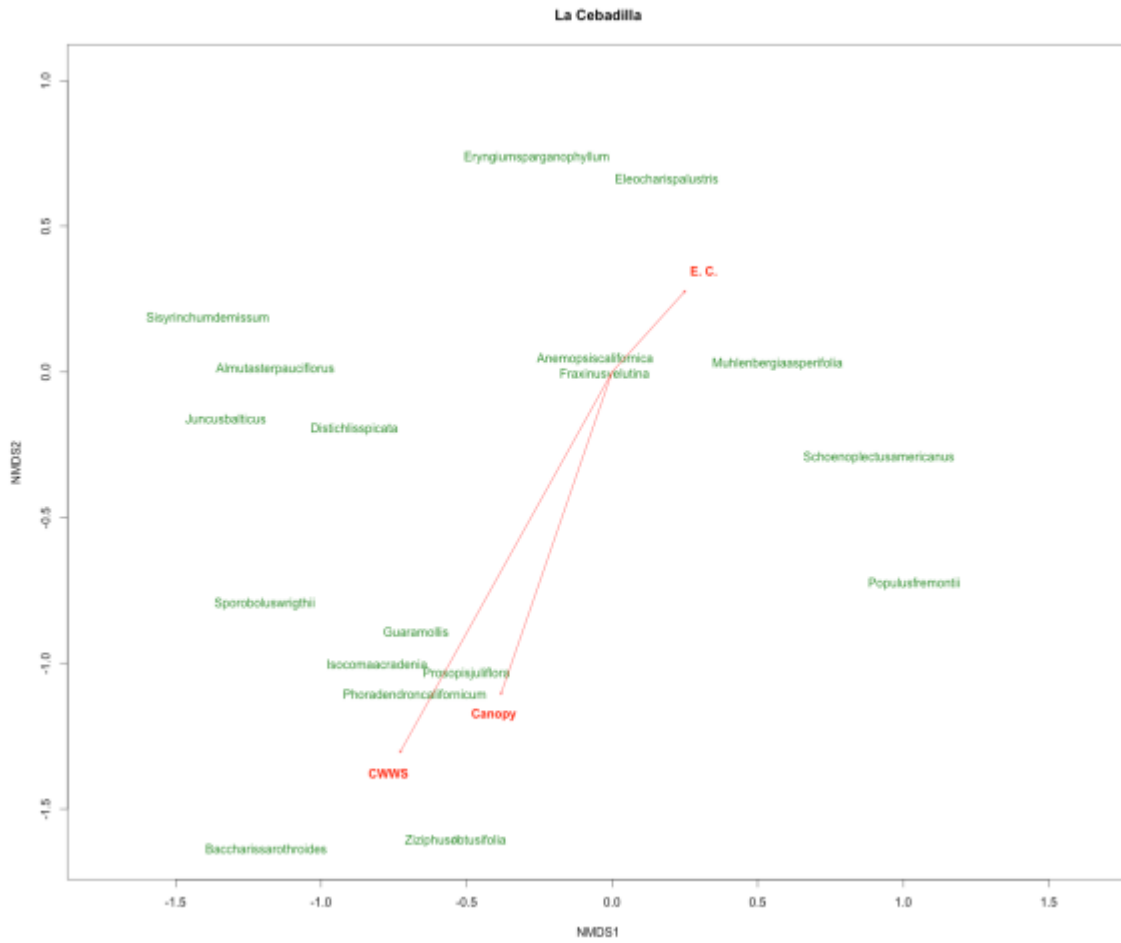


Figure 26. Non-metric multidimensional scaling for post-monsoon 2014 data at La Cebadilla Ciénega. Green text indicates plant species, while red text indicates environmental variables. Length of red arrows indicates significance of variable.

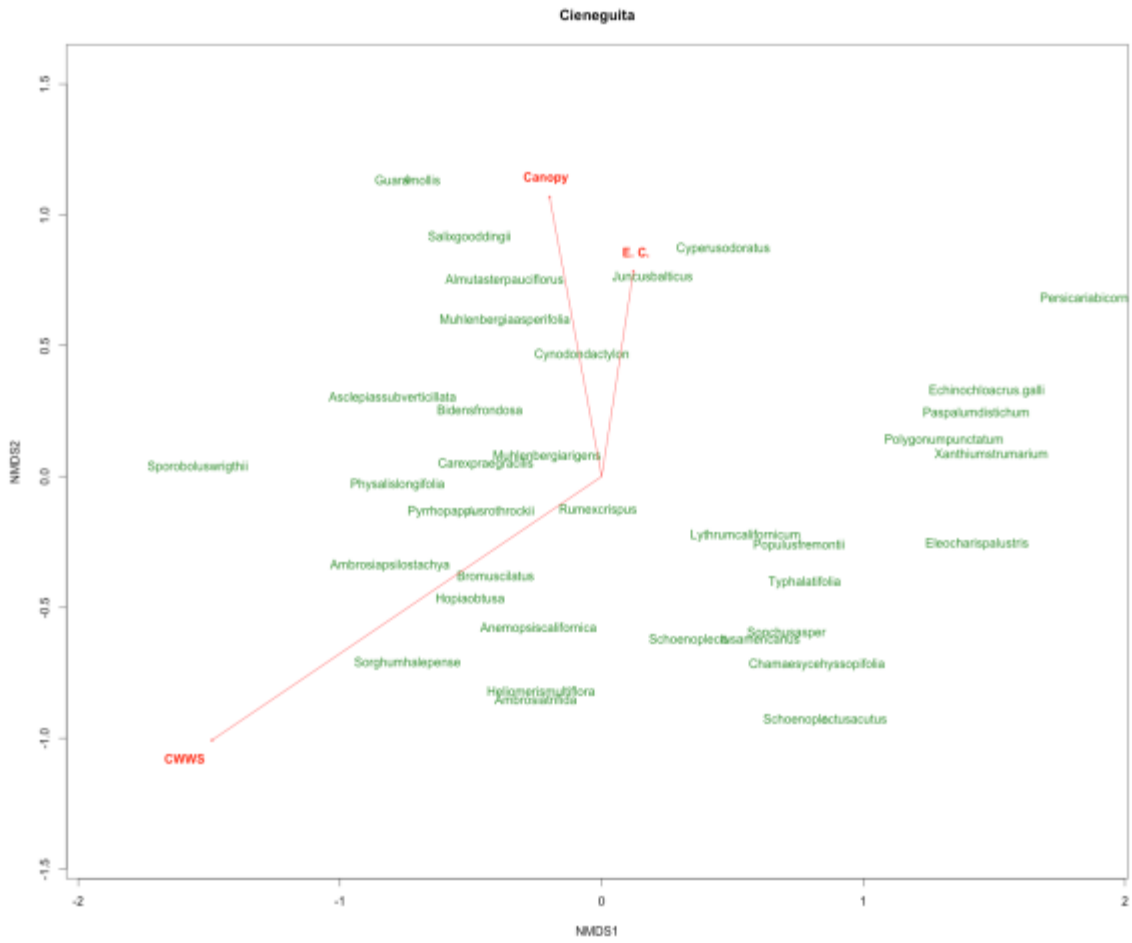


Figure 27. Non-metric multidimensional scaling for post-monsoon 2014 data at Cieneguita Ciénega. Green text indicates plant species, while red text indicates environmental variables. Length of red arrows indicates significance of variable.

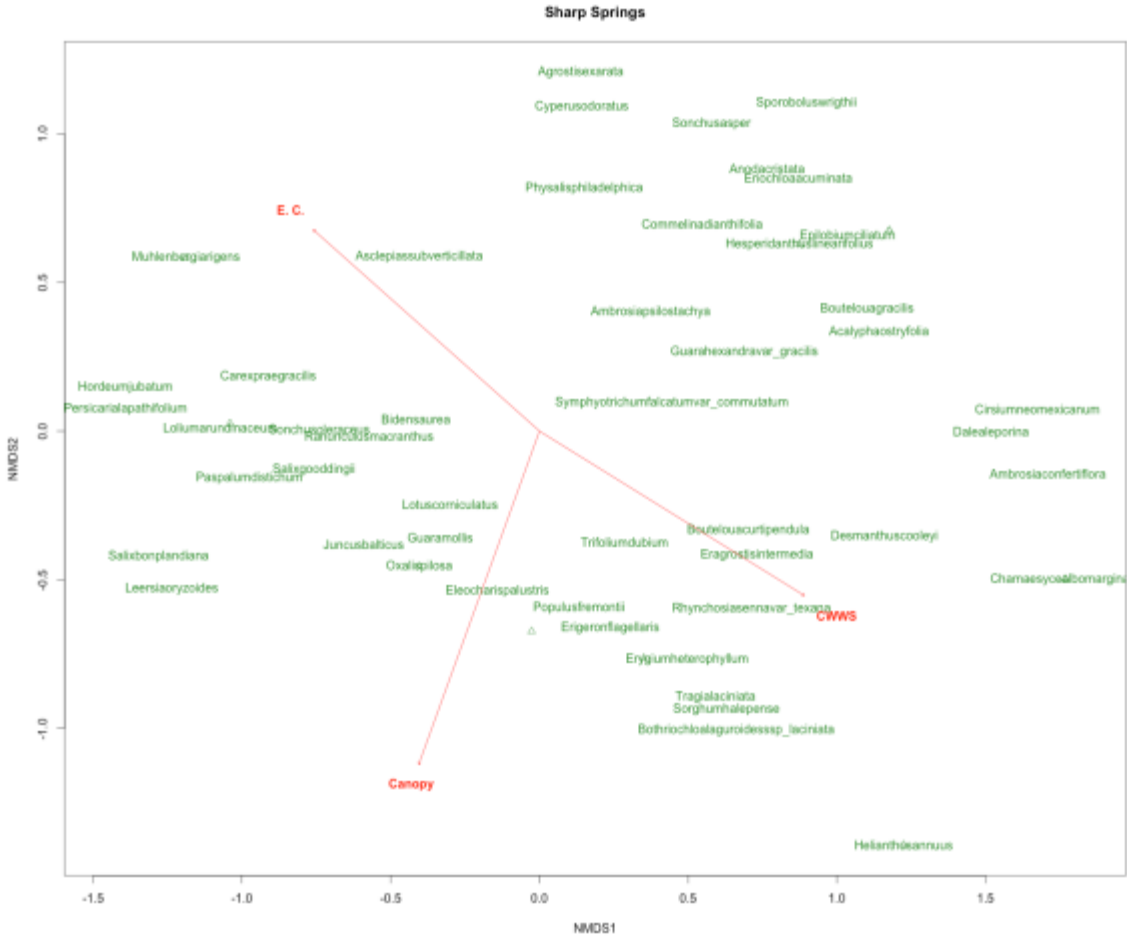


Figure 28. Non-metric multidimensional scaling of post-monsoon 2014 data at Sharp Springs Ciénega. Green text indicates plant species, while red text indicates environmental variables. Length of red arrows indicates significance of variable.

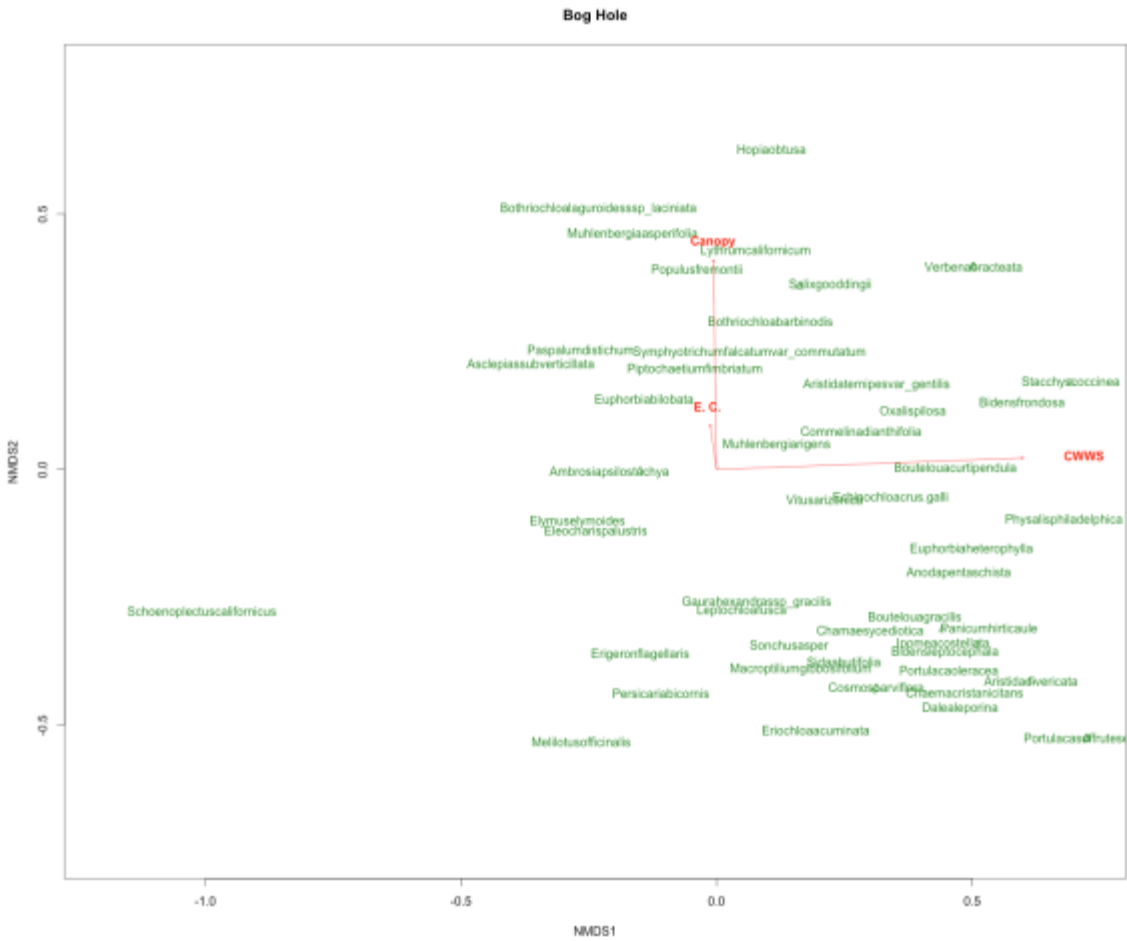


Figure 29. Non-metric multidimensional scaling of post-monsoon 2014 data at Bog Hole Ciénega. Green text indicates plant species, while red text indicates environmental variables. Length of red arrows indicates significance of variable.

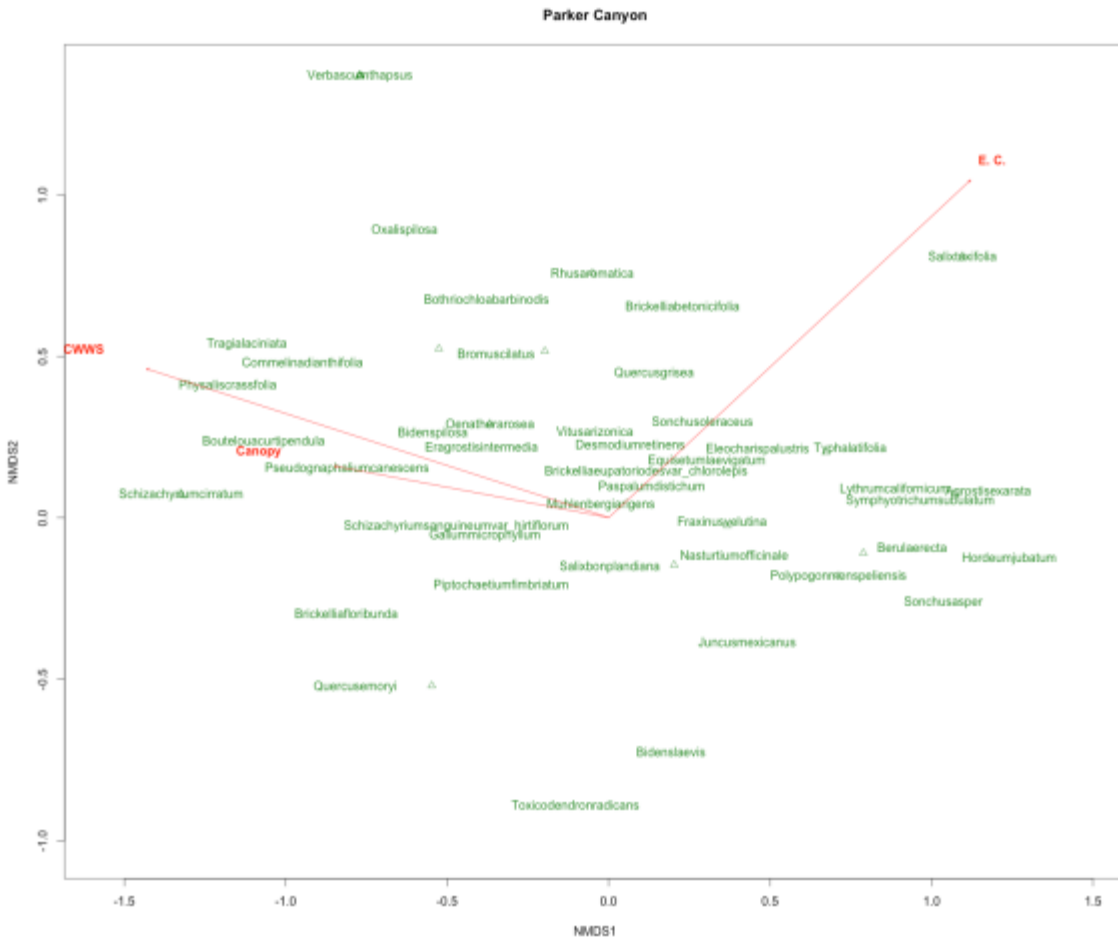


Figure 30. Non-metric multidimensional scaling for post-monsoon 2014 data at Parker Canyon Ciénege. Green text indicates plant species, while red text indicates environmental variables. Length of red arrows indicates significance of variable.

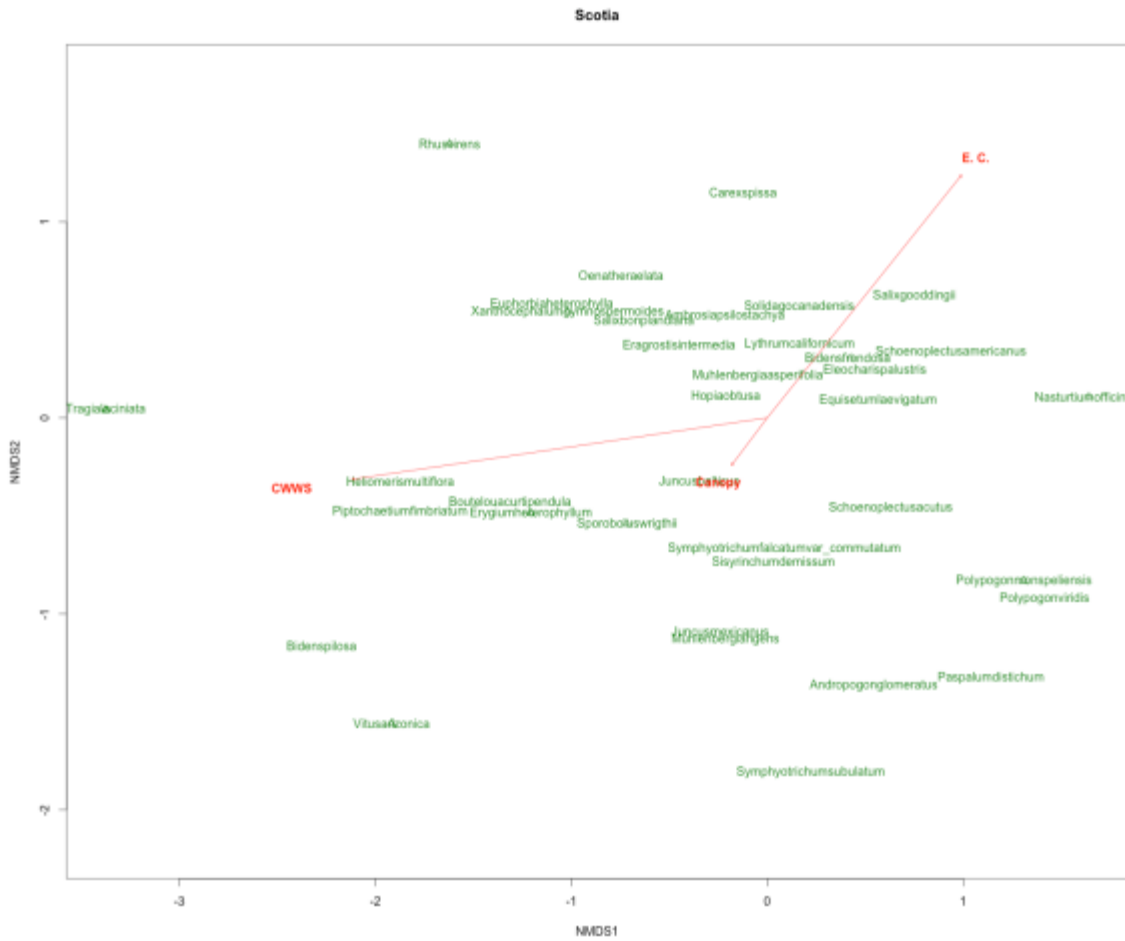


Figure 31. Non-metric multidimensional scaling for post-monsoon 2014 data at Scotia Ciénega. Green text indicates plant species, while red text indicates environmental variables. Length of red arrows indicates significance of variable.

## DISCUSSION

My investigation has laid groundwork for ciénega conservation and restoration by acquiring baseline information into the ecology of six of these unique and threatened systems. Ciénegas are highly variable with respect to wetland area, soil organic matter, plant species richness, and species composition. Plant species richness is influenced

positively by soil salinity, elevation, and flow gradient (percent slope) and negatively by soil moisture. Richness is greatest during the post-monsoon season and is not influenced by canopy cover. Plant species community composition is structured by water availability at all ciénegas while effects of canopy and salinity are site specific.

My first question focused on variability among ciénegas. Because ciénegas even within the same watershed varied widely in not only abiotic variables but species richness and composition as well, it is important to conserve the ciénega landscape as opposed to conserving a single individual ciénega. My findings are consistent with the idea that effective conservation of plant species requires consideration of diversity patterns at a variety of spatial scales, including alpha, beta and gamma (Whittaker et al. 1972).

Wetlands harbor a different suite of species relative to their upland counterparts suggesting that conservation practitioners should include these small isolated wetlands in their regional conservation planning (Sabo et al. 2005). Underlying causes of variability among ciénegas may be attributed to elevation and related temperature stresses, geologic controls on groundwater discharge, topography, site history in terms of impoundments and diversions, and distance between sites. Ciénega area in my study varied from 0.0041 km<sup>2</sup> to 0.0589 km<sup>2</sup>, but it is important to note that Arivaca Ciénega also located in southern AZ is closer to 6.5 km<sup>2</sup> in area (McLaughlin 1992).

Although variable, many of the ciénegas were similar in being dominated by the same plant growth form type, rhizomatous perennial graminoids. Further, a small number of wetland species including *Eleocharis palustris*, *Juncus balticus*, *Muhlenbergia asperifolia*, *Muhlenbergia rigens*, *Paspalum distichum*, *Polypogon monspeliensis*, *Populus fremontii*, *Salix gooddingii*, *Sisyrinchium demissum*, and *Symphyotrichum*

*subulatum* were present at five of the six ciénegas. *Eleocharis palustris* and *Muhlenbergia asperifolia* have been documented at ciénegas in New Mexico including the Roswell Artesian Basin Ciénegas, and Kewa Marsh (Sivinski and Tonne 2001). While many of these species are widespread in the American Southwest, it is possible that seeds of these species were dispersed between watersheds by migrating birds or other animals. Whatever the mechanism, seed dispersal and environmental resources both are importance influences on plant distribution in wetlands (Fraaije et al. 2015). Further, a few typically upland species (*Bothriochloa barbinodis*, *Bouteloua curtipendula*, *Dyschoriste schiedeana* var. *decumbens*, *Leptochloa dubia*) were present at five of the six ciénegas. *Bouteloua curtipendula* is one species that has migrated to higher elevations in southern Arizona owing to recent climate change (Brusca et al. 2013). Although spatially rare, ciénegas may play a role in sustaining populations of high-elevation ‘non-wetland’ species.

I also found high variability in the distribution of rare species, with different ciénegas harboring different rare and endangered species (e.g., *Eryngium sparganophyllum* at La Cebadilla; a new population of ESA listed *Lilaeopsis schaffneriana* subsp. *recurva* at Scotia Ciénega; *Almutaster pauciflorus* at Cieneguita and La Cebadilla; *Leersia oryzoides* at Sharp Springs). Ciénegas can be a catalyst for discovering new species. For example, the lucky morning glory (*Calystegia felix*) was recently described in a historic ciénega belt (mosaic of palustrine wetlands) in which all of its occurrences are within city boundaries and are threatened with habitat destruction (Provance & Sanders 2013).

My second question addressed factors influencing plant species richness. My study found that species richness is most significantly influenced by water availability (CWWS). Species richness decreased as water availability increased, in contrast to some studies such as that of Audet et al. (2015) who found species richness to be positively associated with higher groundwater tables. In arid and semiarid regions, richness may be greater at the more temperate higher elevations (Stohlgren et al. 2005). Despite concerns about woody plant encroachment reducing biodiversity (Briggs et al. 2005), my investigation suggests that canopy cover has no significant influence in either direction on ciénega species richness.

Seed availability also can influence wetlands (Xiong et al. 2003) and it is possible that the ciénegas I studied were not saturated with species, raising the idea of adding seeds to augment species richness. The lowest richness occurred at the lowest elevation ciénega, and this site may be a useful area for such studies. Yatskievych and Jenkins (1981) found fewer species (112) in the fall flora of Hooker Ciénega than I found at most of my study sites but more aquatic species (46) than all of my sites. While Hooker Ciénega has abundant amounts of open water, many of my study areas had limited areas of open water, thus low numbers of aquatic species.

My final question addressed influences on species composition. The fact that plant species community composition was structured by water availability at all ciénegas is consistent with the key role that water availability plays in structuring plant community composition in arid and semiarid regions. This agrees with findings at Babocomari and Canelo Hills Ciénegas where Cross (1991) found moisture availability to be the most important factor influencing vegetation trends at both sites. Long-term drought may also be

influencing species composition in some sites. For example, I was unable to locate the Endangered *Lilaeopsis schaffneriana* ssp. *recurva* at Sharp Spring Ciénega where it has been historically present (Warren et al 1991) a possible clue to the to the overall desiccation of this ciénega. Another wetland species previously documented at this ciénega (*Sisyrinchium demissum* by McLaughlin in 2001) was found in my study, but was represented by only a single drought-stressed individual in 2013, and only occurred in a single quadrat for a total of 3% cover for all sampling periods combined. This study will serve as a baseline for future ciénega conservation and restoration activities including monitoring the possible drying of ciénegas.

One factor I did not address is the influence of disturbance including that from livestock grazing. In dryland riparian zones, high levels of livestock grazing cause streambanks to erode and alter species composition and may exacerbate effects of a warming climate (Beschta et al. 2013). Andrew et al. (2015) suggest cattle grazing should be discouraged to conserve biodiversity, based on study of a tropical wetland. However, Kodric-Brown & Brown (2007) find removal of cattle to decrease biodiversity in certain wetlands in the southwest U. S. and Australia, and further cite Quitobaquito Spring and Canelo Hills Ciénega Reserve as examples of this process in ciénegas of southern Arizona.

Herbaceous wetlands have important ecosystem functions and services such as water quality improvement, flood abatement, carbon sequestration, and as such should be high priority for conservation and restoration (Weisberg et al. 2013; Zedler & Kercher 2005). Fortunately, some restoration techniques have proved successful in ciénega restoration. For example, gabions helped restore ciénega vegetation along the Arizona –

Sonora boarder at Ciénega San Bernardino (Norman et al. 2014). Citing the Las Ciénegas National Conservation Area in southern Arizona as a case study, Caves et al. (2013) suggests that managing lands using collaborative decision-making and adaptive management may be the best strategy for stewardship of these important ecosystems. The high variability of ciénega wetlands and the rare species they harbor combined with the numerous threats against them and their isolated occurrences makes these vanishing communities high priority for conservation.

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## APPENDIX A

EQUATIONS OF FITTED LINES FOR SPECIES ACCUMULATION CURVES AND

AIC BASED ON GLM FOR EACH FIELD SITE

(FROM FIG. 22)

<i>Site</i>	<b>Equation</b>	<b>AIC</b>
Bog Hole	$6.16205+0.54058 \cdot \log(x)+5.41741 \cdot \log(x)^2$	25.24
Cieneguita	$5.71343+1.46533 \cdot \log(x)+3.71445 \cdot \log(x)^2$	-110.26
La Cebadilla	$2.28498+6.45832 \cdot \log(x)+0.23412 \cdot \log(x)^2$	79.04
Parker Canyon	$8.39092 +1.73153 \cdot \log(x)+5.28619 \cdot \log(x)^2$	13.87
Scotia Springs	$15.7189 -10.6577 \cdot \log(x)+9.5503 \cdot \log(x)^2$	373.6
Sharp Springs	$9.74713-3.46324 \cdot \log(x)+7.12899 \cdot \log(x)^2$	209.98

APPENDIX B

SOIL CHEMISTRY MEANS OF MACRONUTRIENTS IN PARTS PER MILLION

AND STANDARD DEVIATION BY SITE

(VALUES SHOWS ARE MEANS WITH STANDARD DEVIATION IN  
PARENTHESES)

<i>Site</i>	Calcium (ppm)	Magnesium (ppm)	Sodium (ppm)	Potassium (ppm)	Nitrate (ppm)	Phosphate (ppm)
Bog Hole	5025 (-1078)	630 (-100)	128 (-80)	623 (-131)	27.2 (-26.3)	40 (-12)
Cieneguita	4100 (-1215)	1058 (-185)	2760 (-1060)	778 (-431)	16.7 (-12.1)	161 (-225)
La Cebadilla	4420 (-1672)	116 (-86)	3840 (-2636)	594 (-396)	12.7 (-8.1)	57 (-54)
Parker Canyon	5240 (-1958)	496 (-263)	177 (-101)	586 (-335)	0.5 (0)	93 (-69)
Scotia	6100 (-700)	753 (-476)	88 (-99)	323 (-71)	6.3 (-10.1)	25 (-10)
Sharp Springs	5260 (-7367)	436 (-38)	60 (-35)	520 (-204)	4.6 (-7)	448 (-7)

APPENDIX C  
MEAN PERCENT CLAY, SILT, AND SAND AT EACH SITE ORDERED BY  
ELEVATION

(n=5)

Site	Clay (%)	Silt (%)	Sand (%)
La Cebadilla	10	40	50
Cieneguita	17	56	27
Sharp			
Springs	15	52	33
Bog Hole	33	51	16
Parker			
Canyon	03	26	71
Scotia	16	29	55

APPENDIX D

WATER CHEMISTRY MEANS OF MACRONUTRIENTS IN PARTS PER MILLION

AND STANDARD DEVIATION BY SITE

(VALUES SHOWN ARE MEANS WITH STANDARD DEVIATION IN PARENTHESES)

Sites	Bog Hole	Cieneguita	La Cebadilla	Parker Canyon	Scotia	Sharp Springs
Calcium (ppm)	28.0 (1.73)	47.0 (12.73)	46.5 (19.09)	35.5 (3.54)	93.25 (27.06)	84.5 (2.12)
Magnesium (ppm)	3.33 (0.58)	17 (9.9)	1.5 (0.71)	5 (0)	19.5 (2.38)	12.5 (2.12)
Potassium (ppm)	9.67 (0.58)	11.5 (13.44)	10.5 (3.54)	6.5 (0.71)	1.25 (0.5)	4 (0)
Nitrate (ppm)	0.1 (0)	0.72 (0.13)	0.8 (0.01)	0.34 (0.34)	0.1 (0)	0.1 (0)
Phosphate (ppm)	0.85 (0.2)	1.78 (1.58)	0.66 (0.01)	0.01 (0)	0.01 (0)	0.01 (0)
Boron (ppm)	0.02 (0)	0.24 (0.11)	0.22 (0.04)	0.01 (0)	0.01 (0)	0.09 (0.1)
pH (SU)	9.47 (0.51)	7.65 (0.21)	7.2 (0.28)	7.25 (0.21)	7.7 (0.16)	7.5 (0)
Ecw (ds/m)	0.4 (0)	1.05 (0.64)	1.45 (0.35)	0.3 (0)	1.94 (2.71)	0.55 (0.07)

APPENDIX E

PLANT FAMILY, SPECIES NAME, WETLAND INDICATOR SCORE (WIS) AND  
ASSIGNED WIS VALUE (1-5) OF PLANTS PRESENT AT SIX CIÉNEGAS

PLANTS ARE ORGANIZED ALPHABETICALLY BY FAMILY \* INDICATE  
 ASSUMED WIS. AN "X" INDICATES THAT A HERBARIUM VOUCHER  
 SPECIMEN WAS COLLECTED

Family	Scientific Name	Duration	Habit	WIS	WIS Value	Voucher
Acanthaceae	<i>Dyschoriste schiedeana</i> var. <i>decumbens</i>	Perennia 1	Forb/herb	UPL*	5	x
Aizoaceae	<i>Trianthema</i> <i>portulacastrum</i>	Annual, Perennia 1	Forb/herb	FAC	3	x
Amaranthaceae	<i>Amaranthus palmeri</i>	Annual	Forb/herb	U	4	x
Amaranthaceae	<i>Chenopodium</i> sp.	---	---	UPL*	5	x
Amaranthaceae	<i>Chenopodium berlandieri</i>	Annual	Forb/herb	UPL*	5	x
Amaranthaceae	<i>Chenopodium murale</i>	Annual	Forb/herb	U	4	x
Amaranthaceae	<i>Gomphrena nitida</i>	Annual	Forb/herb	UPL*	5	x
Amaranthaceae	<i>Salsola tragus</i>	Annual	Forb/herb	U	4	
Anacardiaceae	<i>Rhus aromatica</i>	Perennia 1	Shrub	FAC U	4	x
Anacardiaceae	<i>Rhus lancea</i>	Perennia 1	Tree	UPL*	5	
Anacardiaceae	<i>Rhus trilobata</i>	Perennia 1	Shrub	UPL*	5	
Anacardiaceae	<i>Rhus virens</i>	Perennia 1	Tree, Shrub, Forb/herb,	UPL*	5	
Anacardiaceae	<i>Toxicodendron radicans</i>	Perennia 1	Subshrub, Vine	FAC	3	
Apiaceae	<i>Coriandrum sativum</i>	Annual Perennia	Forb/herb	UPL*	5	x
Apiaceae	<i>Eryngium heterophyllum</i>	1 Perennia	Forb/herb	W	2	x
Apiaceae	<i>Eryngium</i> <i>sparganophyllum</i>	1	Forb/herb	OBL	1	x

	<i>Lilaeopsis schaffneriana</i>	Perennia		OBL		
Apiaceae	var. <i>recurva</i>	1	Forb/herb	*	1	
	<i>Hydrocotyle</i>	Perennia				
Araliaceae	<i>ranunculoides</i>	1	Forb/herb	OBL	1	x
Asclepiadaceae		Perennia				
e	<i>Asclepias lemmonii</i>	1	Forb/herb	UPL*	5	x
Asclepiadaceae		Perennia		FAC		
e	<i>Asclepias subverticillata</i>	1	Forb/herb	U	4	x
Asclepiadaceae		Perennia				
e	<i>Asclepias tuberosa</i>	1	Forb/herb	UPL*	5	
Asparagaceae	<i>Dasyilirion wheeleri</i>	1	Subshrub, Shrub	UPL*	5	
Asparagaceae	<i>Nolina microcarpa</i>	1	Subshrub, Shrub	UPL*	5	
		Perennia		FAC		
Asteraceae	<i>Almutaster pauciflorus</i>	1	Forb/herb	W	2	x
Asteraceae	<i>Ambrosia confertiflora</i>	1	Forb/herb	UPL*	5	x
		Annual, Perennia		FAC		
Asteraceae	<i>Ambrosia psilostachya</i>	1	Forb/herb	U	4	x
			Subshrub,			
Asteraceae	<i>Ambrosia trifida</i>	Annual	Forb/herb	FAC	3	x
		Perennia				
Asteraceae	<i>Baccharis pteronioides</i>	1	Shrub	UPL*	5	x
		Perennia				
Asteraceae	<i>Baccharis salicifolia</i>	1	Shrub	FAC	3	x
		Perennia		FAC		
Asteraceae	<i>Baccharis sarothroides</i>	1	Shrub	U	4	x
		Perennia				
Asteraceae	<i>Berula erecta</i>	1	Forb/herb	OBL	1	x
		Perennia				
Asteraceae	<i>Bidens aurea</i>	1	Forb/herb	OBL	1	x
				FAC		
Asteraceae	<i>Bidens frondosa</i>	Annual	Forb/herb	W	2	x
		Annual, Perennia				
Asteraceae	<i>Bidens laevis</i>	1	Forb/herb	OBL	1	x
Asteraceae	<i>Bidens leptcephala</i>	Annual	Forb/herb	FAC	3	x
Asteraceae	<i>Bidens pilosa</i>	Annual	Forb/herb	FAC	3	x
		Perennia				
Asteraceae	<i>Brickellia betonicifolia</i>	1	Forb/herb	UPL*	5	x
	<i>Brickellia eupatorioides</i>	Perennia	Subshrub,			
Asteraceae	var. <i>chlorolepis</i>	1	Forb/herb	UPL*	5	x

Asteraceae	<i>Brickellia floribunda</i>	Perennia	Subshrub,				
		l	Forb/herb	UPL*	5		
Asteraceae	<i>Carminatia tenuiflora</i>	Annual	Forb/herb	UPL*	5	x	
		Biennial					
		Perennia					
Asteraceae	<i>Cirsium neomexicanum</i>	l	Forb/herb	UPL*	5	x	
		Biennial					
		Perennia					
Asteraceae	<i>Cirsium ochrocentrum</i>	l	Forb/herb	UPL*	5	x	
		Perennia					
Asteraceae	<i>Cirsium wheeleri</i>	l	Forb/herb	UPL*	5	x	
				FAC			
Asteraceae	<i>Cosmos parviflorus</i>	Annual	Forb/herb	U	4	x	
				FAC			
Asteraceae	<i>Erigeron flagellaris</i>	Biennial	Forb/herb	U	4	x	
		Perennia					
Asteraceae	<i>Erigeron neomexicanus</i>	l	Forb/herb	UPL*	5	x	
Asteraceae	<i>Gaillardia arizonica</i>	Annual	Forb/herb	UPL*	5	x	
		Annual,					
		Perennia					
Asteraceae	<i>Gutierrezia wrightii</i>	l	Forb/herb	UPL*	5	x	
				FAC			
Asteraceae	<i>Helianthus annuus</i>	Annual	Forb/herb	U	4	x	
Asteraceae	<i>Heliomeris hispida</i>	Annual	Forb/herb	UPL*	5	x	
Asteraceae	<i>Heliomeris longifolia</i>	Annual	Forb/herb	UPL*	5	x	
		Perennia	Subshrub,				
Asteraceae	<i>Heliomeris multiflora</i>	l	Forb/herb	UPL*	5	x	
Asteraceae	<i>Heterosperma pinnatum</i>	Annual	Forb/herb	UPL*	5	x	
Asteraceae	<i>Heterotheca subaxillaris</i>	Annual	Forb/herb	UPL*	5	x	
		Perennia		FAC			
Asteraceae	<i>Isocoma acradenia</i>	l	Subshrub	U	4		
		Perennia	Subshrub,				
Asteraceae	<i>Isocoma tenuisecta</i>	l	Forb/herb	UPL*	5	x	
		Annual,		FAC			
Asteraceae	<i>Lactuca serriola</i>	Biennial	Forb/herb	U	4	x	
Asteraceae	<i>Laennecia coulteri</i>	Annual	Forb/herb	FAC	3	x	
Asteraceae	<i>Laennecia eriophylla</i>	Annual	Forb/herb	UPL*	5	x	
Asteraceae	<i>Laennecia sophiifolia</i>	Annual	Forb/herb	UPL*	5	x	
		Perennia					
Asteraceae	<i>Lasianthaea podocephala</i>	l	Forb/herb	UPL*	5	x	
Asteraceae	<i>Machaeranthera tagetina</i>	Annual	Forb/herb	UPL*	5	x	
		Perennia	Subshrub,				
Asteraceae	<i>Melampodium leucanthum</i>	l	Forb/herb	UPL*	5	x	

Asteraceae	<i>Melampodium sericeum</i>	Annual	Forb/herb	UPL*	5	x
Asteraceae	<i>Melampodium strigosum</i>	Annual	Forb/herb	UPL*	5	x
Asteraceae	<i>Pectis papposa</i>	Annual	Forb/herb	UPL*	5	x
Asteraceae	<i>Porophyllum ruderale</i> ssp. <i>macrocephalum</i>	Annual	Forb/herb	UPL*	5	x
Asteraceae	<i>Pseudognaphalium arizonicum</i>	Annual Annual, Biennial	Forb/herb	UPL*	5	
Asteraceae	<i>Pseudognaphalium canescens</i>	Perennia l	Forb/herb	FAC U	4	x
Asteraceae	<i>Pseudognaphalium luteoalbum</i>	Annual	Forb/herb	FAC	3	x
Asteraceae	<i>Pseudognaphalium stramineum</i>	Annual, Biennial	Forb/herb	FAC	3	x
Asteraceae	<i>Psilactis gentryi</i>	Annual	Forb/herb	UPL*	5	x
Asteraceae	<i>Pyrrhopappus pauciflorus</i>	Annual, Perennia l	Forb/herb	UPL*	5	x
Asteraceae	<i>Pyrrhopappus rothrockii</i>	Perennia l	Forb/herb	UPL*	5	x
Asteraceae	<i>Rudbeckia laciniata</i>	Perennia l	Forb/herb	FAC FAC	3	x
Asteraceae	<i>Solidago altissima</i>	Perennia l	Forb/herb	U	4	x
Asteraceae	<i>Solidago canadensis</i>	l	Forb/herb	UPL*	5	x
Asteraceae	<i>Sonchus asper</i>	Annual	Forb/herb	FAC FAC	3	x
Asteraceae	<i>Sonchus oleraceus</i>	Annual Annual, Biennial	Forb/herb	UP*	4	
Asteraceae	<i>Stephanomeria exigua</i>	Perennia l	Forb/herb	UPL*	5	x
Asteraceae	<i>Stevia lemmonii</i>	Perennia l	Subshrub, Shrub	UPL*	5	x
Asteraceae	<i>Stevia micrantha</i>	Annual	Forb/herb	UPL*	5	x
Asteraceae	<i>Symphotrichum falcatum</i> var. <i>commutatum</i>	Perennia l	Forb/herb	FAC UP*	4	x
Asteraceae	<i>Symphotrichum potosinum</i>	Perennia l	Forb/herb	FAC WET *	2	

				FAC		
Asteraceae	<i>Symphyotrichum subulatum</i>	Annual, Biennial	Forb/herb	WET *	2	x
Asteraceae	<i>Tagete smicrantha</i>	Annual	Forb/herb	UPL*	5	x
Asteraceae	<i>Taraxacum officinale</i>	Perennia	Forb/herb	FAC U	4	x
Asteraceae	<i>Verbesina rothrockii</i>	1 Perennia	Forb/herb	UPL*	5	x
Asteraceae	<i>Viguiera dentata</i>	1	Forb/herb	UPL*	5	x
Asteraceae	<i>Xanthium strumarium</i>	Annual	Forb/herb	FAC	3	x
Asteraceae	<i>Xanthocephalum gymnospermoides</i>	Annual	Forb/herb	FAC	3	x
Asteraceae	<i>Zinnia peruviana</i>	Annual, Perennia	Forb/herb	UPL*	5	x
Asteraceae	<i>Eclipta prostrata</i>	1	Forb/herb	FAC	3	
Boraginaceae	<i>Heliotropium curassavicum</i>	Annual, Perennia	Subshrub, Forb/herb	FAC U	4	x
Boraginaceae	<i>Lithospermum cobrense</i>	1 Perennia	Forb/herb	UPL*	5	x
Brassicaceae	<i>Descurainia pinnata</i>	Annual, Biennial	Forb/herb	UPL*	5	x
Brassicaceae	<i>Descurainia sophia</i>	Perennia	Forb/herb	UPL*	5	x
Brassicaceae	<i>Hesperidanthus linearifolius</i>	1 Perennia	Forb/herb	UPL*	5	x
Brassicaceae	<i>Nasturtium officinale</i>	1 Biennial	Forb/herb	OBL	1	x
Brassicaceae	<i>Pennellia micrantha</i>	1 Perennia	Forb/herb	UPL*	5	x
Brassicaceae	<i>Sisymbrium irio</i>	Annual, Perennia	Forb/herb	UPL*	5	x
Cactaceae	<i>Carnegiea gigantea</i>	1	Tree	UPL*	5	
Cactaceae	<i>Opuntia</i> sp.	---	---	UPL*	5	
Campanulaceae	<i>Lobelia cardinalis</i>	Perennia	Forb/herb	OBL	1	x

Chenopodiaceae		Annual, Perennia					
	<i>Atriplex elegans</i>	l	Forb/herb	UPL*	5	x	
Chenopodiaceae		Annual	Forb/herb	UPL*	5	x	
	<i>Atriplex wrightii</i>						
Chenopodiaceae		Annual	Forb/herb	UPL*	5	x	
	<i>Dysphania graveolens</i>						
Chenopodiaceae		Annual	Forb/herb	UPL*	5	x	
	<i>Kochia scoparia</i>						
Commelinaceae		Perennia					
	<i>Commelina dianthifolia</i>	l	Forb/herb	UPL*	5	x	
Commelinaceae		Perennia		FAC			
	<i>Commelina erecta</i>	l	Forb/herb	U	4	x	
Convolvulaceae		Annual, Perennia	Vine, Forb/herb	FAC			
	<i>Convolvulus equitans</i>	l		U	4	x	
Convolvulaceae		Perennia					
	<i>Evolvulus arizonicus</i>	l	Forb/herb	UPL*	5	x	
Convolvulaceae		Annual	Vine, Forb/herb	UPL*	5		
	<i>Ipomoea coccinea</i>						
Convolvulaceae		Annual	Vine, Forb/herb	UPL*	5	x	
	<i>Ipomoea costellata</i>						
Convolvulaceae		Annual	Vine, Forb/herb	UPL*	5	x	
	<i>Ipomoea cristulata</i>						
Convolvulaceae		Annual	Vine, Forb/herb	FAC			
	<i>Ipomoea hederacea</i>			U	4	x	
Convolvulaceae		Annual	Vine, Forb/herb	UPL	5	x	
	<i>Ipomoea purpurea</i>						
Convolvulaceae		Perennia	Vine, Forb/herb	UPL*	5	x	
	<i>Ipomoea tenuiloba</i>	l					
Cucurbitaceae		Perennia	Vine, Forb/herb	UPL*	5	x	
	<i>Apodanthera undulata</i>	l					
Cucurbitaceae		Perennia	Vine, Forb/herb	UPL*	5	x	
	<i>Cucurbita foetidissima</i>	l					
Cucurbitaceae		Annual	Vine, Forb/herb	UPL*	5	x	
	<i>Sicyos laciniatus</i>						
Cupressaceae		Perennia	Tree, Shrub	FAC			
	<i>Juniperus deppeana</i>	l		U	4	x	
Cyperaceae		Annual	Graminoi d	FAC			
	<i>Bulbostylis funckii</i>			W	2	x	
Cyperaceae		Perennia	Graminoi d	OBL	1	x	
	<i>Carex alma</i>	l					
Cyperaceae		Perennia	Graminoi d	FAC			
	<i>Carex praegracilis</i>	l		W	2	x	

Cyperaceae	<i>Carex spissa</i>	Perennia l	Graminoi d	FAC	3	x
Cyperaceae	<i>Carex thurberi</i>	Perennia l	Graminoi d	FAC	3	x
Cyperaceae	<i>Cyperus esculentus</i>	Perennia l	Graminoi d	FAC W	2	x
Cyperaceae	<i>Cyperus fendlerianus</i>	Perennia l	Graminoi d	FAC	3	x
Cyperaceae	<i>Cyperus flavicomus</i>	Annual Perennia	d Graminoi	FAC FAC	3	x
Cyperaceae	<i>Cyperus manimae</i>	l	d	U*	4	x
Cyperaceae	<i>Cyperus niger</i>	Annual, Perennia l	Graminoi d	FAC W	2	x
Cyperaceae	<i>Cyperus odoratus</i>	Perennia l	Graminoi d	FAC W	2	x
Cyperaceae	<i>Cyperus squarrosus</i>	Annual Perennia	d Graminoi	OBL FAC	1	x
Cyperaceae	<i>Eleocharis macrostachya</i>	l	d	W*	2	x
Cyperaceae	<i>Eleocharis montevidensis</i>	Perennia l	Graminoi d	FAC W	2	x
Cyperaceae	<i>Eleocharis palustris</i>	Perennia l	Graminoi d	OBL FAC	1	x
Cyperaceae	<i>Eleocharis parishii</i>	Perennia l	Graminoi d	W	2	x
Cyperaceae	<i>Schoenoplectus acutus</i>	Perennia l	Graminoi d	OBL	1	x
Cyperaceae	<i>Schoenoplectus americanus</i>	Perennia l	Graminoi d	OBL	1	x
Cyperaceae	<i>Schoenoplectus californicus</i>	Perennia l	Graminoi d	OBL FAC	1	x
Equisetaceae	<i>Equisetum laevigatum</i>	Perennia l	Forb/herb	W	2	x
Ericaceae	<i>Arbutus arizonica</i>	Perennia l	Tree	UPL*	5	x
Ericaceae	<i>Arctostaphylos pungens</i>	Perennia l	Shrub, Subshrub	UPL*	5	x
Euphorbiaceae	<i>Acalypha neomexicana</i>	Annual	Forb/herb	UPL*	5	x
Euphorbiaceae	<i>Acalypha ostryifolia</i>	Annual	Forb/herb	UPL*	5	x

Euphorbiaceae		Perennia	Forb/herb,				
e	<i>Acalypha phleoides</i>	l	Subshrub	UPL*	5	x	
Euphorbiaceae	<i>Chamaesyce</i>	Perennia					
e	<i>albomarginata</i>	l	Forb/herb	UPL*	5	x	
Euphorbiaceae	<i>Chamaesyce dioica</i>	Annual	Forb/herb	UPL*	5	x	
		Annual,					
Euphorbiaceae	<i>Chamaesyce hyssopifolia</i>	Perennia	Forb/herb	UPL*	5	x	
Euphorbiaceae	<i>Euphorbia bilobata</i>	Annual	Forb/herb	UPL*	5	x	
Euphorbiaceae	<i>Euphorbia dentata</i>	Annual	Forb/herb	UPL*	5	x	
		Annual,					
Euphorbiaceae	<i>Euphorbia heterophylla</i>	Perennia	Forb/herb	UPL	5	x	
Euphorbiaceae	<i>Tragia laciniata</i>	Perennia	Vine,	UPL*	5	x	
Euphorbiaceae	<i>Tragia nepetifolia</i>	Perennia	Forb/herb	UPL*	5	x	
		Perennia		FAC			
Fabaceae	<i>Amorpha fruticosa</i>	l	Shrub	W	2	x	
		Perennia					
Fabaceae	<i>Astragalus humistratus</i>	l	Forb/herb	UPL*	5	x	
		Perennia					
Fabaceae	<i>Astragalus nothoxys</i>	l	Forb/herb	UPL*	5	x	
		Perennia					
Fabaceae	<i>Astragalus vaccarum</i>	l	Forb/herb	UPL*	5	x	
		Perennia	Subshrub,				
Fabaceae	<i>Calliandra humilis</i>	l	Forb/herb	UPL*	5	x	
		Annual,					
Fabaceae	<i>Chamaecrista nictitans</i>	Perennia	Subshrub,	UPL*	5	x	
		Annual,	Forb/herb				
Fabaceae	<i>Crotalaria pumila</i>	l	Forb/herb	UPL*	5	x	
		Annual,					
Fabaceae	<i>Crotalaria sagittalis</i>	Perennia	Subshrub,				
		l	Forb/herb	UPL*	5	x	
Fabaceae	<i>Dalea exigua</i>	Annual	Forb/herb	UPL*	5	x	
Fabaceae	<i>Dalea filiformis</i>	Annual	Forb/herb	UPL*	5	x	
Fabaceae	<i>Dalea leporina</i>	Annual	Forb/herb	UPL	5	x	
		Perennia	Subshrub,				
Fabaceae	<i>Desmanthus cooleyi</i>	l	Forb/herb	UPL*	5	x	

		Annual, Perennia					
Fabaceae	<i>Desmodium psilocarpum</i>	1	Forb/herb	UPL*	5	x	
		Perennia					
Fabaceae	<i>Desmodium retinens</i>	1	Forb/herb	UPL*	5	x	
Fabaceae	<i>Desmodium rosei</i>	Annual	Forb/herb	UPL*	5	x	
		Perennia	Vine,				
Fabaceae	<i>Galactia wrightii</i>	1	Forb/herb	UPL*	5	x	
		Perennia					
Fabaceae	<i>Indigofera sphaerocarpa</i>	1	Shrub	UPL*	5	x	
		Perennia					
Fabaceae	<i>Lotus alamosanus</i>	1	Forb/herb	UPL*	5	x	
		Perennia					
Fabaceae	<i>Lotus corniculatus</i>	1	Forb/herb	FAC	3	x	
Fabaceae	<i>Lupinus concinnus</i>	Annual	Forb/herb	UPL*	5	x	
		Perennia					
Fabaceae	<i>Macroptilium gibbosifolium</i>	1	Forb/herb	UPL*	5	x	
		Annual, Perennia					
Fabaceae	<i>Medicago sativa</i>	1	Forb/herb	UPL FAC	5	x	
Fabaceae	<i>Melilotus indicus</i>	Annual Annual, Biennial	Forb/herb	U	4	x	
		Perennia		FAC			
Fabaceae	<i>Melilotus officinalis</i>	1	Forb/herb	U	4	x	
		Perennia	Tree,				
Fabaceae	<i>Mimosa biuncifera</i>	1	Shrub	UPL*	5		
Fabaceae	<i>Phaseolus sp.</i>	---	---	UPL*	5	x	
			Vine,				
Fabaceae	<i>Phaseolus acutifolius</i>	Annual	Forb/herb	UPL*	5	x	
		Perennia	Tree,				
Fabaceae	<i>Prosopis juliflora</i>	1	Shrub	UPL*	5	x	
		Perennia	Vine,				
Fabaceae	<i>Rhynchosiasenna</i> var. <i>texana</i>	1	Forb/herb	UPL*	5	x	
		Perennia					
Fabaceae	<i>Tephrosia tenella</i>	1	Forb/herb	UPL*	5	x	
Fabaceae	<i>Trifolium dubium</i>	Annual	Forb/herb	UPL	5	x	
		Perennia		FAC			
Fabaceae	<i>Trifolium repens</i>	1	Forb/herb	U	4	x	
		Perennia	Tree,				
Fagaceae	<i>Quercus emoryi</i>	1	Shrub	UPL*	5		
		Perennia	Tree,				
Fagaceae	<i>Quercus grisea</i>	1	Shrub	UPL*	5	x	

Fagaceae	<i>Quercus hypoleucoides</i>	Perennia 1	Tree, Shrub	UPL*	5	x
Garryaceae	<i>Garrya flavescens</i>	Perennia 1	Tree, Shrub	UPL*	5	x
Garryaceae	<i>Garrya wrightii</i>	Perennia 1	Shrub, Tree	UPL*	5	
Gentianaceae	<i>Eustoma exaltatum</i>	Annual, Perennia 1	Forb/herb	OBL	1	x
Geraniaceae	<i>Geranium caespitosum</i>	Perennia 1	Subshrub, Forb/herb	FAC	3	x
Grossulariaceae	<i>Ribes aureum</i>	Perennia 1	Shrub	FAC	3	x
Iridaceae	<i>Sisyrinchium demissum</i>	Perennia 1	Forb/herb	OBL	1	x
Juncaceae	<i>Juncus acuminatus</i>	Perennia 1	Graminoi d	OBL	1	x
Juncaceae	<i>Juncus articulatus</i>	Perennia 1	Graminoi d	OBL	1	x
Juncaceae	<i>Juncus balticus</i>	Perennia 1	Graminoi d	FAC W	2	x
Juncaceae	<i>Juncus bufonius</i>	Annual Perennia	d Graminoi	W FAC	2	x
Juncaceae	<i>Juncus mexicanus</i>	Perennia 1	d Graminoi	W FAC	2	x
Juncaceae	<i>Juncus saximontanus</i>	Perennia 1	d Graminoi	W FAC	2	x
Juncaceae	<i>Juncus torreyi</i>	Perennia 1	d Graminoi	W FAC	2	x
Lamiaceae	<i>Hedeoma dentata</i>	Perennia 1	Forb/herb	UPL*	5	x
Lamiaceae	<i>Monarda citriodora</i> ssp.	Annual, Biennial	Forb/herb	UPL*	5	x
Lamiaceae	<i>Salvia subincisa</i>	Annual Perennia	Forb/herb	UPL*	5	x
Lamiaceae	<i>Stachys coccinea</i>	Perennia 1	Forb/herb	FAC	3	x
Lemnaceae	<i>Lemna minor</i>	Perennia 1	Forb/herb	OBL	1	x
Loasaceae	<i>Mentzelia isolata</i>	Annual	Forb/herb	UPL*	5	x
Lythraceae	<i>Cuphea wrightii</i>	Annual Perennia	Forb/herb	UPL*	5	x
Lythraceae	<i>Lythrum californicum</i>	Perennia 1	Subshrub, Forb/herb	OBL	1	x
Lythraceae	<i>Punica granatum</i>	Perennia 1	Tree, Shrub	UPL*	5	x
Malvaceae	<i>Anoda cristata</i>	Annual	Forb/herb	FAC	3	x

Malvaceae	<i>Anoda pentaschista</i>	Annual Perennia	Forb/herb Subshrub,	UPL*	5	x
Malvaceae	<i>Rhynchosida physocalyx</i>	l Annual, Perennia	Forb/herb	UPL*	5	x
Malvaceae	<i>Sida abutifolia</i>	l Annual, Perennia	Forb/herb Subshrub,	UPL*	5	x
Malvaceae	<i>Sida spinosa</i>	l	Forb/herb	UPL FAC	5	x
Molluginacea e	<i>Mollugo verticillata</i>	Annual	Forb/herb	U	4	x
Montiaceae	<i>Phemeranthus aurantiacus</i>	l Perennia	Forb/herb, Subshrub	UPL*	5	x
Nyctaginacea e	<i>Boerhavia coccinea</i>	l Perennia	Forb/herb	UPL*	5	x
Nyctaginacea e	<i>Mirabilis longiflora</i>	l Perennia	Forb/herb	UPL*	5	x
Oleaceae	<i>Fraxinus velutina</i>	l Perennia	Tree	FAC FAC	3	x
Onagraceae	<i>Epilobium ciliatum</i>	l	Forb/herb	W	2	x
Onagraceae	<i>Gaura hexandra</i> ssp. <i>gracilis</i>	Annual	Forb/herb	UPL*	5	x
Onagraceae	<i>Gaura mollis</i>	--- Biennial	---	UPL*	5	x
Onagraceae	<i>Oenothera elata</i>	l Perennia	Forb/herb	FAC W	2	x
Onagraceae	<i>Oenothera rosea</i>	l Perennia	Forb/herb Subshrub,	W	2	x
Oxalidaceae	<i>Oxalis pilosa</i>	l Perennia	Forb/herb	UPL*	5	x
Papaveraceae	<i>Argemone pleiacantha</i>	l	Forb/herb	UPL*	5	x
Pedaliaceae	<i>Proboscidea parviflora</i>	Annual Perennia	Forb/herb	UPL*	5	x
Pinaceae	<i>Pinus cembroides</i>	l Perennia	Tree	UPL* FAC	5	x
Poaceae	<i>Agrostis exarata</i>	l Perennia	Graminoi d	W	2	x
Poaceae	<i>Agrostis scabra</i>	l Perennia	Graminoi d	FAC	3	x
Poaceae	<i>Andropogon glomeratus</i>	l	Graminoi d	FAC W	2	x
Poaceae	<i>Aristida adscensionis</i>	Annual	Graminoi d	UPL*	5	x

Poaceae	<i>Aristida divaricata</i>	Perennia l	Graminoi d	UPL*	5	x
Poaceae	<i>Aristida schiedeana</i> var. <i>orcuttiana</i>	Perennia l	Graminoi d	UPL*	5	x
Poaceae	<i>Aristida ternipes</i> var. <i>gentilis</i>	Perennia l	Graminoi d	UPL*	5	x
Poaceae	<i>Aristida ternipes</i> var. <i>ternipes</i>	Perennia l	Graminoi d	UPL*	5	x
Poaceae	<i>Bothriochloa barbinodis</i>	Perennia l	Graminoi d	UPL	5	x
Poaceae	<i>Bothriochloa ischaemum</i>	Perennia l	Graminoi d	UPL*	5	x
Poaceae	<i>Bothriochloa laguroides</i> ssp. <i>torreyana</i>	Perennia l	Graminoi d	UPL*	5	x
Poaceae	<i>Bothriochloa laguroides</i> ssp. <i>laciniata</i>	Perennia l	Graminoi d	UPL*	5	
Poaceae	<i>Bouteloua curtipendula</i>	Perennia l	Graminoi d	UPL*	5	x
Poaceae	<i>Bouteloua gracilis</i>	Perennia l	Graminoi d	UPL*	5	x
Poaceae	<i>Bouteloua hirsuta</i>	Perennia l	Graminoi d	UPL*	5	x
Poaceae	<i>Bromus arizonicus</i>	Annual Annual, Perennia	Graminoi d	UPL*	5	x
Poaceae	<i>Bromus carinatus</i>	Perennia l	Graminoi d	UPL*	5	x
Poaceae	<i>Bromus ciliatus</i>	Perennia l	Graminoi d	FAC	3	x
Poaceae	<i>Bromus rubens</i>	Annual	Graminoi d	UPL* FAC	5	
Poaceae	<i>Chloris virgata</i>	Annual	Graminoi d	U	4	x
Poaceae	<i>Cynodon dactylon</i>	Perennia l	Graminoi d	FAC U	4	x
Poaceae	<i>Digitaria californica</i>	Perennia l	Graminoi d	UPL*	5	
Poaceae	<i>Distichlis spicata</i>	Perennia l	Graminoi d	FAC	3	x
Poaceae	<i>Echinochloa colona</i>	Annual	Graminoi d	FAC FAC	3	x
Poaceae	<i>Echinochloa crus-galli</i>	Annual Perennia	Graminoi d	W	2	x
Poaceae	<i>Elymus canadensis</i>	Perennia l	Graminoi d	FAC	3	x

Poaceae	<i>Elymus elymoides</i>	Perennia l	Graminoi d	FAC U	4	x
Poaceae	<i>Elymus trachycaulus</i>	Perennia l	Graminoi d	FAC U	4	x
Poaceae	<i>Eragrostis cilianensis</i>	Annual Perennia	d Graminoi	U FAC	4	x
Poaceae	<i>Eragrostis intermedia</i>	l	d Graminoi	UPL* FAC	5	x
Poaceae	<i>Eragrostis mexicana</i>	Annual	d Graminoi	U FAC	4	x
Poaceae	<i>Eriochloa acuminata</i>	Annual Perennia	d Graminoi	W FAC	2	x
Poaceae	<i>Hilaria belangeri</i>	l Perennia	d Graminoi	UPL* FAC	5	x
Poaceae	<i>Hopia obtusa</i>	l Perennia	d Graminoi	U FAC	4	x
Poaceae	<i>Hordeum jubatum</i>	l Perennia	d Graminoi	FAC	3	x
Poaceae	<i>Leersia oryzoides</i>	l Perennia	d Graminoi	OBL FAC	1	x
Poaceae	<i>Leptochloa dubia</i>	l	d	UPL*	5	x
Poaceae	<i>Leptochloa fusca</i> ssp. <i>fascicularis</i>	Annual, Perennia l	Graminoi d	UPL*	5	x
Poaceae	<i>Leptochloa fusca</i> ssp. <i>uninervia</i>	Annual, Perennia l	Graminoi d	UPL*	5	x
Poaceae	<i>Leptochloa panacea</i> ssp. <i>brachiata</i>	Annual, Perennia l	Graminoi d	UPL*	5	x
Poaceae	<i>Leptochloa viscida</i>	Annual Perennia	d Graminoi	UPL*	5	x
Poaceae	<i>Lolium arundinaceum</i>	l Perennia	d Graminoi	UPL*	5	x
Poaceae	<i>Lycurus setosus</i>	l Perennia	d Graminoi	UPL* FAC	5	x
Poaceae	<i>Muhlenbergia asperifolia</i>	l	d Graminoi	W FAC	2	x
Poaceae	<i>Muhlenbergia fragilis</i>	Annual	d Graminoi	UPL*	5	x
Poaceae	<i>Muhlenbergia minutissima</i>	Annual Perennia	d Graminoi	FAC	3	x
Poaceae	<i>Muhlenbergia repens</i>	l	d	UPL*	5	x

Poaceae	<i>Muhlenbergia rigens</i>	Perennia l	Graminoi d	FAC	3	x
Poaceae	<i>Panicum bulbosum</i>	Perennia l	Graminoi d	UPL*	5	x
Poaceae	<i>Panicum hirticaule</i>	Annual Perennia	d Graminoi	UPL*	5	x
Poaceae	<i>Paspalum dilatatum</i>	l Perennia	d Graminoi	FAC FAC	3	x
Poaceae	<i>Paspalum distichum</i>	l	d Graminoi	W	2	x
Poaceae	<i>Phalaris minor</i>	Annual Perennia	d Graminoi	UPL*	5	x
Poaceae	<i>Piptochaetium fimbriatum</i>	l Perennia	d Graminoi	UPL*	5	x
Poaceae	<i>Poa pratensis</i>	l	d Graminoi	FAC FAC	3	x
Poaceae	<i>Polypogon monspeliensis</i>	Annual Perennia	d Graminoi	W FAC	2	x
Poaceae	<i>Polypogon viridis</i>	l Perennia	d Graminoi	W	2	x
Poaceae	<i>Schizachyrium cirratum</i>	l	d	UPL*	5	
Poaceae	<i>Schizachyrium sanguineum</i> var. <i>hirtiflorum</i>	Perennia l	Graminoi d	UPL*	5	x
Poaceae	<i>Setaria grisebachii</i>	Annual Perennia	d Graminoi	UPL* FAC	5	x
Poaceae	<i>Sorghum halepense</i>	l Annual, Perennia	d Graminoi	U	4	x
Poaceae	<i>Sphenopholis obtusata</i>	l Perennia	d Graminoi	FAC	3	x
Poaceae	<i>Sporobolus wrightii</i>	l Perennia	d Graminoi	FAC	3	x
Poaceae	<i>Trichloris crinita</i>	l	d Graminoi	UPL*	5	x
Poaceae	<i>Urochloa aarizonica</i>	Annual Perennia	d Graminoi	UPL*	5	x
Poaceae	<i>Zuloagaea bulbosa</i>	l	d	UPL*	5	x
Polemoniaceae	<i>Ipomopsis multiflora</i>	Perennia l	Subshrub, Forb/herb	UPL*	5	x

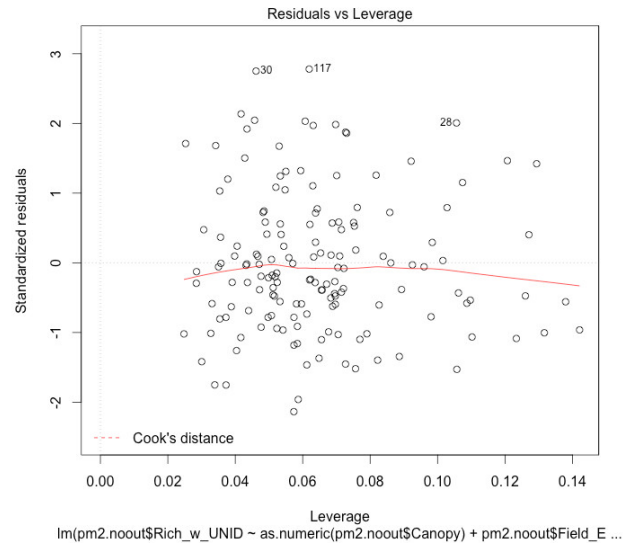
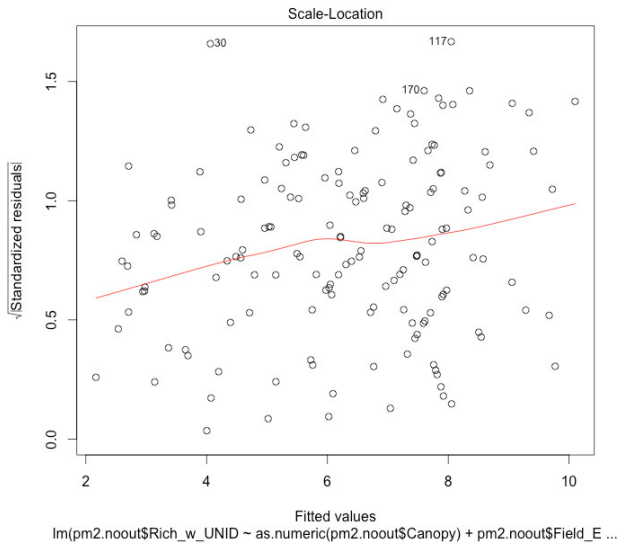
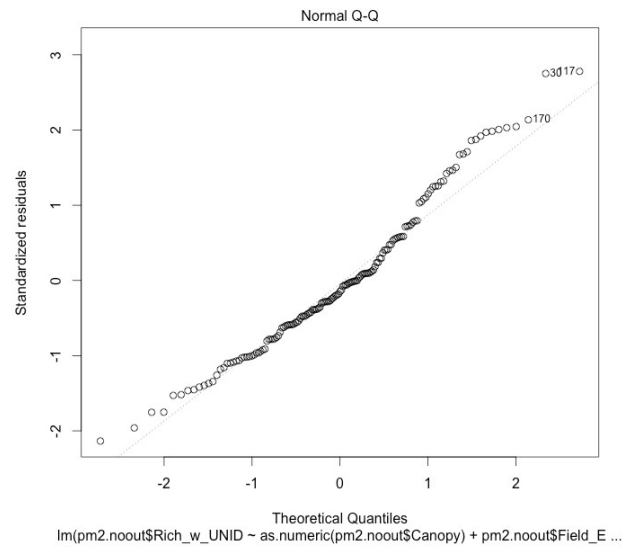
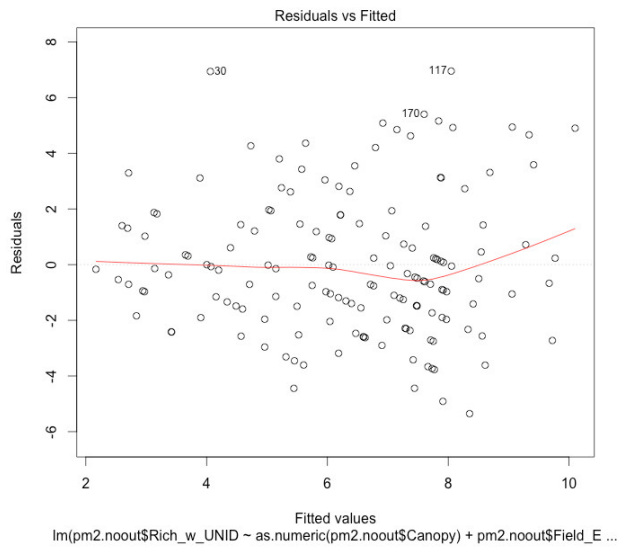
		Biennial					
Polemoniaceae		Perennia					
	<i>Ipomopsis thurberi</i>	l	Forb/herb	UPL*	5	x	
Polemoniaceae		Perennia	Subshrub,				
	<i>Polygala obscura</i>	l	Forb/herb	UPL*	5	x	
Polygonaceae	<i>Eriogonum abertianum</i>	Annual	Forb/herb	UPL*	5	x	
				FAC			
Polygonaceae	<i>Persicaria bicornis</i>	Annual	Forb/herb	W	2	x	
				FAC			
Polygonaceae	<i>Persicaria lapathifolia</i>	Annual	Forb/herb	W	2	x	
		Annual,					
		Perennia		FAC			
Polygonaceae	<i>Polygonum aviculare</i>	l	Forb/herb	W	2	x	
		Annual,					
		Perennia					
Polygonaceae	<i>Polygonum punctatum</i>	l	Forb/herb	UPL*	5	x	
		Perennia					
Polygonaceae	<i>Rumex crispus</i>	l	Forb/herb	FAC	3	x	
		Perennia					
Polygonaceae	<i>Rumex hymenosepalus</i>	l	Forb/herb	UPL*	5	x	
Portulacaceae	<i>Portulaca oleracea</i>	Annual	Forb/herb	FAC	3	x	
		Perennia	Subshrub,				
Portulacaceae	<i>Portula casuffrutescens</i>	l	Forb/herb	UPL*	5	x	
				FAC			
Portulacaceae	<i>Portulaca umbraticola</i>	Annual	Forb/herb	U	4	x	
Potamogetonaceae	<i>Potamogeton</i> sp.	---	---	OBL			
				*	1	x	
		Perennia					
Primulaceae	<i>Samolus vagans</i>	l	Forb/herb	OBL	1	x	
		Perennia					
Pteridaceae	<i>Cheilanthes fendleri</i>	l	Forb/herb	UPL*	5	x	
Ranunculaceae							
	<i>Myosurus minimus</i>	Annual	Forb/herb	OBL	1	x	
Ranunculaceae	<i>Ranunculus</i>	Perennia					
	<i>hydrocharoides</i>	l	Forb/herb	OBL	1	x	
Ranunculaceae		Perennia					
	<i>Ranunculus macounii</i>	l	Forb/herb	OBL	1	x	
Ranunculaceae		Perennia					
	<i>Ranunculus macranthus</i>	l	Forb/herb	UPL*	5	x	
		Perennia	Tree,				
Rhamnaceae	<i>Ziziphus obtusifolia</i>	l	Shrub	UPL*	5	x	
		Perennia	Tree,				
Rosaceae	<i>Purshia stansburiana</i>	l	Shrub	UPL*	5	x	

		Annual, Perennia		FAC		
Rubiaceae	<i>Diodia teres</i>	l	Forb/herb	U	4	x
		Perennia		FAC		
Rubiaceae	<i>Galium microphyllum</i>	l	Forb/herb	U	4	x
Rubiaceae	<i>Mitracarpus breviflorus</i>	Annual	Forb/herb	UPL*	5	x
		Perennia		FAC		
Salicaceae	<i>Populus fremontii</i>	l	Tree	*	3	
		Perennia		FAC		
Salicaceae	<i>Salix bonplandiana</i>	l	Tree	W	2	x
		Perennia		FAC		
Salicaceae	<i>Salix gooddingii</i>	l	Tree	W	2	x
		Perennia		FAC		
Salicaceae	<i>Salix taxifolia</i>	l	Tree	U*	4	x
		Perennia				
Saururaceae	<i>Anemopsis californica</i>	l	Forb/herb	OBL	1	x
		Annual, Perennia				
Scrophulariac eae	<i>Mimulus guttatus</i>	l	Forb/herb	OBL	1	x
Scrophulariac eae	<i>Schistophragma intermedia</i>	Annual	Forb/herb	UPL*	5	x
Scrophulariac eae	<i>Verbascum blattaria</i>	Biennial	Forb/herb	UPL	5	x
Scrophulariac eae	<i>Verbascum thapsus</i>	Biennial Biennial	Forb/herb	FAC U	4	x
		Perennia				
Scrophulariac eae	<i>Veronica anagallis- aquatica</i>	l	Forb/herb	OBL	1	x
Scrophulariac eae	<i>Veronica peregrina</i>	Annual	Forb/herb	OBL FAC	1	x
Solanaceae	<i>Calibrachoa parviflora</i>	Annual Perennia	Forb/herb	W	2	x
Solanaceae	<i>Lycium andersonii</i>	l Perennia	Shrub Tree,	UPL*	5	x
Solanaceae	<i>Nicotiana glauca</i>	l	Shrub	FAC	3	x
Solanaceae	<i>Physalis acutifolia</i>	Annual	Forb/herb	UPL*	5	x
		Annual, Perennia				
Solanaceae	<i>Physalis crassifolia</i>	l Perennia	Subshrub, Forb/herb	UPL*	5	
Solanaceae	<i>Physalis hederifolia</i>	l Perennia	Subshrub, Forb/herb	UPL*	5	x
Solanaceae	<i>Physalis longifolia</i>	l	Forb/herb	UPL*	5	x

Solanaceae	<i>Physalis philadelphica</i>	Annual	Forb/herb	UPL FAC	5	x
Solanaceae	<i>Physalis pubescens</i>	Annual	Forb/herb	U	4	x
Solanaceae	<i>Solanum elaeagnifolium</i>	Perennia	Subshrub, Forb/herb	UPL*	5	x
Tamaricaceae	<i>Tamarix chinensis</i>	Perennia	Tree, Shrub	FAC	3	x
Typhaceae	<i>Typha latifolia</i>	Perennia	Forb/herb	OBL	1	x
Ulmaceae	<i>Celtis pallida</i>	Perennia	Tree, Shrub	UPL*	5	x
Verbenaceae	<i>Glandularia bipinnatifida</i>	Annual, Perennia	Forb/herb	UPL*	5	x
Verbenaceae	<i>Verbena bracteata</i>	Biennial, Perennia	Forb/herb	FAC	3	x
Verbenaceae	<i>Verbena carolina</i>	Perennia	Forb/herb	UPL*	5	x
Verbenaceae	<i>Verbena neomexicana</i>	Perennia	Forb/herb	UPL*	5	x
Viscaceae	<i>Phoradendron californicum</i>	Perennia	Subshrub, Shrub	UPL* FAC	5	x
Vitaceae	<i>Vitis arizonica</i>	Perennia	Vine	U	4	x
Zannichelliaceae	<i>Zannichellia palustris</i>	Perennia	Forb/herb	OBL	1	x

APPENDIX F  
RESIDUAL PLOTS FOR LINEAR MODEL

## Residual plots based linear model (TABLE 11).



APPENDIX G

COLLECTIONS OF EACH PLANT SPECIES AT EACH FIELD SITE

	Bog Hole	Cieneg uita	La Cebadilla	Parker Canyon	Scotia Springs	Sharp Springs	Total
Acanthaceae	1			1	1	1	4
Dyschoriste decumbens					1		1
Dyschorist e schiedeana var. decumbens	1			1		1	3
Aizoaceae		1					1
Trianthema portulacastrum		1					1
Amaranthace ae	1	1				3	5
Amaranthus palmeri		1				3	4
Gomphren a nitida	1						1
Anacardiaceae				1			1
Rhus aromatica				1			1
Apiaceae	1	3	3	3	4	1	15
Berula erecta		1		3	1		5
Coriandrum sativum		1					1
Eryngium heterophyllu m	1				3	1	5
Eryngium sparganophyllum			3				3
Hydrocotyle ranunculoides		1					1
Asclepiadace ae	1	1		1		5	8
Asclepias lemmonii				1			1
Asclepias subverticillat a	1	1				5	7
Asteraceae	23	20	4	26	36	30	139
Almutaster pauciflorus		2	2				4
Ambrosia confertiflora		1			1	1	3
Ambrosia	1	1			1	2	5

psilostachya					
Ambrosia trifida		2		2	4
Artemisia	1			1	2
Baccharis pteronioides			1	1	2
Baccharis salicifolia			1		1
Baccharis sarothroides		1			1
Bidens			1		1
Bidens	1			2	3
aurea					
Bidens	1	2		2	5
frondosa					
Bidens laevis		2	1		4
Bidens	1			1	2
leptocephala					
Bidens pilosa				1	1
Brickellia betonicifolia			1		1
Brickellia eupatorioides			1		2
Carminatia tenuiflora			1	2	4
Cirsium					
neomexicanu	1			1	2
m					
Cirsium ochrocentrum				1	1
Cirsium wheeleri			1		1
Cosmos	1		1	1	3
parviflorus					
Erigeron	2			1	4
flagellaris					
Erigeron neomexicanus			1		1
Gaillardia arizonica				1	1
Gutierrezia wrightii				1	1
Helianthus annuus	1			1	2
Heliomeris	1				1
hispidus					
Heliomeris		1			1
longifolia					
Heliomeris	1				1
multiflora					
Heterosper	1		1		2
ma pinnatum					
Heterotheca subaxillaris			1		1
Isocoma tenuisecta		1			1
Lactuca serriola				1	1
Laennecia coulteri	1				1

Laennecia eriophylla			1		1
Laennecia sophiifolia			1	1	2
Lasianthaea podocephala			1		1
Machaeranthera					
tagetina	1			1	2
Melampodium leucanthum				1	1
Melampodium sericeum			1		1
Melampod					
ium	1		1		2
strigosum					
Pectis					
papposa	1			1	2
Porophyllum ruderale ssp.					
macrocephalum			1		1
Pseudogna					
phalium	1		2	1	4
canescens					
Pseudogna					
phalium	1				1
luteoalbum					
Pseudogna					
phalium	1				1
stramineum					
Psilactis					
gentryi	1				1
Pyrrhopappus					
pauciflorus	1			2	3
Pyrrhopappus					
rothrockii	1			1	2
Rudbeckia					
laciniata				1	1
Solidago				2	2
Solidago altissima				3	3
Solidago canadensis				1	1
Sonchus					
asper	1	1	1	1	4
Stephanom					
eria exigua	1			1	2
Stevia lemmonii			1	1	2
Stevia micrantha			1	1	2
Symphiotr					
ichum	1	1		4	2
falcatum					
Symphiotrichum falcatum var.					
commutatam				2	2

Symphyotrichum subulatum			1	4		5
Tagetes micrantha				1		1
Taraxacum officinale					1	1
Verbesina rothrockii			1			1
Viguiera dentata				1		1
Xanthium strumarium	1	2				3
Xanthocep halum	1		1	1	1	4
gymnosperm oides						
Zinnia peruviana					1	1
Boraginaceae	3					3
Heliotropi um	1					1
curassavicum						
Lithosper mum	2					2
cobrense						
Brassicaceae	1	4	4	2	2	13
Descurainia pinnata		2				2
Descuraini a sophia	1					1
Hesperidanthus linearifolius			1	1	1	3
Nasturtium officinale		1	3	1		5
Pennellia micrantha					1	1
Sisymbrium irio		1				1
Cactaceae	1		1			2
Opuntia	1		1			2
Campanulaceae		1		2		3
Lobelia cardinalis		1		2		3
Characeae				1	1	2
Chara				1	1	2
Chenopodiac eae	3	4	1		1	9
Atriplex elegans		1				1
Atriplex wrightii		1				1
Chenopodi um	1	2				3

Chenopodi							
um	1						1
berlandieri							
Chenopodium murale					1		1
Dysphania graveolens			1				1
Kochia	1						1
scoparia							
Commelinac	1		1	2	1		5
eae							
Commelina dianthifolia				2	1		3
Commelin	1		1				2
a erecta							
Convolvulac	2	4	4	3	2		15
eae							
Convolvulus equitans					1		1
Evolvulus arizonicus			3				3
Ipomoea	1		1		1		3
costellata							
Ipomoea	1	1		1			3
crisulata							
Ipomoea hederacea		2		1			3
Ipomoea purpurea		1					1
Ipomoea tenuiloba				1			1
Cucurbitaceae		3				1	4
Apodanthera undulata						1	1
Cucurbita							
foetidissima		1					1
Sicyos laciniatus		2					2
Cupressaceae	2				1		3
Juniperus	1						1
Juniperus	1				1		2
deppeana							
Cyperaceae	10	7	4	12	19	11	63
Bulbostylis funckii				1			1
Carex				1	1		2
Carex alma				1			1
Carex praegracilis		1		2		7	10
Carex spissa					1		1
Carex thurberi					2		2
Cyperus				1			1
Cyperus	1				2	1	4
esculentus							
Cyperus	1			1		1	3
fendlerianus							

Cyperus flavicomus	1					1
Cyperus manimae			1	3		4
Cyperus niger			2	2		4
Cyperus odoratus		2				2
Cyperus squarrosus	1					1
Eleocharis	1	1				2
Eleocharis engelmanni	1					1
Eleocharis macrostachya		1				1
Eleocharis montevidensis			1			1
Eleocharis palustris	1	2		4	2	9
Eleocharis parishii	1		1			2
Schoenopl ectus acutus	2			2		4
Schoenoplectus americanus		1	2	2		5
Schoenopl ectus californicus	1					1
Equisetaceae			2	1		3
Equisetum laevigatum			2	1		3
Ericaceae			2	1		3
Arbutus arizonica				1		1
Arctostaphylos pungens			2			2
Euphorbiaceae	7	7	6	10	11	41
Acalypha neomexicana	1			2		3
Acalypha ostroyifolia	1	1		1	4	7
Acalypha phleoides			1			1
Chamaesyce albomarginata	1	2			1	4
Chamaesyce dioica	1		1			2
Chamaesyce hyssopifolia		2	1	2	2	7
Euphorbia			1			1

Euphorbia							
bilobata	1			1			2
Euphorbia dentata					2	2	4
Euphorbia	1	2			1	1	5
heterophylla							
Tragia	1				1	1	3
laciniata							
Tragia nepetifolia				1	1		2
Fabaceae	7	4	2	12	8	12	45
Amorpha fruticosa				1			1
Astragalus humistratus						1	1
Astragalus	1						1
nothoxys							
Astragalus		1					1
vaccarum							
Calliandra	1						1
humilis							
Chamaecri	1			1		1	3
sta nictitans							
Crotalaria pumila					1		1
Crotalaria sagittalis				1	1		2
Dalea exigua				1	1		2
Dalea filiformis				1			1
Dalea	1					2	3
leporina							
Desmanth	1						1
us cooleyi							
Desmodium psilocarpum					1		1
Desmodium retinens				1			1
Desmodium rosei				1	1		2
Galactia wrightii				1			1
Indigofera sphaerocarpa				1			1
Lotus alamosanus						1	1
Lotus corniculatus						2	2
Lupinus concinnus						1	1
Macroptilium							
gibbosifolium				1	1		2
Medicago sativa						1	1
Melilotus indicus		2					2
Melilotus	1						1
officinalis							
Phaseolus					1		1
Phaseolus	1			1			2
acutifolius							

Prosopis juliflora	1	2				3
Rhynchosia senna var. texana					2	2
Tephrosia tenella			1			1
Trifolium dubium					1	1
Trifolium repens				1		1
Fagaceae			1	1		2
Quercus grisea			1			1
Quercus hypoleucoides				1		1
Garryaceae				1		1
Garrya flavescens				1		1
Gentianaceae		1				1
Eustoma exaltatum		1				1
Geraniaceae				1		1
Geranium caespitosum				1		1
Grossulariaceae					2	2
Ribes					1	1
Ribes aureum					1	1
Iridaceae	1	4	1	1	2	9
Sisyrinchium demissum	1	4	1	1	2	9
Juncaceae	3	1	2	3	6	21
Juncus acuminatus			1			1
Juncus articulatus	1					1
Juncus balticus	1	2		1	3	7
Juncus bufonius				1		1
Juncus mexicanus	1		1	2		4
Juncus saximontanus	1		1	2	2	6
Juncus torreyi					1	1
Lamiaceae	2		3	1		6
Hedeoma dentata			1			1
Monarda citriodora ssp. austromontana			1	1		2
Salvia subincisa	1		1			2
Stachys coccinea	1					1
Lemnaceae	1	1	1		1	4
Lemna minor	1	1	1		1	4

Loasaceae				1			1
Mentzelia isolata				1			1
Lythraceae	2	1	1	2	6		12
Cuphea	1			1	1		3
wrightii							
Cuphea wrightii					1		1
var. wrightii							
Lythrum	1	1		1	4		7
californicum							
Punica granatum			1				1
Malvaceae	3	2		1		5	11
Anoda cristata		1		1		3	5
Anoda	1						1
pentaschista							
Rhynchosida		1					1
physocalyx							
Sida						1	1
Sida	1						1
abutilifolia							
Sida	1					1	2
spinosa							
Molluginaceae	1					1	2
e							
Mollugo	1					1	2
verticillata							
Montiaceae	1						1
Phemerant							
hus	1						1
aurantiacus							
Nyctaginaceae		2				1	3
Boerhavia coccinea						1	1
Mirabilis longiflora		2					2
Oleaceae			2	2			4
Fraxinus velutina			2	2			4
Onagraceae	2	3	1	4	7	6	23
Epilobium ciliatum		2		3	2		7
Gaura							
hexandra ssp.	1					1	2
gracilis							
Gaura mollis		1	1			1	3
Oenothera	1						1
Oenothera elata					2	1	3
Oenothera rosea				1	3	3	7
Oxalidaceae	2			2	1	1	6

Oxalis	2			2	1	1	6
pilosa							
Papaveraceae	1						1
Argemone	1						1
pleiakantha							
Pedaliaceae						1	1
Proboscidea parviflora						1	1
Pinaceae					3		3
Pinus cembroides					3		3
Poaceae	32	20	16	23	31	46	168
Agrostis exarata				1			1
Agrostis scabra				1			1
Andropogon glomeratus				1	4		5
Aristida							
adscensionis	1						1
Aristida							
divaricata	1						1
Aristida schiedeana							
var. orcuttiana					3		3
Aristida							
ternipes var.	1	1				1	3
gentilis							
Aristida							
ternipes var.	1					2	3
ternipes							
Bothriochloa							
barbinodis		2					2
Bothriochl							
oa	1						1
ischaemum							
Bothriochl							
oa laguroides	2				1	3	6
ssp.							
torreyana							
Bouteloua							
curtipendula	2	1			1	2	6
Bouteloua							
gracilis	1					1	2
Bouteloua hirsuta				1	1		2
Bromus arizonicus				1			1
Bromus carinatus					2		2
Bromus ciliatus				1	1		2
Chloris virgata		1					1
Cynodon dactylon		1	2				3

Distichlis spicata	1	2		1	4
Echinochloa colona		1			1
Echinochloa crus-galli	1	1		1	5
Elymus canadensis				4	4
Elymus elymoides	4			2	6
Elymus trachycaulus		2			2
Eragrostis cilianensis	1	1		1	3
Eragrostis intermedia	1		1	2	4
Eragrostis mexicana			1	1	2
Eriochloa acuminata	1		1	2	4
Festuca arundinacea				1	1
Hilaria belangeri	1			2	3
Hopia obtusa	1			2	4
Hordeum jubatum	1	2	1	3	7
Leersia oryzoides				2	2
Leptochloa dubia				2	2
Leptochloa fusca ssp. fascicularis	1				1
Leptochloa fusca ssp. uninervia	1				1
Leptochloa panicea ssp. brachiata		1			1
Leptochloa viscida	1				1
Lolium arundinaceum				1	4
Lycurus setosus	1		1	1	3
Muhlenbergia asperifolia	1	2	3	2	8
Muhlenbergia fragilis	1		1		2
Muhlenbergia minutissima				1	1

Muhlenbergia repens				1		1
Muhlenbergia rigens				1		1
Panicum bulbosum				1		1
Panicum hirticaule	1		1	1	1	4
Paspalum dilatatum					3	3
Paspalum distichum				2	2	4
Phalaris minor		1				1
Piptochaetium fimbriatum	1			2	2	5
Poa pratensis					1	1
Polypogon monspeliensis	1	2	2	1		6
Polypogon viridis				1	2	3
Schizachyrium sanguineum	1			2		3
var. hirtiflorum						
Setaria grisebachii	1			2		3
Sorghum halepense	2				1	3
Sphenopholis obtusata				1		1
Sporobolus wrightii	2		1			3
Trichloris crinita			1			1
Urochloa arizonica	1					1
Zuloagaea bulbosa				1		1
Polemoniaceae				1	1	2
Ipomopsis multiflora					1	1
Ipomopsis thurberi				1		1
Polygalaceae					1	1
Polygala obscura					1	1
Polygonaceae	3	6		3		18
Eriogonum abertianum					2	2
Persicaria bicornis	2	3			1	6
Persicaria lapathifolia				1	1	2
Polygonum aviculare	1					1
Polygonum		1		1		2

punctatum					
Rumex crispus			1	2	3
Rumex		2			2
hymenosepalus					
Portulacaceae	2			1	3
Portulaca	1				1
oleracea					
Portulaca	1				1
suffrutescens					
Portulaca umbraticola				1	1
Potamogetonaceae				1	1
Potamogeton				1	1
Primulaceae			2	2	4
Samolus vagans			2	2	4
Pteridaceae			1		1
Cheilanthes fendleri			1		1
Ranunculaceae	1	2		2	5
Myosurus	1				1
Ranunculus hydrocharoides					1
Ranunculus		1			1
macounii					
Ranunculus		1		2	4
macranthus					7
Rhamnaceae			1		1
Ziziphus obtusifolia			1		1
Rosaceae				1	1
Purshia stansburiana				1	1
Rubiaceae			1	4	5
Diodia teres				2	2
Galium microphyllum				1	1
Mitracarpus breviflorus			1	1	2
Salicaceae	1		2	4	1
Salix	1		1	3	1
bonplandiana					6
Salix gooddingii				1	1
Salix taxifolia			1		1
Saururaceae		1	2		3
Anemopsis		1	2		3
californica					
Scrophulariaceae	2	1	3	3	2
ceae					11

Mimulus guttatus				2	1	1	4
Schistophragma intermedia	1						1
Verbascum blattaria						1	1
Verbascum thapsus				1			1
Veronica anagallis-aquatica		1			1		2
Veronica peregrina	1				1		2
Solanaceae	5	5	3	1		4	18
Calibrachoa parviflora	2	1					3
Lycium andersonii			1				1
Nicotiana glauca			1				1
Physalis acutifolia						1	1
Physalis hederifolia		1					1
Physalis longifolia		2				1	3
Physalis philadelphica	1					2	3
Physalis pubescens	1			1			2
Solanum elaeagnifolium	1	1	1				3
Tamaricaceae	1						1
Tamarix chinensis	1						1
Typhaceae		1		1	1		3
Typha latifolia		1		1	1		3
Ulmaceae			1				1
Celtis pallida			1				1
Verbenaceae	1			2	7		10
Glandularia bipinnatifida				1	1		2
Verbena				1	1		2
Verbena bracteata	1						1
Verbena carolina					2		2
Verbena neomexicana					3		3
Viscaceae			1				1
Phoradendron californicum			1				1
Vitaceae					1		1

Vitis arizonica					1		1
Zannichelliaceae	1		2				3
Zannichellia palustris	1		2				3
<b>Total</b>	<b>131</b>	<b>107</b>	<b>50</b>	<b>138</b>	<b>177</b>	<b>174</b>	<b>777</b>