Fire and Reseeding Effects on Arizona Upland Plant Community Composition and a Preliminary Floristic Inventory of Cave Creek Regional Park

by

Kara Lynn Barron

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Graduate Supervisory Committee:

Juliet Stromberg, Co-Chair
Kathleen Pigg, Co-Chair
Elizabeth Makings
Kimberlie McCue

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ABSTRACT

Baseline community composition data provides a snapshot in time that allows changes in composition to be monitored more effectively and can inform best practices. This study examines Arizona Upland plant community composition of the Sonoran Desert through three different lenses: floristic inventory, and fire and reseeding effects.

A floristic inventory was conducted at Cave Creek Regional Park (CCRP), Maricopa County, AZ. One hundred fifty-four taxa were documented within Park boundaries, including 148 species and six infraspecific taxa in 43 families. Asteraceae, Boraginaceae, and Fabaceae accounted for 40% of documented species and annuals accounted for 56% of documented diversity.

Fire effects were studied at three locations within McDowell Sonoran Preserve (MSP), Scottsdale, AZ. These fires occurred throughout the 1990s and recovered naturally. Fire and reseeding effects were studied at the site of a 2005 fire within CCRP that was reseeded immediately following the fire.

Two questions underlie the study regarding fire and reseeding effects: 1) How did fire and reseeding affect the cover and diversity of the plant communities? 2) Is there a difference in distribution of cover between treatments for individual species or growth habits? To address these questions, I compared burned and adjacent unburned treatments at each site, with an additional reseeded treatment added at CCRP.

MSP sites revealed overall diversity and cover was similar between treatments, but succulent cover was significantly reduced, and subshrub cover was significantly greater in the burn treatment. Seventeen species showed significant difference in distribution of cover between treatments.

The CCRP reseeded site revealed 11 of 28 species used in the seed mix persist 12 years post-fire. The reseeded treatment showed greater overall diversity than burned and unburned treatments. Succulent and shrub cover were significantly reduced by fire while subshrub cover was significantly greater in the reseeded treatment. Sixteen species showed significant difference in distribution of cover between treatments.

Fire appears to impact plant community composition across Arizona Upland sites. Choosing species to include in seed mixes for post-fire reseeding, based on knowledge of pre-fire species composition and individual species' fire responses, may be a useful tool to promote post-fire plant community recovery.

DEDICATION

To John, Anthony, and Josefina because your combined presence in my life led me here.

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A VASCULAR PLANT INVENTORY OF CAVE CREEK REGIONAL PARK

INTRODUCTION

A flora is an inventory of all the plants at a site (Lawrence 1951). It provides a valuable snapshot in time of local biodiversity. Understanding overall biodiversity at a given time is baseline data that can be compared both spatially with its surrounding areas and temporally as changes occur. The need for botanists to conduct floras remains high, particularly in under-explored areas, as many sites remain unsurveyed or incompletely surveyed.

Cave Creek Regional Park (CCRP) is one of 11 parks and conservation areas managed by the Maricopa County Parks and Recreation Department in central Arizona, United States. To date, 10 of the 11 have been surveyed (Table 1; Damrel 2007; Hunkins & Smith 2013; Keil 1973; Lane 1981; Lehto 1970; Marshall 2017; Pierce 1979; Sundell 1974; Wolden et al. 1995)

County Park	Year
Lake Pleasant Regional Park	1970
White Tank Mountains Regional Park	1973 (update in progress)
Sierra Estrella Regional Park	1974
Buckeye Hills Recreation Area	1979
McDowell Mountains Regional Park	1981
Hassayampa River Preserve	1995
San Tan Mountain Regional Park	2007
Usery Mountain Regional Park	2011
Spur Cross Conservation Area	2013
Cave Creek Regional Park	in progress
Adobe Dam Regional Park	n/a

Table 1. Maricopa County Regional Parks and year each had a floristic inventory published.

CCRP sits close to the northern edge of the Sonoran Desert, in the Arizona Upland subdivision as defined by Shreve and Wiggins (1964; Fig. 1) and was acquired by the county in 1992 in part to preserve its biological resources. The original master plan

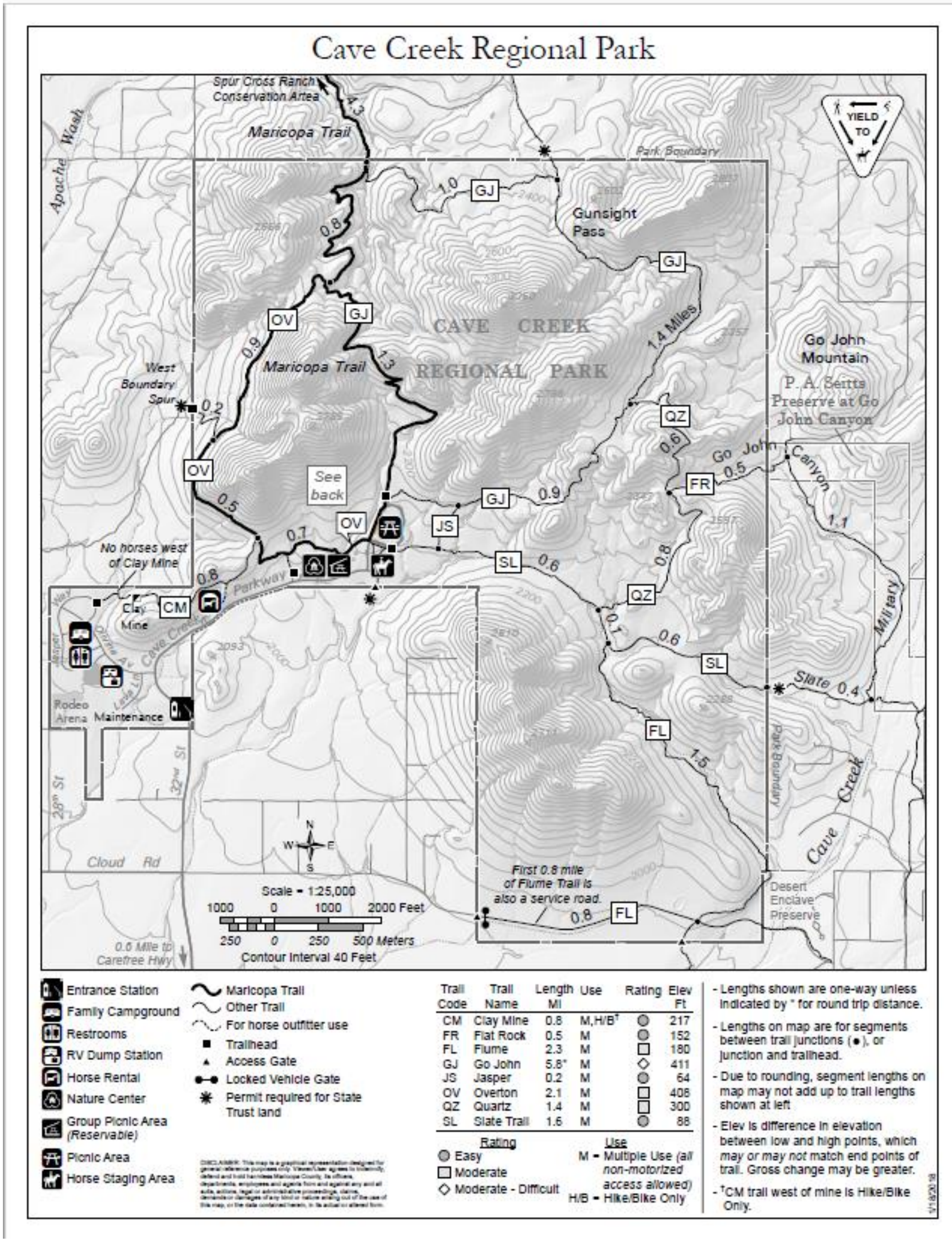
(Wirth Associates, Inc. 1980) included a botanical survey but voucher specimens were not collected at the time and therefore occurrence data could not be verified. Depositing herbarium vouchers allows the data to be substantiated with a physical specimen so that it may be utilized by other scientists and for future research.

The current survey was undertaken to provide comprehensive baseline data that will be useful not only to the Park managers, but to the wider audience of researchers and other individuals interested in the plants of the area.

STUDY AREA

Boundaries - CCRP covers 1,183 ha (2,922 acres) on the western edge of the town of Cave Creek, approximately 17 km (27 miles) northeast of the city of Phoenix (United States Census 2010) in Maricopa County, Arizona. It is bounded by 33.850, 33.810 north latitudes and -112.022, -111.978 west longitudes (Fig. 1).

A mix of Arizona State Trust Land and private owners border most of the Park. The two exceptions are a patch of land to the south managed by the Bureau of Land Management, and the Desert Enclave Preserve, owned by the Desert Foothills Land Trust (DFLT) adjacent to the Park's southeastern border. The DFLT encompassing six hectares (15 acres) that include a stretch of Cave Creek (Maricopa County Assessor's parcel map, https://mcassessor.maricopa.gov/, and Desert Foothills Land Trust website, https://www.dflt.org/).



Trail Code	Trail Name	Length Mi	Use	Rating	Elev Ft
CM	Clay Mine	0.8	M,H/B†	●	217
FR	Flat Rock	0.5	M	●	152
FL	Flume	2.3	M	□	180
GJ	Go John	5.8*	M	◇	411
JS	Jasper	0.2	M	●	64
OV	Overton	2.1	M	□	408
QZ	Quartz	1.4	M	□	300
SL	Slate Trail	1.6	M	●	88

Figure 1. Map of Cave Creek Regional Park courtesy of Maricopa County Parks and Recreation Department.

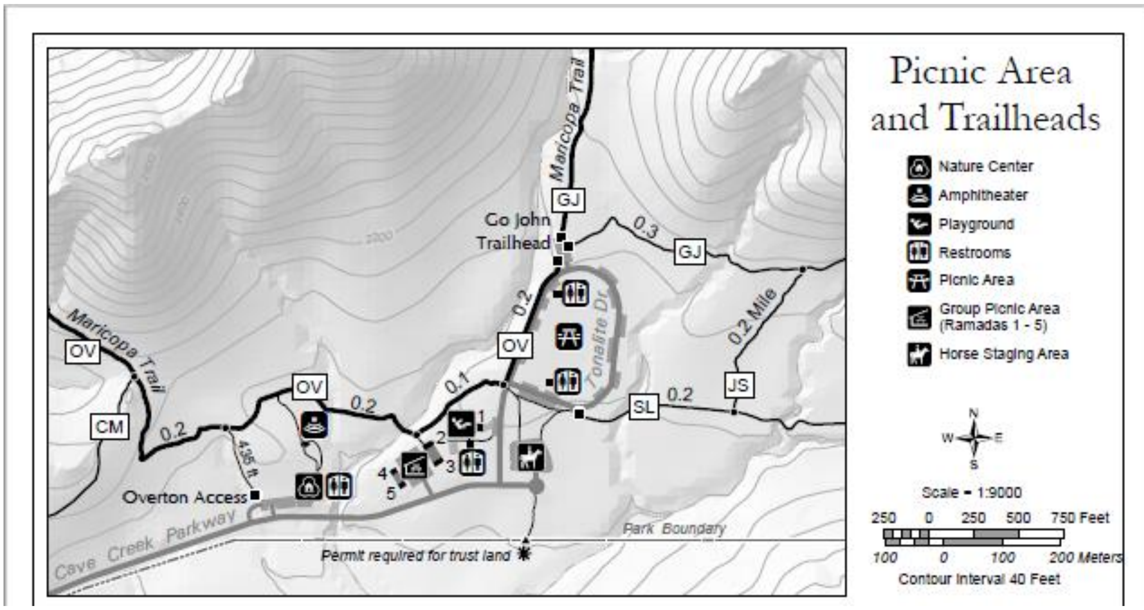


Figure 2. Map of Cave Creek Regional Park campground courtesy of Maricopa County Parks and Recreation Department.

Topography - CCRP spans from the northwestern corner of the United States Geological Survey (USGS) Cave Creek 7.5-minute Series Quadrangle topographic map to the northeastern corner of the USGS New River SE 7.5-minute Series Quadrangle topographic map. The elevation is between 586 m in the south of the Park along New River road to 932 m at one of the unnamed mountain peaks ringed by the Go John Loop Trail.

The Park gains elevation gradually from south to north with fan terraces dominating the lower elevations and mountains composed mostly of volcanic rock to the north, dissected by ephemeral washes. The park is part of the Agua Fria – Lower Gila watershed with drainage of ephemeral washes most likely emptying into nearby Cave Creek, when rains are heavy enough. (http://www.azwater.gov/azdwr/StatewidePlanning/WaterAtlas/ActiveManagementAreas/PlanningAreaOverview/SurfaceWaterHydrology.htm).

Geology – CCRP is mostly made up of Early Proterozoic and metasedimentary and metavolcanics rocks (Busch 2004). Middle Pleistocene surficial deposits comprise the southernmost portion of the Park and a relatively small area (<4 ha) of Early Proterozoic granitic rocks lie in the northwest corner. A belt of slate with a folded meta-diorite intrusion is present in the center of the Park (Busch 2004).

Climate - Precipitation is recorded by the Maricopa County Flood Control District Cave Creek rain gauge #19000. The mean annual precipitation between 2003 and 2017 was 28.8 cm per year, with the wettest year in 2005 (60.1 cm) and the driest year 2006 (17.5 cm) (https://www.maricopa.gov/625/Rainfall-Data accessed 3/27/2018).The hottest month during the time period between 2003 and 2017 was July with an average high temperature of 38.8˚ C, and the coldest month was December with an average high temperature of 17.2˚ C (https://wrcc.dri.edu/cgi-bin/cliMAIN.pl?az1282).

Land use/management – The Park has approximately 17.7 kilometers (11 miles) of mixed-use trails for hikers, bicyclists, and horseback riders (Fig. 1). A trail riding business operates near the nature center during fall, winter, and spring, offering guided horseback rides. A dedicated campground at the southwestern corner of the park boundary includes 44 campsites that accommodate tents or recreational vehicle camping with water and electrical hook-ups (Fig. 2).

Exploratory mining in the area was common from the early 1870's into the mid-20th century (Maricopa County Parks Recreation Commission & Arizona Historical Foundation 1963). Park staff have identified at least 80 areas where the ground was excavated in hopes of finding valuable rocks and minerals (Mark Paulet, Maricopa County Parks and Recreation Department, from personal communication, 2016). The most well-known mine within the Park boundaries was owned by Lelia Irish, who touted that the mineral clay, or kaolinite, that her company mined was good for various skin ailments. The product was intended to be mixed with water and drunk (http://docs.azgs.az.gov/OnlineAccessMineFiles/M-R/PearlchemicalMaricopa544.pdf accessed 3/28/18). Kaolinite can be used medicinally to treat diarrhea and other gastrointestinal illnesses because of its ability to adsorb bacteria and viruses (Williams & Haydel 2010). Clay of this type is also used today in products such as ceramics and paper (https://www.mindat.org/min-2156.html accessed 3/28/18). The mine that Ms. Irish owned is no longer in production but is currently used as an educational tool with tours given on a regular basis by Park staff.

Historically, water from Cave Creek and its tributaries was used to irrigate pastures in the southeastern portion of the Park for domestic cattle grazing (Maricopa County Parks Recreation Commission & Arizona Historical Foundation 1963). This section was grazed until the 1950's and remnants of a flume, cattle tank, and cabin remain. Prehistorically, the land was used mostly by the Hohokam and Sinagua peoples, with evidence of petroglyphs and cave habitation (Wirth Associates, Inc. 1980).

METHODS

I led plant collecting trips with the assistance of numerous volunteers from January 2014 to April 2018. Most of the trips were made in spring (March – May) and winter (December – February) with fewer trips during the fall (September – November). Collections were not made during the summer months (June – August).

I personally prepared vouchers for every taxon collected. Data recorded for each collection included coordinates and elevation using a GPS unit, locality and plant description, habitat type, associated species, relative abundance, and field photographs. The voucher specimens were deposited at the Desert Botanical Garden Herbarium (DES) in Phoenix with duplicates deposited at the Arizona State University Vascular Plant Herbarium (ASU) in Tempe. I used several resources to identify the plants including

Arizona Flora (Kearney et al. 1960), *Flora of North America* (Flora of North America Editorial Committee 1993+), treatments published in *Journal of the Arizona-Nevada Academy of Science* and *Canotia* (Vascular Plants of Arizona Editorial committee 1992+). I studied herbarium material at DES and ASU and consulted with botanical experts on staff at these herbaria.

RESULTS

Cave Creek Regional Park (CCRP) is located in the Arizona Upland subdivision of the Sonoran Desert and the most common plant association is Paloverde-cacti-mixed scrub (Shreve & Wiggins 1964). The northern half of the Park is comprised of hillslopes and rocky outcrops that are dominated by *Ambrosia deltoidea, Carnegiea gigantea*, *Cylindropuntia acanthocarpa, Encelia farinosa, Larrea tridentata, Olneya tesota,* and *Parkinsonia microphylla*. The southern half is comprised of fan terraces that are similar in floral composition but more heavily dominated by *Ambrosia deltoidea* and *Larrea tridentata*.

The campground area, located at the southwest corner of the Park (Fig. 1), has gravelly clay soils that include the species *Cylindropuntia spp., Ephedra aspera, Canotia holacantha, Larrea tridentata* and *Olneya tesota*. The southeastern portion of the Park is fan terrace heavily dominated by *Ambrosia deltoidea* with *Cylindropuntia acanthocarpa*, *Larrea tridentata*, *Parkinsonia florida* and *P. microphylla* dotting the landscape. Ephemeral drainages often include *Ambrosia ambrosioides*, *Bebbia juncea*, and *Lycium spp.*

An old cattle tank in the southeast corner of the Park is home to a small mesquite bosque dominated by *Prosopis velutina*. The soils along the southernmost boundary of the Park harbor a population of *Parkinsonia florida*. Both species require more consistent water sources, so these are areas of the park where rain and/or runoff from the hill slopes probably collect.

I collected 243 vouchers over 25 visits for a total of 154 taxa including 148 species and 6 infraspecific taxa. These species belong to 125 genera within 43 families (Table 2). The five largest families, in order from largest to smallest, are Asteraceae, Boraginaceae, Fabaceae, Poaceae, and Brassicaceae and make up 54% of the total flora (Table 3). *Eriogonum* was the genus most represented in the flora at four species (Table 4). Annuals account for 56% of the flora followed by shrubs and subshrubs with a combined 28% (Table 5).

To estimate how complete this flora is, I used the equation set forth by Bowers and McLaughlin (1982) that uses elevation range in meters (E) and collecting time to the nearest 0.5 years (T) to predict how many species ($\hat{S}$) should be found:

$$\hat{S} = 47 + 0.349E + 8.20T.$$

$$\hat{S} = 47 + 0.349(345) + 8.20(4.5) = 204$$

Data from the CCRP study substituted into the equation indicate that the inventory would be predicted to have produced 204 species.

This flora is preliminary. I observed species such as *Selaginella sp.* and members of the Cactaceae family while in the field that have not yet been vouchered and several areas of the Park have yet to be explored. A map of the collection points (Fig. 3) show the potential gaps in collection. Since plant communities change along elevation, precipitation, moisture availability and disturbance gradients (Shryock et al. 2015b), the unexplored areas most likely to provide additional species include Go John Canyon, the top of the highest peak, and the campground. Visiting the Park during the summer would also likely add species to the checklist.

	Family	Genera	Species	Infra-specific Species	Inter-specific Species	Total Taxa
Pteridophytes	0	0	0	0	0	0
Gymnosperms	1	1	1	0	0	1
Angiosperms						
Magnoliids	0	0	0	0	0	0
Monocots	2	13	13	1	0	14
Eudicots	40	111	134	5	0	139
Totals	43	125	148	6	0	154

Table 2. Taxonomic composition of Cave Creek Regional Park

Family	Genera	Species	Percent of Total Flora
Asteraceae	31	34	22
Boraginaceae	8	15	10
Fabaceae	9	13	8
Poaceae	12	13	8
Brassicaceae	8	10	6
Polygonaceae	2	6	4
Plantaginaceae	3	5	3
Solanaceae	3	5	3
Amaranthaceae	4	4	3
Polemoniaceae	2	4	3

Table 3. Most important families of Cave Creek Regional Park

Genus	Number of species
Eriogonum	4
Lepidium	3
Lycium	3
Parkinsonia	3
Phacelia	3
Plantago	3

Table 4. Most abundant genera of Cave Creek Regional Park

Growth Habit	Number of Taxa	Percent of Total Flora
Tree	6	4
Shrub	27	17.5
Subshrub	16	10.4
Perennial Herb	18	11.6
Annual	87	56.5

Table 5. Number of taxa by growth habit at Cave Creek Regional Park

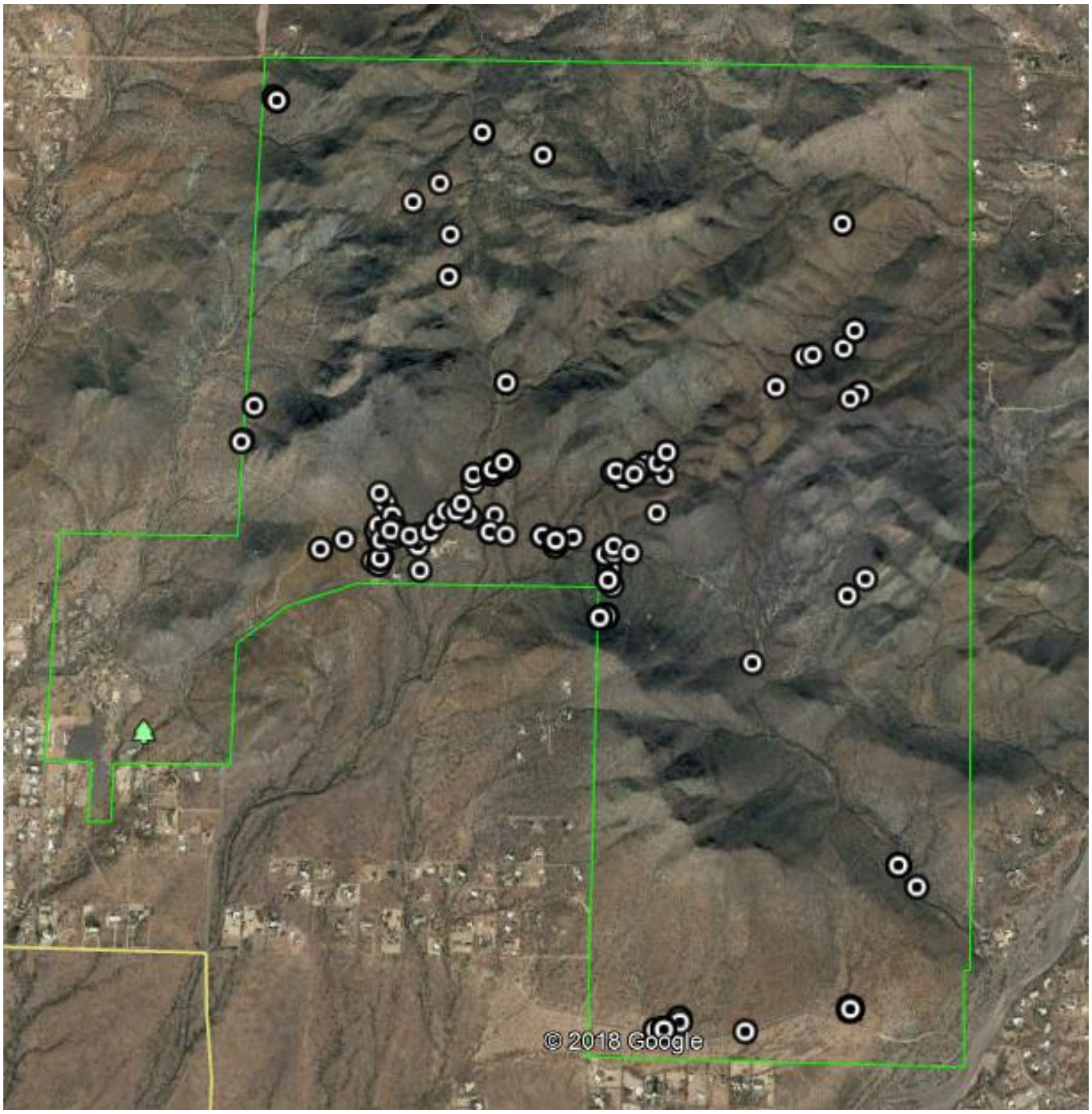


Figure 3. Map of collection points in Cave Creek Regional Park. (basemap from Google Earth, https://www.google.com/earth/)

DISCUSSION

The floristic survey presented here provides the first look at the botanical biodiversity within Cave Creek Regional Park, Maricopa County, AZ. One hundred fifty-four species were recorded within the 1,183-ha area but a complete flora is expected to include at least 50 more species (Bowers & McLaughlin 1982).

In comparison to this estimate, two floristic surveys closest in proximity to CCRP are reported as more speciose: Spur Cross Ranch Conservation Area (396 taxa) and the Phoenix Sonoran Preserve (264 taxa). This disparity may indicate that CCRP harbors many more than 204 taxa but most likely less than these two surveys produced. Spur Cross Ranch Conservation Area is smaller in area (870 ha) but has a larger elevation range (533 m versus 350 m) with a significant reach of riparian vegetation with perennial surface water that influences its diversity. The Phoenix Sonoran Preserve has less of a range in elevation (290 m) but is much larger (7,285 ha) and includes four major washes.

I documented one species, *Penstemon subulatus*, that is endemic to Arizona. Two other species, *Atriplex canescens* and *Sphaeralcea ambigua ssp. rosacea*, were only found in a post-burn reseeded area and were known to be species used in the seed mix, discussed in more detail in Chapter Three. Both species were documented only at the Park in the burned area and were locally frequent. Both species occur naturally within the Sonoran Desert but were not found elsewhere in the Park. This is surprising for *Atriplex canescens*, but not for *Sphaeralcea ambigua ssp. rosacea*, which is found more often around the Tucson area.

Two species documented as planted near the nature center and not found elsewhere in the Park are *Parkinsonia aculeata* and *Asclepias subulata*. *Parkinsonia aculeata* occurs naturally in the nearby Tonto National Forest, but many records from the Phoenix area show it in irrigated places, like parking lots and front yards so it is unlikely to be found within the Park boundaries naturally due to a lack of water. On the other hand, I was surprised that the only documented *A. subulata* was planted near the nature center. It is known to occur in similar habitats as those found at CCRP.

During the spring of 2017 the introduced annual *Oncosiphon piluliferum* showed an abundant display of yellow blooms along the slopes and flats of Cave Creek Regional Park and the surrounding areas. This species is common to CCRP and is currently being considered for addition to the Arizona noxious weed list (John Sheuring, Southwest Vegetation Management Association Weed Rule Revision Committee member, personal communication, 2018). This change in status is something for land managers to be aware of as they plan future actions.

In 1980, Wirth Associates, Inc. conducted a botanical survey for CCRP and the list of species they found was included in the Master Plan for CCRP (Wirth Associates, Inc. 1980). The survey included 62 species, 10 of which I did not find during my inventory. Some of these are plausible and known to occur locally and in similar habitats (*Asclepias albicans, Hilaria rigida,* and *Krameria erecta*), others are less common in the surrounding areas (*Cucurbita digitata, Encelia frutescens, Isocoma tenuisecta, Notholaena californica,* and *Opuntia phaecantha*). However, Wirth Associates (1980) reported two dubious species for the CCRP that are highly unlikely to occur there. They are *Polypogon monspeliensis,* which is found only in riparian habitats, and *Condalia ericoides,* that is not known to occur in Maricopa County. This is one reason why having access to verifiable vouchers is important.

Preliminary checklist of the vascular plants of Cave Creek Regional Park

Taxa are listed by major plant groups: Pteridophytes, Gymnosperms, and Angiosperms. The Angiosperms fall under eudicots and monocots (no Magnoliids were found). Within these groups, plants are listed alphabetically by family then by species. Family names follow the Angiosperm Phylogeny Group IV system of classification (Stevens 2017, http://www.mobot.org/MOBOT/research/APweb/).

Species whose native range is outside Arizona according to the United States Department of Agriculture (https://plants.sc.egov.usda.gov/java/) are preceded with a carat (^), and those observed by me but not vouchered before the writing of this thesis are preceded by double asterisks (**). Abundance measures are from the scale proposed by Palmer et al. (1995).

PTERIDOPHYTES (ferns and lycophytes)

SELAGINACEAE

***Selaginella arizonica* Maxon. Arizona spikemoss. Perennial herb; occasional to frequent on north facing slopes after rain.

GYMNOSPERMS (cone-bearing plants)

EPHEDRACEAE

Ephedra aspera Engelm. ex S. Watson. Rough jointfir. Shrub; frequent. KB210.

ANGIOSPERMS (flowering plants)

EUDICOTS

ACANTHACEAE

Justicia californica (Benth.) D. Gibson. Beloperone, chuparosa. Shrub; occasional. KB130.

AIZOACEAE

Trianthema portulacastrum L. Desert horsepurslane . Annual; occasional. KB47.

AMARANTHACEAE

Amaranthus palmeri S. Watson. Palmer's amaranth, carelessweed. Annual; infrequent. KB18.

***Atriplex canescens* (Pursh) Nutt. Four-wing saltbush. Shrub; Rare.

Atriplex polycarpa (Torr.) S. Watson. Cattle saltbush. Shrub; infrequent. KB7, KB58, KB59.

Chenopodium fremontii S. Watson. Fremont's goosefoot. Annual; infrequent. KB131.

^*Salsola tragus* L. Prickly Russian thistle. Annual; occasional. KB45.

APIACEAE

Bowlesia incana Ruiz & Pav. Hoary bowlesia. Annual; infrequent. KB129.

Daucus pusillus Michx. American wild carrot. Annual; frequent. KB99.

APOCYNACEAE

Asclepias subulata Decne. Rush milkweed. Perennial herb; cultivated at nature center. KB26.

Sarcostemma cynanchoides Decne. Fringed twinevine. Vine; infrequent. KB41.

ASTERACEAE

Acourtia wrightii (A. Gray) Reveal & R. M. King. Brownfoot. Perennial herb; infrequent. KB228.

Adenophyllum porophylloides (A. Gray) Strother. San Felipe dogweed. Subshrub; frequent. KB215.

*Ambrosia ambrosioides (*Cav.) Payne. Canyon ragweed, ambrosia leaf bur ragweed. Shrub; frequent along washes. KB187.

***Ambrosia confertiflora* DC. Weakleaf bur ragweed, slimleaf bursage. Perennial herb; occasional.

Ambrosia deltoidea (Torr.) Payne. Triangle bur ragweed, triangle-leaf bursage. Shrub; abundant. KB85.

****Baccharis salicifolia* A. Gray. Desert broom. Shrub; infrequent.

Baccharis sarothroides (Ruiz & Pav.) Pers. Seep willow. Shrub; occasional.

Bahiopsis parishii (Greene) E.E. Schilling & Panero. Parish's goldeneye. Shrub; frequent. KB34, KB218.

Baileya multiradiata Harvey & A. Gray ex A. Gray. Desert marigold. Annual; infrequent. KB15.

Bebbia juncea (Benth.) Greene. Sweetbush. Shrub; infrequent. KB40, KB103.

Brickellia californica (Torr. & A. Gray) A. Gray. California bricklebush, brickle-bush. Shrub; infrequent. KB54.

Brickellia coulteri A. Gray. Coulter's bricklebush. Shrub; occasional. KB200, KB212.

Calycoseris wrightii A. Gray. White tackstem. Annual; infrequent. KB188.

^*Centaurea melitensis* L. Maltese star-thistle. Annual; infrequent. KB98.

Chaenactis carphoclinia A. Gray. Pebble pincushion. Annual; infrequent. KB171.

Cirsium neomexicanum A. Gray. New Mexico thistle. Annual; infrequent. KB227.

Encelia farinosa A. Gray ex Torr. Brittlebush. Shrub; frequent to abundant in disturbed areas. KB12.

Ericameria laricifolia (A. Gray) Shinners. Turpentine bush. Shrub; frequent. KB57.

Erigeron divergens Torr. & A. Gray. Spreading fleabane. Perennial herb; infrequent. KB232.

Eriophyllum lanosum (A. Gray) Rydb. White easterbonnets, wooly eriophyllum. Annual; occasional. KB145.

****Gutierrezia sarothrae* (Pursh) Britton & Rusby. Broom snakeweed. Subshrub; infrequent.

**Lasthenia californica* DC. ex Lindl. California goldfields. Annual; rare.

Layia glandulosa (Hook.) Hook. & Arn. Whitedaisy tidytips. Annual; infrequent. KB182.

Logfia arizonica (A. Gray) Holub. Arizona cottonrose. Annual; frequent after wet winter. KB106.

Machaeranthera tagetina Greene. Mesa tansyaster. Annual; infrequent. KB67.

^*Matricaria discoidea* DC. Disc mayweed. Annual; infrequent. KB193.

Monoptilon bellioides (A. Gray) H.M. Hall. Mojave desertstar. Annual; occasional. KB172.

^*Oncosiphon piluliferum* (L. f.) Källersjö. Stinknet, globe chamomile. Annual; frequent to abundant after wet winter. KB14, KB87.

Perityle emoryi Torr. Emory's rockdaisy. Annual; infrequent in washes. KB176, KB198.

Porophyllum gracile Benth. Slender poreleaf. Subshrub; frequent. KB22.

Psilostrophe cooperi (A. Gray) Greene. Whitestem paperflower. Subshrub; occasional. KB226.

Rafinesquia neomexicana A. Gray. New Mexico plumeseed. Annual; infrequent under shrub cover. KB168, KB177.

^*Sonchus oleraceus* L. Common sowthistle. Annual; rare to infrequent in disturbed soils. KB98a, KB113.

Stephanomeria pauciflora (Torr.) A. Nelson. Brownplume wirelettuce. Subshrub; occasional. KB61, KB209.

Stylocline micropoides A. Gray. Woollyhead neststraw. Annual; frequent. KB135, KB179.

Trixis californica Kellogg. American threefold. Shrub; frequent. KB144.

Uropappus lindleyi (DC.) Nutt. Lindley's silverpuffs. Annual; occasional. KB159, KB160.

Xanthisma gracile (Nutt.) D.R.Morgan & R.L.Hartm. Slender goldenweed. Annual; frequent. KB28, KB50.

Xanthisma spinulosum (Pursh) D.R. Morgan & R.L. Hartm. Spiny haplopappus. Subshrub; frequent. KB230.

BORAGINACEAE

Amsinckia menziesii (Lehm.) A. Nelson & J.F. Macbr. Menzies' fiddleneck. Annual; frequent. KB10, KB72, KB109.

Amsinckia tessellata A. Gray. Bristly fiddleneck. Annual; occasional. KB72A, KB151.

Cryptantha barbigera (A. Gray) Greene. Bearded cryptantha. Annual; infrequent. KB100.

Cryptantha pterocarya (Torr.) Greene. Wingnut cryptantha. Annual; infrequent. KB154.

Emmenanthe penduliflora Benth. Whisperingbells. Annual; rare. KB195.

Eucrypta chrysanthemifolia (Benth.) Greene. Spotted hideseed. Annual; infrequent. KB78, KB93.

Eucrypta micrantha (Torr.) A. Heller. Dainty desert hideseed. Annual; rare. KB73.

Harpagonella palmeri A. Gray. Palmer's grapplinghook. Annual; occasional. KB142.

***Pectocarya heterocarpa* (I.M. Johnst.) I.M. Johnst. Chuckwalla combseed. Annual; infrequent.

Pectocarya platycarpa (Munz & I.M. Johnst.) Munz & I.M. Johnst. Broadfruit combseed. Annual; frequent. KB74.

Pectocarya recurvata I.M. Johnst. Curvenut combseed. Annual; frequent. KB8, KB71.

Phacelia crenulata Torr. ex S. Watson. var. ambigua (M.E. Jones) J.F. Macbr. Purplestem phacelia. Annual; occasional. KB13.

Phacelia crenulata Torr. ex S. Watson. Cleftleaf wild heliotrope. Annual; infrequent. KB170a.

Phacelia distans Benth. Distant phacelia. Annual; infrequent. KB89, KB170b, KB185.

Pholistoma auritum (Lindl.) Lilja. Blue fiestaflower. Annual; infrequent under shrub cover. KB127, KB164, KB204.

Plagiobothrys arizonicus (A. Gray) Greene ex A. Gray. Arizona popcornflower. Annual; occasional. KB136, KB143.

BRASSICACEAE

^*Brassica tournefortii* Gouan. Asian mustard. Annual; infrequent. KB150.

Caulanthus lasiophyllus (Hook. & Arn.) Greene. California mustard. Annual; frequent. KB76, KB146.

Draba cuneifolia Nutt. ex Torr. & A. Gray. Wedgeleaf draba. Annual; occasional. KB189.

Lepidium densiflorum Schrad. Common pepperweed. Annual; infrequent. KB140.

Lepidium lasiocarpum Nutt. Shaggyfruit pepperweed. Annual; frequent. KB92.

Lepidium virginicum L. Pepperweed. Annual; occasional. KB92A.

^*Matthiola parviflora* (Schousb.) R.Br. Annual; frequent. KB80, KB108.

*******Physaria gordonii* (A. Gray) O'Kane & Al-Shehbaz. Gordon's bladderpod. Annual; rare.

Physaria tenella (A. Nelson) O'Kane & Al-Shehbaz. Moapa bladderpod. Annual; rare. KB169.

^*Sisymbrium irio* L. London rocket. Annual; infrequent. KB11.

Thysanocarpus curvipes Hook. Sand fringepod. Annual; infrequent. KB162, KB205.

CACTACEAE

***Carnegiea gigantea* (Engelm.) Britton & Rose. Saguaro. Tree; abundant.

***Cylindropuntia acanthocarpa* (Engelm. & J.M. Bigelow) F.M. Knuth. Buck-horn cholla. Shrub; abundant.

***Cylindropuntia bigelovii* (Engelm.) F.M. Knuth. Teddybear cholla. Shrub; abundant.

***Cylindropuntia fulgida* (Engelm.) Knuth. Jumping cholla, chainfruit cholla. Shrub; infrequent.

***Cylindropuntia leptocaulis* (DC.) F.M. Knuth. Christmas cholla. Shrub; occasional.

Echinocereus engelmannii (Parry ex Engelm.) Lem. Engelmann's hedgehog cactus. Shrub; occasional.

***Ferocactus spp*. Engelm. Barrel cactus. Shrub; occasional.

***Mammillaria grahamii* Engelm. Graham's nipple cactus. Shrub; occasional.

***Opuntia engelmannii* Salm-Dyck ex Engelm. Cactus apple. Shrub; locally abundant.

CANNABACEAE

Celtis pallida Torr. Spiny hackberry. Shrub; occasional. KB53.

CARYOPHYLLACEAE

^*Herniaria hirsuta* L. Hairy rupturewort. Annual; occasional. KB190, KB241.

Silene antirrhina L. Sleepy silene. Annual; occasional in protection of shrubs. KB147, KB186.

CELASTRACEAE

Canotia holacantha Torr. Crucifixion thorn. Shrub; infrequent. KB64.

CRASSULACEAE

***Crassula connata* (Ruiz & Pav.) A. Berger. Sand pygmyweed. Annual; infrequent.

EUPHORBIACEAE

Ditaxis lanceolata (Benth.) Pax & K. Hoffmann. Narrowleaf silverbush. Subshrub; frequent. KB6, KB29, KB65.

Ditaxis neomexicana (Muell. -Arg.) Heller. New Mexico silverbush. Annual; rare.

Euphorbia polycarpa Benth. Smallseed sandmat. Perennial; abundant. KB31.

FABACEAE

***Acacia constricta* Benth. Whitethorn acacia. Tree; infrequent.

Acacia greggii A. Gray. Catclaw acacia. Tree; frequent. KB175.

Acmispon rigidus (Benth.) Brouillet. Shrubby deervetch. Subshrub; occasional. KB161.

***Astragalus nuttallianus* DC. Smallflowered milkvetch. Annual; rare.

Calliandra eriophylla Benth. Fairyduster. Shrub; frequent. KB132.

Dalea pulchra Gentry. Santa Catalina prairie clover. Perennial herb; infrequent. KB238.

***Lotus humistratus* Greene. Foothill deervetch. Annual; occasional.

Lotus salsuginosus Greene. Coastal bird's-foot trefoil. Annual; occasional. KB104, KB138.

Lotus strigosus (Nutt.) Greene. Strigose bird's-foot trefoil. Annual; occasional. KB84, KB139.

Lupinus sparsiflorus Benth. Coulter's lupine. Annual; occasional. KB91, KB137, KB220.

***Marina parryi* (Torr. & A. Gray) Barneby. Parry's false prairie-clover. Perennial herb.

Olneya tesota A. Gray. Desert ironwood. Tree; abundant. KB235.

Parkinsonia aculeata L. Jerusalem thorn. Tree; Planted at nature center. KB236.

Parkinsonia florida (Benth. ex A. Gray) S. Watson. Blue paloverde. Tree; locally frequent. KB123.

Parkinsonia microphylla Torr. Yellow paloverde. Tree; abundant. KB66, KB115.

***Prosopis glandulosa* Torr. Honey mesquite. Tree; rare, Planted near camping area.

Prosopis velutina Woot. Velvet mesquite. Tree; frequent. KB96.

Senna covesii (A. Gray) Irwin & Barneby. Coues' cassia, rattlebox senna. Subshrub; occasional. KB43.

FOUQUIERIACEAE

Fouquieria splendens Engelm. Ocotillo. Shrub; occasional. KB152.

GERANIACEAE

^*Erodium cicutarium* (L.) L'Hér. ex Aiton. Redstem stork's bill. Annual; frequent. KB88, KB105, KB206.

Erodium texanum A. Gray. Texas stork's bill. Annual; rare. KB158.

KRAMERIACEAE

Krameria bicolor S.Watson. White ratany. Shrub; frequent. KB21, KB116.

LAMIACEAE

Hyptis emoryi Torr. Desert lavender. Shrub; occasional. KB39.

Salazaria mexicana Torr. Mexican bladdersage. Shrub; occasional. KB55, KB229.

***Salvia columbariae* Benth. Chia. Annual; occasional.

LINACEAE

^*Linum usitatissimum* L. Common flax. Annual; rare. KB233.

LOASACEAE

Mentzelia affinis Greene. Yellowcomet. Annual; infrequent. KB81.

MALPHIGIACEAE

Cottsia gracilis A. Gray. Slender janusia. Vine; infrequent. KB32.

MALVACEAE

Abutilon incanum (Link) Sweet. Indian mallow, pelotazo. Subshrub; infrequent. KB42, KB70.

***Hibiscus coulteri* Harv. ex A. Gray. Desert rosemallow. Shrub.

Sphaeralcea ambigua A. Gray. Desert globemallow. Subshrub; abundant. KB209.

Sphaeralcea ambigua (Munz & Johnston) Kearney subsp. *rosacea*. Rose globemallow. Subshrub; rare. KB17, KB60.

***Sphaeralcea coulteri* (S. Watson) A. Gray. Coulter's globemallow. Annual; rare.

MONTIACEAE

Calandrinia ciliata (Ruiz & Pav.) DC. Fringed redmaids . Annual; occasional. KB83.

NYCTAGINACEAE

Allionia incarnata L. Trailing windmills. Perennial herb; occasional. KB62.

Mirabilis laevis (Benth.) Curran. var. *villosa* (Kellogg) Spellenb. Wishbone-bush. Subshrub; frequent. KB20, KB77, KB119, KB133.

OLEACEAE

Menodora scabra A. Gray. Rough menodora. Subshrub; occasional. KB51, KB167, KB214, KB223.

ONAGRACEAE

Eulobus californicus Nutt. California suncup. Annual; infrequent. KB243.

Oenothera primiveris A. Gray. Desert evening primrose. Annual; infrequent. KB203.

OROBANCHACEAE

Castilleja exserta (A. Heller) T.I. Chuang & Heckard. Exserted Indian paintbrush. Annual; infrequent. KB156.

PAPAVERACEAE

Eschscholzia californica Cham. California poppy. Annual; occasional. KB181, KB208, KB219.

Eschscholzia minutiflora S. Watson. Pygmy poppy. Annual; infrequent. KB86.

PHRYMACEAE

Erythranthe guttata (Fisch. ex DC.) G. L. Nesom. Seep monkeyflower. Perennial herb; rare. KB192.

PLANTAGINACEAE

Penstemon subulatus M.E. Jones. Hackberry beardtongue. Perennial herb; infrequent. KB183, KB184, KB231.

Plantago ovata Forsk. Desert Indianwheat. Annual; frequent. KB101, KB202.

Plantago patagonica Jacq. Woolly plantain. Annual; frequent. KB102, KB211.

Plantago virginica L. Virginia plantain. Annual; rare. KB107.

***Sairocarpus nuttallianus* (Benth. ex A. DC.) D.A. Sutton. Violet snapdragon. Annual; rare.

Veronica peregrina L. Neckweed. Annual; infrequent. KB110.

POLEMONIACEAE

Eriastrum diffusum (A. Gray) H. Mason. Miniature woollystar. Annual; frequent. KB94.

Eriastrum eremicum (M.E. Jones) Mason. subsp. *yageri*. Yager's woollystar. Annual; occasional. KB216.

Gilia flavocincta A. Nelson. Lesser yellowthroat gilia. Annual; occasional. KB95, KB155.

Gilia stellata Heller. Star gilia. Annual; infrequent. KB191.

POLYGONACEAE

Chorizanthe brevicornu Torr. Brittle spineflower. Annual; infrequent. KB221.

Chorizanthe rigida (Torr.) Torr. & A. Gray. Devil's spineflower. Annual; infrequent. KB173.

Eriogonum deflexum Torr. Flatcrown buckwheat. Annual; infrequent. KB24.

Eriogonum fasciculatum Benth. Eastern Mojave buckwheat. Shrub; frequent. KB3, KB9, KB46, KB213.

Eriogonum inflatum Torr. & Frém. Desert trumpet. Perennial herb; frequent. KB5, KB19, KB69.

Eriogonum wrightii Torr. ex Benth. Bastardsage. Shrub; occasional. KB242.

PRIMULACEAE

Androsace occidentalis Pursh. Western rockjasmine. Annual; occasional. KB148, KB178.

RANUNCULACEAE

Anemone tuberosa Rydb. Tuber anemone. Perennial herb; infrequent. KB165.

Delphinium parishii A. Gray. Desert larkspur. Perennial herb; rare. KB234.

RHAMNACEAE

Ziziphus obtusifolia (Hook. ex Torr. & A. Gray) A. Gray. Lotebush. Shrub; occasional. KB120.

RUBIACEAE

Galium stellatum Kellogg. Starry bedstraw. Subshrub; infrequent. KB222.

SANTALACEAE

Phoradendron californicum Nutt. Mesquite mistletoe. Subshrub; occasional. KB2, KB124.

SIMMONDSIACEAE

Simmondsia chinensis (Link) C.K. Schneid. Jojoba. Shrub; frequent. KB1, KB118, KB121.

SOLANACEAE

Datura discolor Bernh. Desert thorn-apple. Annual; rare. KB63.

Lycium andersonii A. Gray. Water jacket. Shrub; occasional. KB33.

Lycium berlandieri Dunal. Berlandier's wolfberry. Shrub; occasional. KB16, KB122.

Lycium exsertum A. Gray. Arizona desert-thorn. Shrub; occasional. KB117.

Nicotiana obtusifolia M. Martens & Galeotti. Desert tobacco. Subshrub; infrequent. KB25.

URTICACEAE

Parietaria hespera Hinton. Rillita pellitory. Annual; infrequent. KB79, KB114, KB128.

VERBENACEAE

***Aloysia wrightii* (A. Gray ex Torr.) A. Heller. Wright's beebrush. Shrub; infrequent.

ZYGOPHYLLACEAE

Larrea tridentata (DC.) Coville. Creosote bush. Shrub; abundant. KB23.

MONOCOTS

ASPARAGACEAE

Agave murpheyi F. Gibson. Murphy's agave. Perennial herb; cultivated.

Dichelostemma capitatum (Benth.) Alph. Wood. Bluedicks, desert hyacinth, coveria. Perennial herb; occasional. KB134, KB201.

LILIACEAE

***Calochortus kennedyi* Porter. Desert mariposa lily. Perennial herb; infrequent.

POACEAE

Aristida purpurea Nutt. var. *parishii* (Hitchc.) Allred Parish's threeawn. Perennial herb; occasional. KB30, KB166.

Bouteloua aristidoides (Kunth) Griseb. Needle grama. Annual; infrequent. KB44.

***Bromus arizonicus* (Shear) Stebbins. Arizona brome. Annual; rare.

^*Bromus rubens* L. Red brome. Annual; abundant. KB90, KB97.

Dasyochloa pulchella (Kunth) Willd. ex Rydb. Low woollygrass. Perennial herb; occasional. KB56.

^*Echinochloa colona* (L.) Link. Jungle rice. Annual; rare in wet soils. KB52.

Hilaria mutica (Buckl.) Benth. Tobosagrass. Perennial herb; occasional in fine textured soils. KB49. KB217.

^*Hordeum murinum* L. Mouse barley. Annual; occasional. KB111.

Pappostipa speciosa (Trin. & Rupr.) Romasch. Desert needlegrass. Perennial herb; rare. KB199.

^*Phalaris minor* Retz. Littleseed canarygrass. Annual; rare. KB112.

Poa bigelovii Vasey & Scribn. Bigelow's bluegrass. Annual; infrequent. KB126.

^*Schismus barbatus* (Loefl. ex L.) Thell. Common Mediterranean grass. Annual; abundant. KB75, KB125.

Vulpia microstachys (Nutt.) Munro. Small fescue. Annual; infrequent.

Vulpia octoflora (Walter) Rydb. Sixweeks fescue. Annual; occasional. KB157, KB239.

CHAPTER 2

EFFECTS OF FIRE ON ARIZONA UPLAND PLANT COMMUNITY COMPOSITION

INTRODUCTION

Historically, fire in the Sonoran Desert was thought to be rare (Humphrey 1974), but it has been documented to be increasing over the last century, due in part to human activity (Schmid & Rogers 1988). Directly human-influenced factors such as increased nitrogen deposition from fertilizers and fossil fuels (Fenn et al. 2003), and introduction of nonnative species (Balch et al. 2013) have been documented to contribute to increased biomass density from annual species, increasing the potential fuel load during dry periods. Broader factors of biotic and abiotic influence such as climate change (Abatzoglou & Kolden 2011; Munson et al. 2012) and drought (Shryock et al. 2015b) not only contribute to increased frequency of fires in this ecosystem but also influence how post-fire plant communities are comprised.

Although some Sonoran Desert plants are fire adapted, others are not (Rogers & Steele, 1980; Brown & Minnich, 1986) so recovery of the plant community can take longer than the time it takes for fire to recur. It is estimated to take 20 years for species richness to begin to be comparable to adjacent unburned sites and approximately 76 years for perennial plant cover to reach its pre-fire condition (Abella 2009). Community composition was still found to be changed after this amount of time, though. (Abella 2010; Engel & Abella 2011; Esque et al. 2013; Shryock et al. 2014, 2015).

Unsurprisingly, water availability was found to be a major factor in the slow recovery time for plant communities (Abella 2009; Esque et al. 2013; Shryock et al. 2015). The first year of precipitation following a fire is thought to have a major influence in plant community recovery, but other abiotic factors such as elevation and aspect were also found to be important (Shryock et al. 2015a).

Studies on post-fire recovery of plant community composition in the Sonoran Desert exist, but many of them focus on short term recovery (Abella 2010; Alford 2001; Brown & Minnich 1986; Cave & Patten 1984; Esque et al. 2013; McLaughlin & Bowers 1982; Phillips & Cooperative National Park Resources Studies Unit 1997; Shryock et al. 2015b; Steers & Allen 2011). With the Sonoran Desert sustaining larger and more frequent fires under a changing climate, there is a need to monitor how plant community composition is being affected over a broader time scale.

To gain a better understanding of how Sonoran Desert Upland plant communities are affected over the long term I studied three fires from the 1990's that burned in the McDowell Sonoran Preserve, asking the questions: (a) in what ways did the fires at the McDowell Sonoran Preserve affect plant community attributes, such as cover and diversity, and (b) are there any significant differences in the distribution of cover between treatments for individual species?

STUDY AREA

The McDowell Sonoran Preserve is a 12,760-ha (34,000-acre) swath of land situated in the Arizona Upland subdivision of the Sonoran Desert northeast of Phoenix, AZ (Bodmer et al., 2014). It is a landscape dominated by *Ambrosia deltoidea, Carnegiea gigantea, Ferocactus spp., Cylindropuntia spp., Larrea tridentata,* and *Parkinsonia microphylla*, that weave their way through the high desert of the McDowell Mountains.

This Preserve was established officially in 1994 to be maintained as a "natural open space" for people to enjoy (Bodmer et al., 2014). The land is protected from development, but it endured three fires throughout the 1990's. In 1992, the Granite fire burned approximately 810 ha (2,000 acres) near the Brown's Ranch area. In 1993, the Ancala fire burned approximately 100 ha (250 acres) near Lost Dog Wash in the southern portion of the preserve and, in 1995, the Rio fire burned approximately 2,023 ha (5,000 acres) through the eastern midsection of the preserve (Fig. 4). All three burned plant communities were left to recover without human intervention.

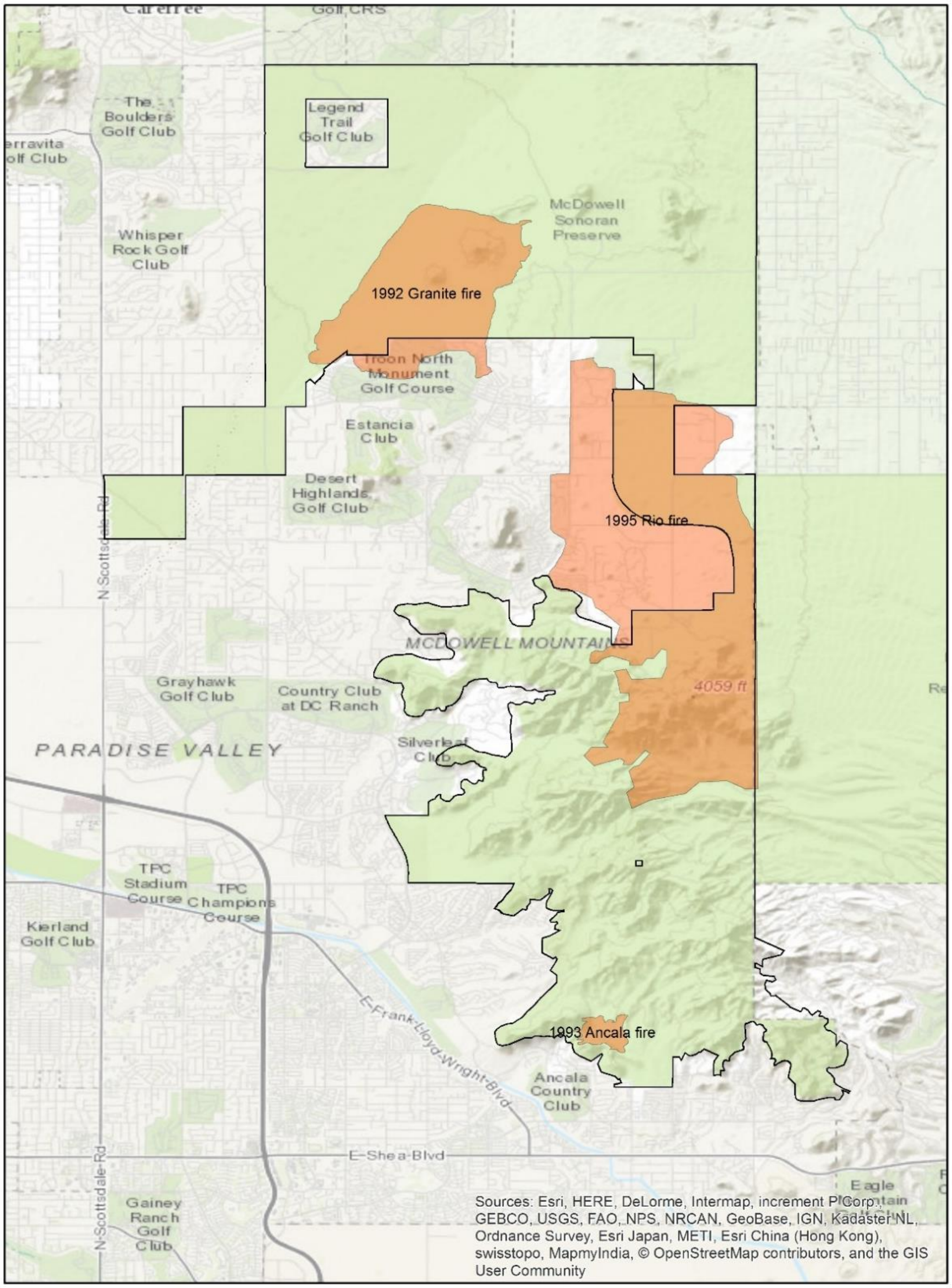


Figure 4. Map of the McDowell Sonoran Preserve with fire polygons. Park boundary is outlined in black and locations of the fires are shown as orange polygons.

METHODS

I used ArcMap 10.4 to look at polygons of the three fires, Granite (1992), Ancala (1993), and Rio (1995) (Figure 4) and identify potential transect locations. I obtained a permit from the city of Scottsdale, with the assistance of the McDowell Sonoran Conservancy Parsons Field Institute, to work off trail in the preserve and the areas near potential transects were scouted to visually confirm the burn area boundaries by looking for remnants of charred/scorched plant material. Transects were placed at least 15 meters away from trails. Transects were marked with rebar stakes with the help of McDowell Sonoran Conservancy stewards, using a GPS unit to maintain consistent elevation throughout.

Each site had two treatments, one burn and one control. A piece of rebar was placed at the 5-m mark and then every ten meters thereafter along two 100-m transects, one for each treatment. Each piece of rebar marked the center of a 10-m diameter plot (78.5 m^2), so that there were ten consecutive plots along each transect. Transects were not always a straight 100-m line. For example, the Ancala transects were split into two and three shorter lines because of elevation changes.

Alpha diversity was measured using species richness. Beta diversity, including turnover and nestedness values, was calculated using the betapart package in R Studio (Baselga and Orme, 2012).

Percent cover was measured for all perennial plants rooted inside each plot in the fall of 2016 and again in the spring of 2017. Cover was then averaged for each species. During the spring of 2017, cover for annual species was also measured using a 1 m^2 quadrat subplot randomly placed on within the interspace (defined as a space not occupied by shrub or tree stems) near the center of each plot. Perennial species, such as *Dichelostemma capitatum*, were measured using the 1 m^2 subplots and recorded under the term “annual” if their cover was difficult to quantify as a percentage of the larger 78.5 m^2 plot. The Mann Whitney U test was performed in R Studio (version 1.1.442) to test for significant differences in distribution of cover for growth habits and individual species between treatments at the 95% confidence level. Results for each statistical analysis are in Appendix A.

It should be noted that I measured the entire canopy of any plant rooted in a plot even if the canopy occurred outside the plot for this study. A more common method for measuring cover involves measuring only plant canopy that occurs within the boundary of a plot. To determine whether there was a significant difference between these two methods, three plots were randomly chosen along each of the six transects and cover was measured for each species using both methods. A Mann Whitney test was used to analyze the difference between these two methods and they were found not to be significantly different at the 95% confidence level (p=0.062).

RESULTS

Diversity

Species richness between treatments is similar, both across sites and at the site level, except for the Rio site (Fig. 5). Beta diversity, or number of species that were unique to each treatment, totaled 24 at Ancala, 34 at Granite, and 21 at Rio, with a total of 31 species across sites (Fig. 6).

Further analysis of these numbers (Table 6) showed that the differences in species composition is approximately 16% dissimilar across sites and is attributed entirely to species turnover (one species being replaced by another), rather than nestedness (species in one treatment being a subset of species in another treatment).

At the site level, there was some indication that the differences in diversity were due to nestedness. Rio had the largest proportion of dissimilarity attributed to nestedness with twice as many species unique to the unburned treatment than the burned (Fig. 6).

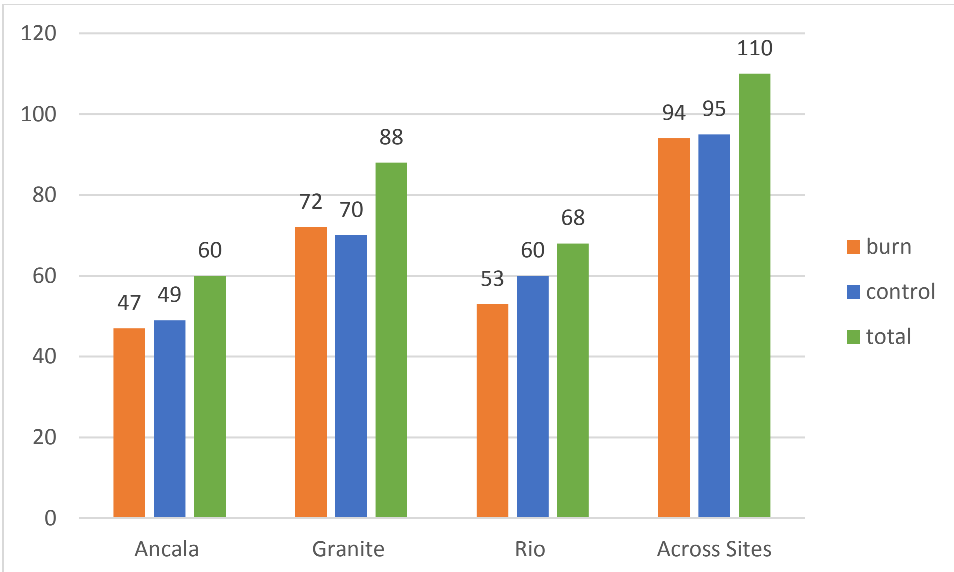


Figure 5. Species richness by treatment across sites at McDowell Sonoran Preserve.

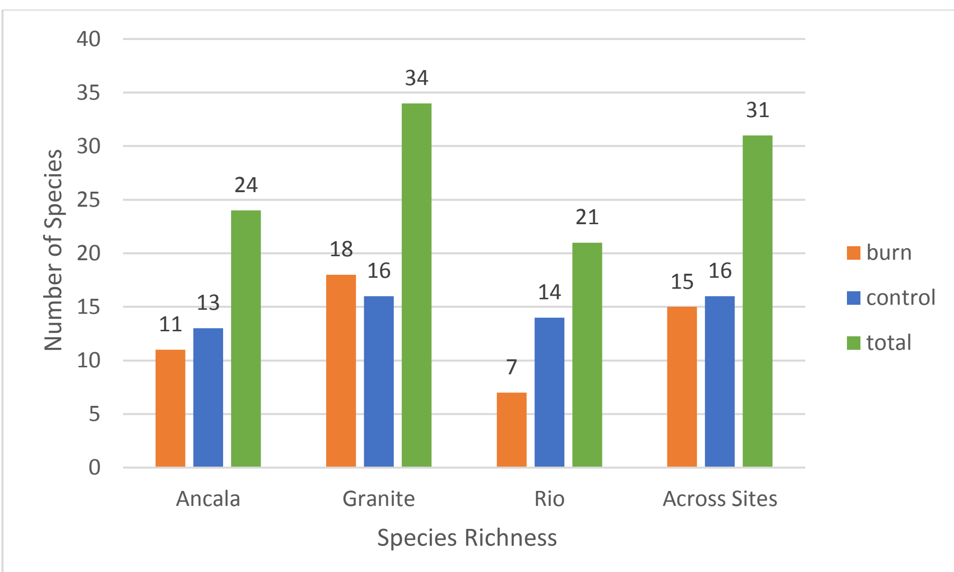


Figure 6. Beta diversity at McDowell Sonoran Preserve sites

Site	Sørensen Dissimilarity	Sørensen Turnover	Sørensen Nestedness
Ancala	0.250	0.234	0.016
Granite	0.239	0.229	0.011
Rio	0.193	0.148	0.045
Total	0.168	0.168	0.000

Table 6. Beta diversity at McDowell Sonoran Preserve sites, including nestedness and turnover components.

Cover

Cover is similar between treatments for perennials both across sites and at the site level (Fig. 7), but when the community composition was split into functional groups by growth habit across sites (Fig. 8) subshrubs and succulents showed significant differences in distribution of cover ($p<=0.05$). Succulents ($p=0.006$) were significantly reduced while subshrubs ($p<<0.001$) were significantly increased in the burn treatment.

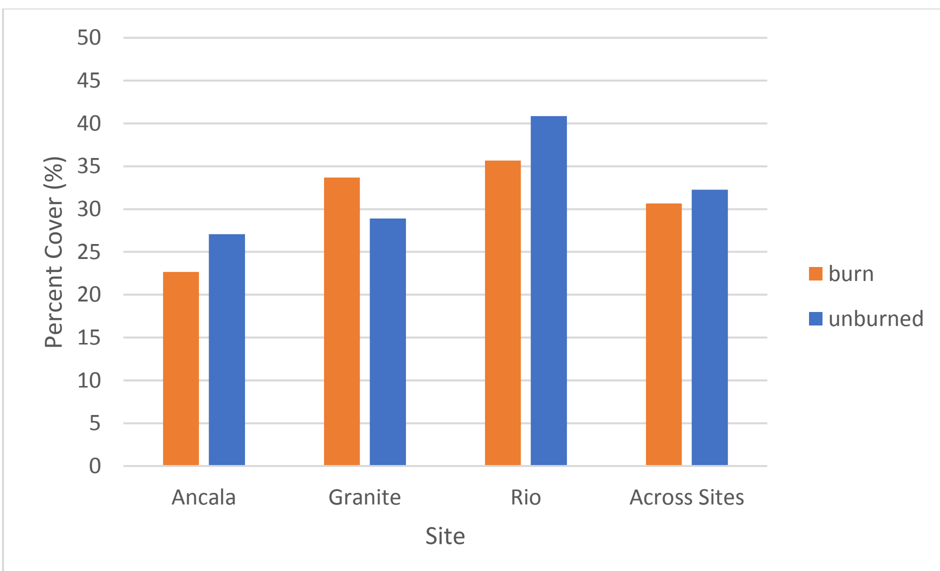


Figure 7. Mean perennial cover between treatments by site and across sites at McDowell Sonoran Preserve.

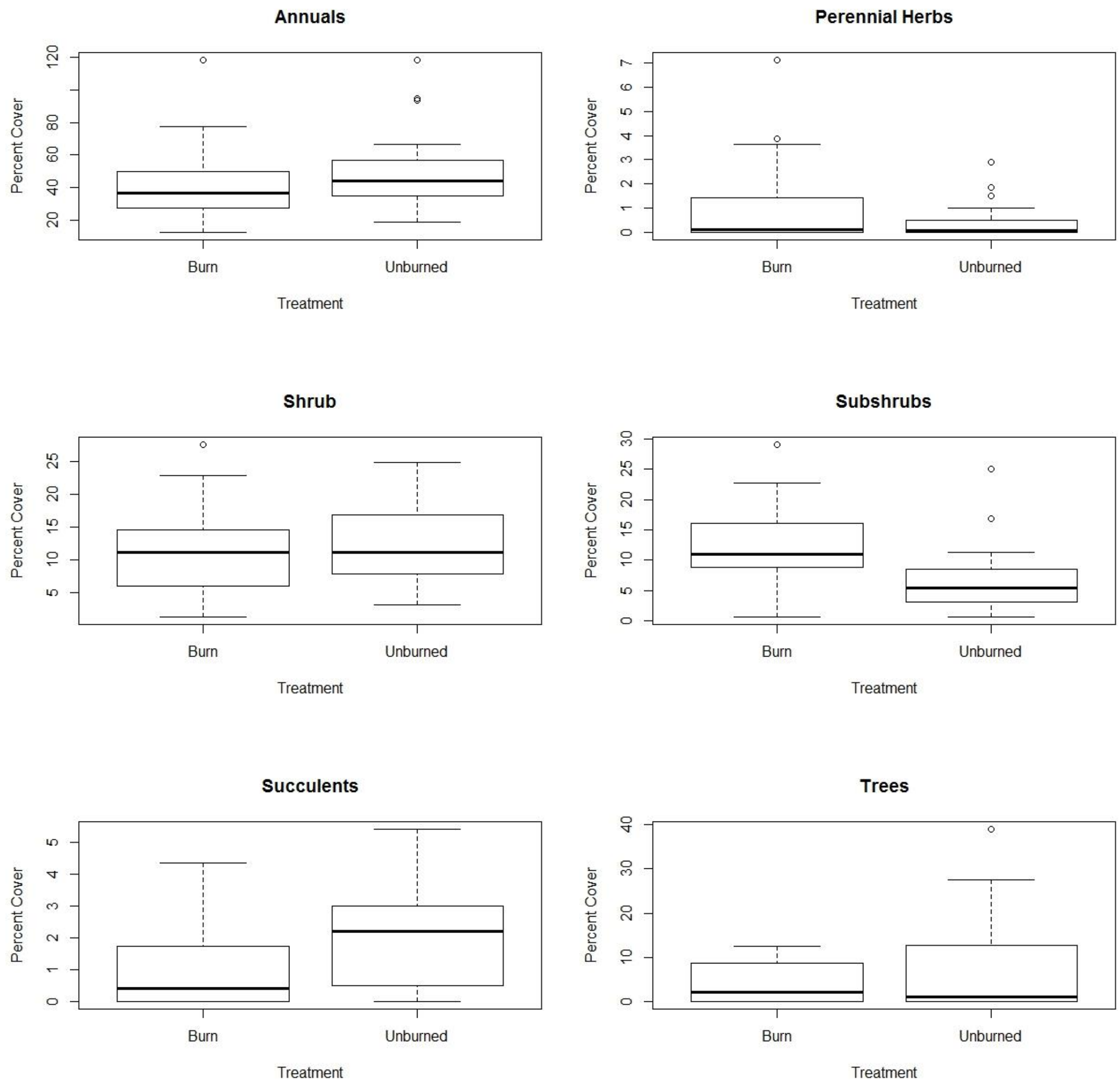


Figure 8. Mean plot cover in each treatment by growth habit at McDowell Sonoran Preserve sites.

Species

Annual species found to have significant difference in distribution of cover between treatments (p<=0.05) include *Crassula connata* (p=0.015), *Descurainia pinnata* (p=0.019), *Draba cuneifolia* (p=0.013), *Logfia arizonica* (p=0.015), *Parietaria hespera* (p=0.010), *Pectocarya heterocarpa* (p=0.033), *Pectocarya platycarpa* (p=0.002), *Pectocarya recurvata* (p=0.022), *Phacelia distans* (p=0.001), and

Pholistoma auritum ($p<0.001$). Of these findings, only *Descurainia pinnata* showed increased cover in the burned treatment. All other annuals showed significant decline in cover in the burned treatment.

Perennial species found to have significant difference in distribution of cover between treatments ($p<=0.05$) include *Acacia greggii* ($p=0.019$), *Echinocereus engelmannii* ($p=0.003$), *Encelia farinosa* ($p<0.001$), *Eriogonum wrightii* ($p=0.033$), *Penstemon subulatus* ($p=0.002$), *Phoradendron californicum* ($p=0.043$), and *Senna covesii* ($p=0.035$).

DISCUSSION

The Rio site had a greater amount of dissimilarity attributed to nestedness than the other sites at the McDowell Sonoran Preserve. This may be due to recurring disturbance, indicated by bike tire tracks and hoof prints near the burn transect.

Several rebar stakes marking our burned transect plots, which were located more than 100 meters away from the nearest designated trail, were removed by an unauthorized party. It was also brought to my attention during this study that a nearby resident had been known to allow their horses to graze in the area even though this activity is prohibited (McDowell Sonoran Conservancy steward, personal communication). Evidence of off trail use by humans and horses were not found in the control treatment and this is likely due to the abundance of cacti cover in these areas making it more difficult to access. These factors may have influenced the results of this study.

For many of the annual species with significantly different distributions of cover between treatments their response to fire has been poorly documented, with few previous studies at other localities. An exception is a study by Steers and Allen (2011). In this report the authors state that *Crassula connata* was shown as being negatively associated with burned areas while the opposite was true regarding *Pectocarya heterocarpa*.

Annual species, such as *Pholistoma auritum* and *Parietaria hespera,* are known to be found under the canopy of shrubs and trees. The decline in cover of these species within the burn treatment, therefore, was most likely caused because fires burn hotter in areas of dense biomass (Brooks 2002) resulting in the destruction of the soil seed bank. Other annual species may have been outcompeted (Brooks 2002; Steers & Allen 2010) by *Descurainia pinnata* or have seed dispersal strategies that are short range and will take longer to reestablish in the burned treatment.

My results show a significant increase in cover for perennials *Acacia greggii*, *Encelia farinosa,* and *Senna covesii* in the burn treatment. These findings are consistent with results from other studies (Abella 2010; Alford 2001; Brown & Minnich 1986; Cave & Patten 1984; Phillips & Cooperative National Park Resources Studies Unit 1997; Shryock et al. 2015b). *Senna covesii*, for example, was used post-fire to reseed an area in Cave Creek Regional Park in 2005 and was described as being the most successful at establishing a population in the burned treatment after a 32-month monitoring period (Abella 2010; Abella et al. 2009). *Acacia greggii* is adept at resprouting post-fire (Alford 2001) and *Encelia farinosa* is regularly seen in abundance in disturbed areas (Abella 2010; Brown & Minnich; Cave & Patten 1984).

Echinocereus engelmannii, Eriogonum wrightii, Penstemon subulatus, and *Phoradendron californicum* showed a significant decrease in cover in the burn treatment.

The Cactaceae have shown a high rate of mortality after fire (Alford 2001; Brown & Minnich 1986; Bunting et al. 1980; Cave & Patten 1984; McLaughlin & Bowers 1982; Phillips & Cooperative National Park Resources Studies Unit 1997). *Echinocereus* *engelmannii* was the only species in this family to show a statistically significant difference between treatments, but as mentioned previously, the succulent growth habit overall was found to show a significant difference in distribution of cover between treatments and that supports this finding.

Penstemon subulatus is a species like the above mentioned *Pholistoma auritum* and *Parietaria hespera* that is found under the protection of shrubs and trees, so it was also likely reduced due to increased temperatures that occur in areas with dense biomass. This species is an Arizona endemic, so conservation of this species should be high priority in areas where it is known to occur. This could involve measures such as seed banking or more concentrated fire prevention methods such as fire breaks and invasive species management.

Phoradendron californicum showed a significant decline in cover while its host plant, *Parkinsonia microphylla* declined in cover as well, but not significantly. There is evidence that *P. microphylla* is attempting to reestablish, anecdotally noted in many plots by young plants or branches that have resprouted from exposed roots or bases of scorched plants.

There was visual evidence of herbivory and this combined with prolonged drought may be limiting their ability to grow to their full height. The average height of these trees was less than 30 centimeters in my study areas. In fact, there were occasions during the spring monitor when data collectors tripped over *P. microphylla* because the density of spring annuals were rendering them invisible. I would recommend caging the *P. microphylla* until they can achieve a height that allows them to be more resistant to herbivory.

The literature indicates that *P. microphylla* is highly susceptible to fire (Cave & Patten 1984; Shryock et al. 2015a). One study found that abundance returned to pre-fire density and cover after 21 years (Alford 2001), but another study showed an overall significant decrease in cover of *P. microphylla* after fire in the Arizona Uplands (Shryock et al. 2015a). All three of the fires studied at the McDowell Sonoran Preserve were a minimum of 22 years old at the time of sampling.

CONCLUSION

This study provides data regarding long term recovery of Arizona Upland plant communities, including individual species and growth habit responses. My findings indicate that fire acted as a catalyst for changes in plant community composition at McDowell Sonoran Preserve sites. These changes persist more than 22 years post-fire.

Faster growing subshrubs are replacing succulents in the burn treatment. The treatments are similar in cover and diversity now, but recovery will continue if slower growing species have time to mature to their pre-fire cover and faster growing species with short range seed dispersal can reestablish without further incident.

If the fire return interval is shorter than the time it takes for these species to return to the community species such as *Carnegiea gigantea* and *Penstemon subulatus* may drop out altogether. Seed banking is an option for conservation but cannot preserve wild populations of slow growing species in a landscape with a shorter fire return interval. Finding ways to decrease fire risk is going to be the best conservation method for overall community health.

CHAPTER 3

EFFECTS OF RESEEDING ON ARIZONA UPLAND PLANT COMMUNITY COMPOSITION

INTRODUCTION

The ability for a species to recover after a fire depends on its ability to resprout or reseed in the disturbed site. Temperatures between 100˚C and 225˚C, which are typical temperatures reached in a fire fueled by dried annual biomass, destroy 55 to 80% of the desert annual seed bank (Esque et al. 2010). Losses are highest for seeds under canopy cover because the shrubs and trees provide fuel for fires to burn their hottest in these microsites (Brooks 2002).

In the previous chapter, I discussed that recovery after fire in arid environments can take decades. For this reason, land managers may find it necessary to facilitate the recovery or stabilization of a site to avoid establishment of unwanted or invasive species, to minimize soil erosion, improve aesthetics, increase diversity, or prevent subsequent human impacts (Bean et al. 2004; Monsen et al. 2004). This can be done with seeding or out planting, but out planting is not always economically feasible for large scale disturbances (Bean et al. 2004).

Reseeding with native species to accomplish these outcomes has been discouraged in arid environments because of findings that they do not establish well (Bainbridge 2007; Cox et al. 1984; Judd & Judd 1976; Monsen et al. 2004). There are variables that land managers can manipulate to increase the chances of successful reseeding, such as timing of the planting, seed pelleting, species selection, mulching, and site preparation (Abella & Newton 2009; Anderson 2002; Montalvo et al. 2002). More research is needed to better understand which combinations of treatments provide the best outcomes, though.

In 2005, after a fire in Cave Creek Regional Park, a post-fire reseeding in Cave Creek Regional Park was performed that incorporated several techniques including mulching and a diverse mix of 28 species. The site had been sampled five times over a 32-month period following the revegetation to monitor the establishment of seeded species (Abella et al. 2009). On the last sampling date, seeded transects were compared to unburned and burned (but not revegetated) transects to compare diversity.

I sampled this site in 2017 and used the data to address the questions set forth in Chapter Two, (a) in what ways did the fire and reseeding at Cave Creek Regional Park affect plant community attributes, such as cover and diversity and (b) are there any significant differences in the distribution of cover between treatments for individual species, with the addition of asking (c) which of the seeded species are still present?

STUDY AREA

In June of 2005, a fire started on private property immediately south of Cave Creek Regional Park and then spread into the park (33.8086 N, -111.9907 W), burning approximately 1.5 ha (3.7 acres) (Fig. 9). The unburned area surrounding the site is dominated by *Ambrosia deltoidea* and the entire area, including the burn site is in an alluvial fan.

Private residences border the site to the south. A service road cuts east-west through the park to the north of the burned site and just north of that begin the slopes of the southernmost mountain of the park.

Figure 9. Polygon of the Cave Creek Regional Park fire. The fire polygon is colored orange and the perimeter of the park is outlined in green.

METHODS

I used the plots established during the initial sampling period. This included two 100-m transects in the reseeded area, one 50-m transect in an adjacent unburned area and one 50-m transect in an area that was burned but not reseeded. Plots were spaced evenly along each transect, 10 m apart, and each plot was 10 m in diameter for a plot area of 78.5 m^2. There was a total of 22 plots in the reseeded treatment, five plots in the burned treatment, and five plots in the unburned treatment. Differences in transect size were due to the limited amount of land that was burned but not reseeded.

Alpha diversity was measured as species richness. Differences in diversity between treatments was measured using the Sørensen dissimilarity index. This index used beta diversity to measure differences and included values for turnover and nestedness components. The betapart package, version 1.5.1 (Baselga and Orme, 2012) was utilized to calculate these measures in R Studio. To account for unequal sample sizes, a random subset of five plots from the seeded treatment were used to compare to the burn and unburned treatments for the beta diversity analyses.

During the spring of 2017, I measured the cover of all perennials rooted in the plots and recorded the presence for all annual species occurring in the plots. The cover for annuals was measured using a 1 m^2 quadrat subplot randomly placed in an interspace near the center of each plot. Perennial species, such as *Dichelostemma capitatum*, were measured as an annual, using the 1 m^2 subplots and recorded under the term "annual", if their small stature made it difficult to quantify cover as a percentage of the larger 78.5 m^2 plot.

Differences in distribution of cover for perennials, growth habit, and individual species were measured using Analysis of variance with a Tukey HSD post hoc test or Kruskal Wallace rank sum test with Dunn's Test of Multiple Comparisons Using Rank Sums in the "dunn.test" package, version 1.3.5, if the data were not normally distributed. All plots were used in these analyses and performed using R Studio. Significant results are at the 95% confidence level and all results for the above mentioned analyses are listed in Appendix B.

RESULTS

Diversity

The total species richness was 66 species. Species richness was highest in the seeded treatment (58), followed by the unburned (31) and burned (29) treatments (Fig. 10a). This is likely due to the number of plots in the seeded treatment being higher (n=22) than both the burned (n=5) and unburned (n=5) plots.

To account for skewed results due to unequal sample size, I used five randomly selected plots from the seeded treatment to compare to the entire burned and unburned treatments. This lowered the total species richness to 56 species and the seeded treatment to 35 species (Fig. 10b).

Pairwise beta diversity showed a total difference of 30 species for both the burn/unburned treatment comparison and the unburned/seeded treatment comparison and 28 species for the burn/seeded comparison (Fig. 11). Using the Sorensen dissimilarity indices, this results in a total dissimilarity of 53.0% among all treatments, with 49.4% of the difference attributed to turnover and 3.7% attributed to nestedness. Pairwise comparisons follow the same pattern but with slightly higher nestedness values when the seeded treatment is compared to the unburned and burned plots than there is when the burn and unburned treatments are compared (Table 7).

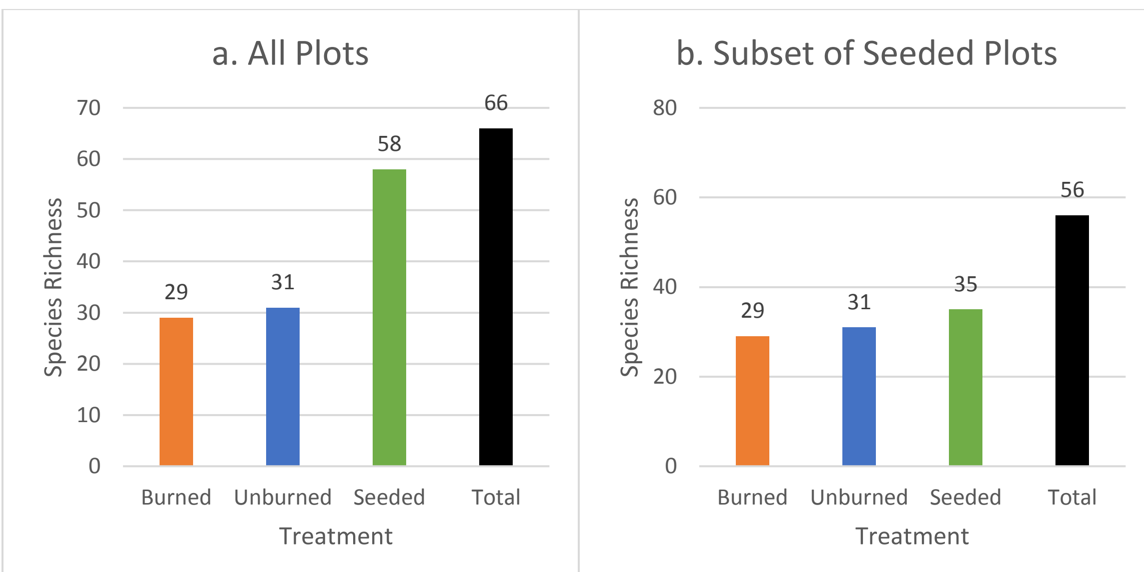


Figure 10. Species richness for each treatment and across treatments at Cave Creek Regional Park using (a) data from all plots and (b) data from a random subset of 5 seeded plots.

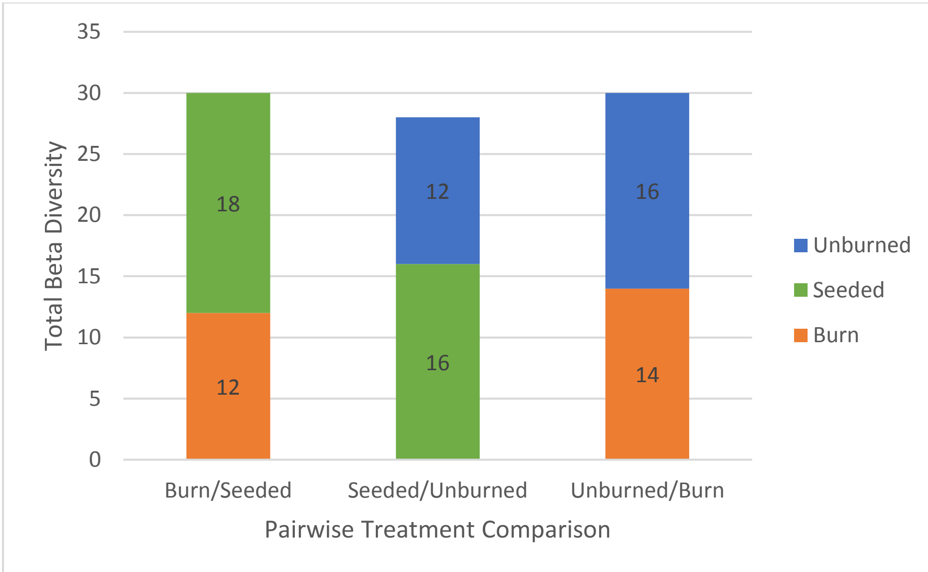


Figure 11. Pairwise beta diversity at Cave Creek Regional Park Pairwise using data from a subset of 5 seeded plots.

Treatments	Sørensen Dissimilarity	Sørensen Turnover	Sørensen Nestedness
Unburned/Burn	0.500	0.483	0.017
Burn/Seeded	0.469	0.414	0.055
Seeded/Unburned	0.424	0.387	0.037
Total	0.530	0.490	0.037

Table 7. Beta diversity at Cave Creek Regional Park, including nestedness and turnover components

Cover

Mean cover of perennials was highest in the unburned treatment at 17.58%, followed by the seeded treatment at 11.6%, and the burned treatment at 7.06% (Fig. 12). Differences in distribution of cover among treatments was not significantly different (p=0.127) until the analysis was split into functional groups by growth habit (Fig. 13). This analysis showed shrubs, subshrubs, and succulents with a significant difference in distribution of cover (p<=0.05) (Figure 3-5 and 3-6). Succulents (p=0.015) and shrubs (p<0.001) had significantly higher distribution of cover in the unburned treatment and subshrubs had a significantly higher distribution of cover in the restored treatment (p=0.036).

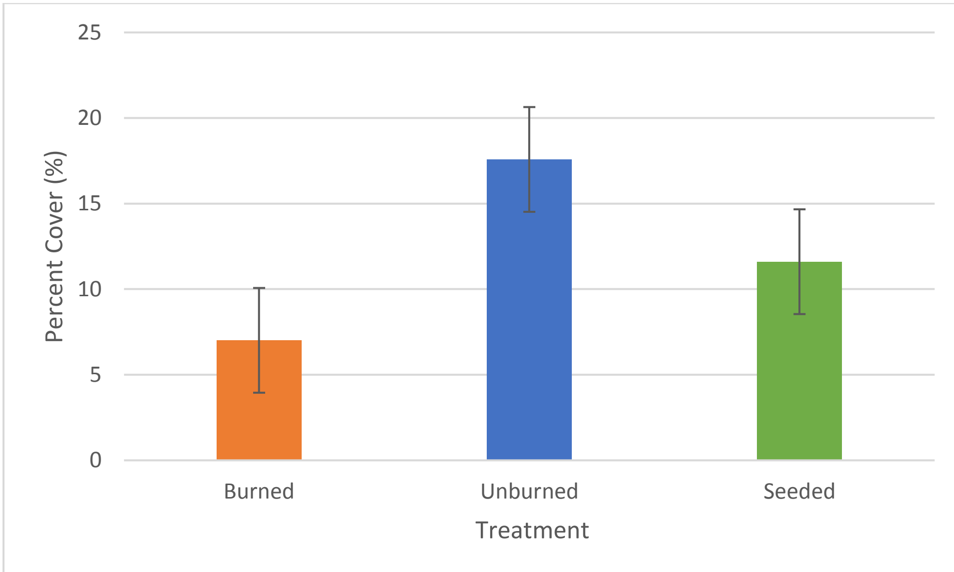


Figure 12. Mean perennial plot cover by treatment at Cave Creek Regional Park.

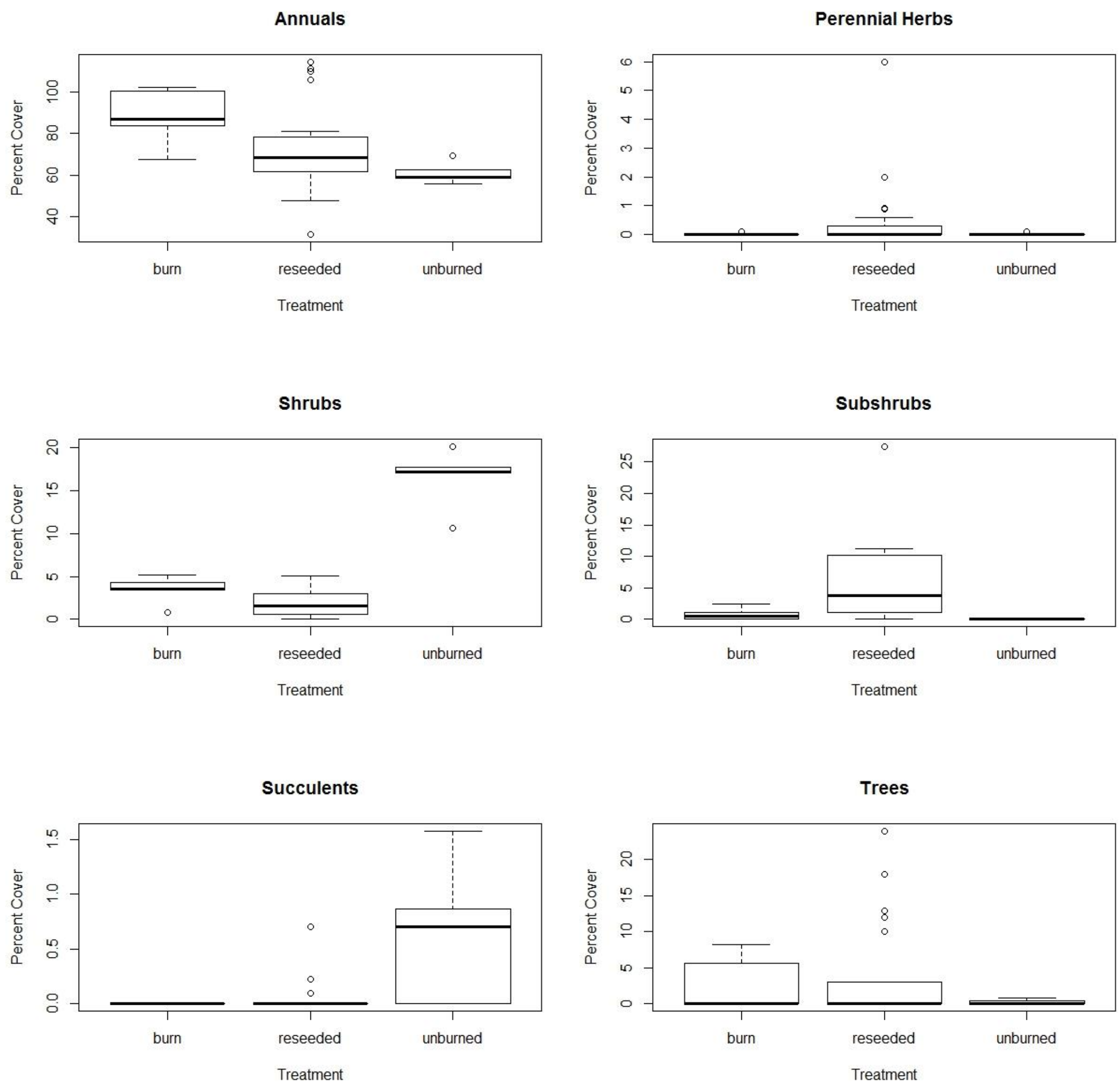


Figure 13. Mean plot cover in each treatment by growth habit at Cave Creek Regional Park.

Species

Eleven of the 28 species seeded into the burn area in 2005 were present during my sampling 12 years post-treatment. Initially 18 species had shown successful germination and 12 species had shown some establishment by the final sampling (Abella et al., 2009).

Analysis of seeded species that were present during the most recent sampling period showed that there were three species with significantly greater distribution of cover in the seeded treatment (p<=0.05). All three were only found in the seeded treatment and are not known to have naturally occurring populations in Cave Creek Regional Park. These were *Atriplex canescens* (p=0.047), *Phacelia crenulata* (p=0.001), and *Sphaeralcea ambigua subsp. rosacea* (p=0.015).

Analysis of naturally occurring species resulted in 14 species with a significant difference in distribution (p<=0.05) of cover among treatments. Responses to the fire and reseeding events were variable and are addressed below.

Species with significantly greater distribution of cover in the unburned treatment over both the burned and reseeded treatment included *Astragalus nuttalianus* (p=0.036), *Cryptantha pterocarya*(p=0.004), and *Pectocarya recurvata* (p=0.014).

Ambrosia deltoidea showed a significantly lower distribution of cover in the reseeded area when compared to both unburned and burned treatments (p=<0.001). *Vulpia octoflora* favored the unburned over the reseeded but did not show a significant result when compared to the burn (p=0.005).

Species with significantly greater distribution of cover in the burned treatment over both the unburned and reseeded treatment included *Bromus rubens* (p=0.003), *Daucus pusillus* (p=0.01), *Hordeum murinum* (p=0.004), *Oncosiphon piluliferum* (p=0.01), *Plantago patagonica* (p=0.037). *Pectocarya heterocarpa* (p=0.014) and *Schismus barbatus* (p=0.003).

Encelia farinosa (p=0.046) and *Matthiola parvifolia* (p=0.03) showed a significantly greater distribution of cover in the reseeded treatment when compared to the unburned, but not compared to the burned. *E. farinosa* was the dominant species across all the burned McDowell Sonoran Preserve treatments.

DISCUSSION

Diversity was highest for the reseeded treatment, even after unequal sample size was accounted for. Beta diversity shows that the three treatments are 53% dissimilar 12 years post-fire. This was primarily attributed to species turnover.

The dissimilarity in plant community composition due to turnover between treatments was likely caused by a combination of factors in addition to the fire, including species that were introduced during the reseeding event and drought. Additionally, the community composition of the burn treatment was likely influenced by an edge effect.

Eleven species from the reseeding event persist in the site twelve years post-treatment. This is one less than was present at the end of the initial sampling period in 2008. Two of the 12 species present during that sampling period, *Glandularia gooddingii* and *Baileya multiradiata*, have dropped out of the community and one of the species seeded but not seen during the initial sampling period, *Larrea tridentata*, has since showed some establishment (Table 8).

Larrea tridentata found in the reseeded plots during the current sampling period were no bigger than 0.3 m in diameter. It has been documented that the seeds of *Larrea tridentata* need to be flushed with water repeatedly to have successful germination in a greenhouse setting (Leslie Defalco, USGS, via personal communication, 2017). This may have been why this species did not appear in the reseeded treatment during the first monitoring period, although it is also likely that the plants counted during the current study were germinated from seeds that blew in from the surrounding area. For this reason, *Larrea tridentata* would not be a good choice for a seed mix unless the seeds are pretreated, or heavy rains are imminent.

One of the reasons that recovery is slow in arid ecosystems is because of lack of precipitation. Results from a study conducted by Shryock et al. (2015) showed that the first year of precipitation following a fire has more influence on how the plant community recovers than time since fire. The annual rainfall recorded for Cave Creek in 2005, the year of the fire, was 60.1 cm. This is the highest on record for that rain gauge. The very next year, 2006, had the lowest recorded annual precipitation for that rain gauge at 17.5 cm. The use of hydroseeding and a layer of straw mulch over the seeded area most likely improved the ability for both introduced and naturally occurring seeds to germinate and establish in that treatment.

Drought is not the only factor affecting the composition of the burn treatment. The composition here was likely different from the unburned treatment even before the fire due to its location between two wire/metal fences designating the perimeter of the park and the perimeter of the adjacent private property. Fencing can create microclimates and an area where plant debris and seeds can gather. The adjacent homes have horses, and some have landscaped yards are known to introduce species into the community that wouldn't occur in the habitat naturally (Fonseca 2008).

The results of this study showed that six annual species had significantly higher distribution of cover in the burn area – *Bromus rubens*, *Daucus pusillus*, *Hordeum murinum, Oncosiphon piluliferum, Plantago patagonica*, *Pectocarya heterocarpa*, and *Schismus barbatus* – and four of those were non-native, one of which is potentially invasive. The study from Chapter Two showed a pattern of decreased annual cover in the burned treatment but none of those sites were immediately adjacent to a suburban development.

Overall perennial cover was greatest in the unburned treatment but when cover was grouped by growth habit, subshrubs had significantly greater distribution of cover in the reseeded treatment while succulents and shrubs showed significantly higher distribution of cover in the unburned treatment.

Ambrosia deltoidea is the dominant shrub in the unburned treatment and showed significantly greater cover in the unburned treatment only when compared to the reseeded treatment. It is being replaced by the subshrubs *Encelia farinosa* and *Sphaeralcea ambigua*. *Ambrosia deltoidea* is present but may be a slower growing species. Since *A. deltoidea* is typically a dominant species in this ecosystem, I would recommend continued monitoring to ensure that *A. deltoidea* is returning to pre-fire cover or that, at the very least, the species replacing *A. deltoidea* are providing similar ecosystem services.

Seeded Species	Germinated during 2005-2008 monitoring period	Established during 2005-2008 monitoring period	Present during 2017 monitoring period
Allionia incarnata			
Argemone hispida	X		
Aristida purpurea	X	X	X
Atriplex canescens	X	X	X
Baileya multiradiata	X	X	
Bothriochloa barbinodus			
Bouteloua curtipendula			
Bouteloua rockrothii (barbata)			
Calliandra eriophylla			
Castelleja exserta	X	X	X
Eragrostis intermedia			
Eschscholzia californica	X	X	X
Glandularia gooddingii	X	X	
Heteropogon contortus	X		
Hilaria belangeri	X		
Larrea tridentata			X
Lupinus sparsiflorus	X	X	X
Muhlenbergia porteri			
Olneya tesota	X	X	X
Panicum obtusum			
Penstemon eatonii	X		
Penstemon parryi	X		
Phacelia crenulata	X	X	X
Physaria gordonii	X	X	X
Senna covesii	X	X	X
Setaris vulpiseta			
Sphaeralcea ambigua subsp. rosacea	X	X	X
Sporobolus cryptandrus			
TOTAL	**18**	**12**	**11**

Table 8. Species used to reseed at Cave Creek Regional Park. Those that that germinated and/or established are marked with an “X”.

CONCLUSION

This information adds to the body of knowledge regarding which species can be seeded in Sonoran Desert revegetation projects when straw mulch is applied post-seeding (Abella et al. 2009). The twelve species that showed establishment during the initial monitoring period from 2005 to 2008 would all be good candidates for reseeding using straw mulch. Consideration for timing of planting and adjacent plant community composition should be considered when choosing a seed mix to ensure successful establishment and to prevent seeded species from altering the composition of the landscape unnecessarily.

This study also contributes to the knowledge of growth habit and species responses to fire and reseeding. Subshrubs are replacing shrubs and succulents on the landscape during the first 12 years post-fire. Subshrubs are known from the study in Chapter Two to continue to be significantly greater in cover even more than 20 years post-fire, though. It will take decades for succulent cover to return and care for fire prevention will be the first and best line of defense in safe guarding this type of growth habit.

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APPENDIX A

STATISTICAL RESULTS FOR MCDOWELL SONORAN PRESERVE SITES

Results from each species and growth habit testing the null hypothesis that the distribution of cover between treatments is equal. A Mann Whitney U test was used for most analyses, but a t test was used whenever data were normally distributed and had equal variance. Species or growth habits marked with an asterisk (*) indicate tests with significant outcomes at the 95% confidence level (p<=0.05).

Species	(W)	p-value	N
ACGR*	285.5	0.019	40
ADPO	221	0.494	40
AMCO3	56	0.657	20
AMDE4	423.5	0.697	60
AMMEI2	391	0.334	60
AMTE3	55	0.368	20
ANOC3	35	0.077	20
ARAD	55	0.368	20
ARNE2	228	0.39	40
ARPU9	55	0.368	20
ASNU4	493.5	0.306	60
BOIN3	442.5	0.894	60
BRRU2	440	0.887	60
CAER	240	0.28	40
CAEXE	35	0.078	20
CAGI10	191	0.615	40
CAHO3	60	0.168	20
CALA35	370	0.195	60
CHBR*	160	0.0401	40
CRBA5	191.5	0.8101	40
CRCO34*	299	0.015	60
CRMU2	45	0.368	20
CRPT	55	0.687	20
CYACC2	130.5	0.963	60
CYBI9	49	0.965	20
CYLE8	85.5	0.269	40
DAPU3	499	0.374	60
DEPI*	250	0.019	40
DICA14	340.5	0.077	60
DRCU*	325.5	0.013	60
ECEN*	101.5	0.003	40
EMPE	55	0.368	20
ENFA*	366	<0.001	40
EPAS	211	0.374	60
ERCI6	556.5	0.097	60
ERDI2	60	0.168	20
ERER2	132	0.053	40
ERFAP	70	0.137	20
ERLA12	183	0.648	40
ERLA15	38.5	0.335	20
ERPR4	60	0.168	20
ERTE13	55	0.368	20
ERWR*	273.5	0.033	40
EUCH	142.5	0.104	40
EUME3	185	0.604	40
EUPO3	550.5	0.126	60
FECY	394	0.683	60
FOSP2	45	0.368	20
GAAP2	45	0.368	20
GIFL	510	0.091	60
GUSA2	192	0.838	40
HAPAA	372.5	0.113	60
HEHI	464.5	0.584	60
HYEM	165	0.427	40
JAGR	45	0.368	20
KRER	34.5	0.214	20
KRGR	396.5	0.423	60
LACA7	231.5	0.367	40
LATR2	464	0.827	60
LELA	470	0.764	60
LOAR12*	287	0.015	60

LOHU2	200.5	1.00	40
LORI3	205	0.228	40
LOSA8	197.5	0.952	40
LOSQ	39.5	0.278	20
LOSTT	490.5	0.511	60
LUCO	40	0.168	20
LUSP2	204	0.909	40
LYEX	449	0.999	60
MAGR9	462.5	0.785	60
MAPA9	40	0.168	20
MEAF2	55	0.368	20
MESC	40	0.168	20
MILAV	213.5	0.704	40
MUPO2	50.5	1.00	20
OLTE	45	0.368	20
ONPI	196	0.892	40
PAHEH*	329	0.0102	60
PAMI5	263	0.884	60
PEHE*	327	0.033	60
PEPL*	101	0.002	40
PERE*	299.5	0.022	60
PESU7*	85	0.002	20
PHAUA*	99.5	0.0006	40
PHCA8*	150	0.043	40
PHCRA2	45	0.368	20
PHDI*	261.5	0.001	60
PICA14	45	0.368	20
PLAR	167	0.333	40
PLOV	269.5	0.059	40
PLPA2	396.5	0.411	60
POBI	200.5	1.00	40
POGR5	230.5	0.367	40
PRVE	58.5	0.387	20
RANE	45	0.368	20
SACO6	55	0.368	20
SCBA	408.5	0.540	60
SECO10*	70	0.035	20
SIAN2	172	0.421	40
SIIR	55	0.368	20
SOOL	45	0.368	20
SPAM2	137	0.398	40
STMI2	464	0.748	60
STPA4	133.5	0.194	40
THCU	180	0.447	40
TRCA8	238.5	0.098	40
VIPA14	52.5	0.880	20
VUMI	55	0.368	20
VUOC	490	0.524	60
ZIOB	45	0.368	20

Growth Habit	**Test Stat**	**p value**	**N**
annuals	W = 345.5	0.124	30
perennial herbs	W = 517.5	0.316	30
trees	W = 433.5	0.812	30
shrub	t= -1.1188, df = 57.939	0.268	30
subshrub	W = 760.5	<0.001	30
succulents	W = 266.5	0.006	30

APPENDIX B

STATISTICAL RESULTS FOR CAVE CREEK REGIONAL PARK RESEEDED SITE

Results from each species and growth habit testing the null hypothesis that the distribution of cover between treatments is equal. A Kruskal Wallace rank sum test was used for most analyses, but the Analysis of Variance (ANOVA) test was used whenever data were normally distributed and had equal variance. Species or growth habits marked with an asterisk (*) indicate tests with significant outcomes at the 95% confidence level (p<=0.05).

Species	Test Stat	df	p value	N
ABIN	0.455	2	0.797	32
AMDE4	19.536	2	<0.001	32
AMMEI	3.284	2	0.194	32
AMTE	5.400	2	0.067	32
ARPU9	0.938	2	0.626	32
ASNU4	6.674	2	0.036	32
ATCA2	6.120	2	0.047	32
BOIN3	1.544	2	0.463	32
BRAR4	5.400	2	0.067	32
BRRU2	11.320	2	0.003	32
CAEXE	2.208	2	0.332	32
CAGI10	1.990	2	0.369	32
CALA35	4.141	2	0.126	32
CRBA	2.013	2	0.366	32
CRCO34	3.921	2	0.141	32
CRPT	11.160	2	0.004	32
CYACC2	4.958	2	0.084	32
DAPU7	9.283	2	0.010	32
DICA14	0.455	2	0.797	32
DINE2	0.455	2	0.797	32
ENFA	6.156	2	0.046	32
ERCI6	4.186	2	0.123	32
ERDI	5.400	2	0.067	32
ESCAM	2.609	2	0.271	32
EUCH	4.603	2	0.100	32
EUME3	0.455	2	0.797	32
GIFL	5.400	2	0.067	32
HAPAA	1.834	2	0.400	32
HEHI	1.310	2	0.519	32
HOMU	11.160	2	0.004	32
LASA	5.400	2	0.067	32
LATR2	1.458	2	0.483	32
LELA	0.900	2	0.638	32
LOAR12	0.736	2	0.692	32
LOHU2	5.400	2	0.067	32
LOSAB	2.153	2	0.341	32
LOSTT	3.507	2	0.173	32
LUSP2	3.515	2	0.173	32
MATPA	6.022	2	0.049	32
MILAV	1.454	2	0.484	32
OLTE	0.455	2	0.797	32
ONPI	9.223	2	0.010	32
PAFL6	0.100	2	0.951	32
PAHEH	1.147	2	0.564	32
PAMI5	0.455	2	0.797	32
PEHE	10.387	2	0.006	32
PEPL	5.771	2	0.056	32
PERE	8.508	2	0.014	32
PHCR	23.323	2	<0.001	32
PHDI	1.147	2	0.564	32
PHGO	1.458	2	0.483	32
PLAR	1.087	2	0.581	32
PLOV	0.939	2	0.625	32
PLPA	6.600	2	0.037	32
POBI	1.834	2	0.400	32
PRVE	0.455	2	0.797	32
SCBA	11.812	2	0.003	32

SECO10	0.796	2	0.672	32
SIAN	0.455	2	0.797	32
SIIR	0.205	2	0.903	32
SPAM2	13.308	2	0.001	32
SPCO2	0.455	2	0.797	32
STGN	0.455	2	0.797	32
STMI2	0.455	2	0.797	32
TRCA8	0.455	2	0.797	32
VUOC	8.062	2	0.018	32

Growth Habit	**Test Stat**	***df***	**p value**	**N**
annual	$F = 2.554$	2	0.095	32
perennial herb	$\chi^2 = 2.7149$	2	0.257	32
tree	$\chi^2 = 0.10363$	2	0.950	32
shrub	$\chi^2 = 15.409$	2	<0.001	32
subshrub	$\chi^2 = 6.6405$	2	0.036	32
succulents	$\chi^2 = 8.3516$	2	0.015	32

APPENDIX C

USDA SPECIES CODE DEFINITION

USDA Code	Scientific Name
ABIN	*Abutilon incanum*
ACGR	*Acacia greggii*
ADPO	*Adenophyllum porophylloides*
AMCO3	*Ambrosia confertiflora*
AMDE4	*Ambrosia deltoidea*
AMMEI2	*Amsinckia menziesii*
AMTE3	*Amsinckia tessellata*
ANOC2	*Androsace occidentalis*
ARAD	*Aristida adscensionis*
ARNE2	*Ditaxis neomexicana*
ARPU9	*Aristida purpurea*
ASNU4	*Astragalus nuttalianus*
ATCA2	*Atriplex canescens*
ATPO	*Atriplex polyarcpa*
BAMU	*Baileya multiradiata*
BOIN3	*Bowlesia incana*
BRAR4	*Bromus arizonicus*
BRRU2	*Bromus rubens*
CAER	*Calliandra eriophylla*
CAEXE	*Castelleja exserta*
CAGI10	*Carnegiea gigantea*
CAHO3	*Canotia holacantha*
CALA35	*Caulanthus lasiophylla*
CHBR	*Chorizanthe brevicornu*
CRBA5	*Cryptantha barbigera*
CRCO34	*Crassula connata*
CRMU2	*Cryptantha muricata*
CRPT	*Cryptantha pterocarya*
CYACC2	*Cylindropuntia acanthacarpa*
CYBI9	*Cylindropuntia bigelovii*
CYLE8	*Cylindropuntia leptocaulis*
DAPU3	*Daucus pusillus*
DEPI	*Descurainia pinnata*
USDA Code	Scientific Name
DICA14	*Dichelostemma capitatum*
DINE2	*Ditaxis neomexicana*
DRCU	*Draba cuneifolia*
ECEN	*Echinocereus engelmannii*
EMPE	*Emmenanthe penduliflora*
ENFA	*Encelia farinosa*
EPAS	*Ephedra aspera*
ERCI6	*Erodium cicutarium*
ERDI2	*Eriastrum diffusum*
ERER2	*Eriastrum eremicum*
ERFAP	*Eriogonum fasciculatum*
ERLA12	*Ericameria laricifolia*
ERLA15	*Eriophyllum lanosum*
ERPR4	*Eriophyllum pringlei*
ERTE13	*Erodium texanum*
ERWR	*Eriogonum wrightii*
ESCAM	*Eschscholzia californica*
EUCH	*Eucrypta chrysanthemifolia*
EUME3	*Euphorbia melanadenia*
FECY	*Ferocactus cylindraceus*
FOSP2	*Fouquieria splendens*
GAAP2	*Galium aparine*
GIFL	*Gilia flavocincta*
GUSA2	*Gutierrezia sarothrae*
HAPAA	*Harpogonella palmeri*
HEHI	*Herniaria hirsuta*
HOMU	*Hordeum murinum*
HYEM	*Hyptis emoryi*
JAGR	*Cottsia gracilis*
KRER	*Krameria erecta*
KRGR	*Krameria bicolor*
LACA7	*Lasthenia californica*
LASA3	*Lactuca sativa*
LATR2	*Larrea tridentata*
LELA	*Lepidium lasiocarpum*

LOAR12	*Logfia arizonica*
LOHU2	*Lotus humistratus*
LORI3	*Lotus rigidus*
LOSA8	*Lotus salsuginosis*
LOSQ	*Loeflingia squarrosa*
LOSTT	*Lotus strigosis*
LUCO	*Lupinus concinnus*
LUSP2	*Lupinus sparsiflorus*
LYEX	*Lycium exsertum*
MAGR9	*Mammillaria grahamii*
MAPA9	*Matelea parvifolia*
*MATPA	*Matthiola parviflora*
MEAF2	*Mentzelia affinis*
MESC	*Menodora scabra*
MILAV	*Mirabilis laevis*
MUPO2	*Muhlenbergia porteri*
OLTE	*Olneya tesota*
ONPI	*Oncosiphon piluliflorum*
PAFL6	*Parkinsonia florida*
PAHEH	*Parietaria hespera*
PAMI5	*Parkinsonia microphylla*
PEHE	*Pectocarya heterocarpa*
PEPL	*Pectocarya platycarpa*
PERE	*Pectocarya recurvata*
PESU7	*Penstemon subulatus*
PHAUA	*Pholistoma auritum*
PHCA8	*Phoradendron californicum*
PHCRA2	*Phacelia crenulata*
PHDI	*Phacelia distans*
PHGO	*Physaria gordonii*
PICA14	*Pisonia capitata*
PLAR	*Plagiobothrys arizonicus*
PLOV	*Plantago ovata*
PLPA2	*Plantago patagonica*
POBI	*Poa bigelovii*
POGR5	*Porophyllum gracile*
PRVE	*Prosopis velutina*
RANE	*Rafinesquia neomexicanus*
SACO6	*Salvia columbariae*
SCBA	*Schismus barbatus*
SECO10	*Senna covesii*
SIAN2	*Silene antirrhina*
SIIR	*Sisybrium irio*
SOOL	*Sonchus oleraceous*
SPAM2	*Sphaeralcea ambigua*
SPCO2	*Sphaeralcea coulteri*
STGN	*Stylocline gnaphalioides*
STMI2	*Stylocline micropoides*
STPA4	*Stephanomeria pauciflora*
THCU	*Thysanocarpus curvipes*
TRCA8	*Trixis californicus*
VIPA14	*Bahiopsis parishii*
VUMI	*Vulpia microstachys*
VUOC	*Vulpia octoflora*
ZIOB	*Ziziphus obtusifolia*

*Note that the species code for *Matthiola parviflora* was devised by me because information regarding this species is not present in the USDA database.