AN ABSTRACT OF THE THESIS OF

Ryan James Summers for the degree of Master of Science in Rangeland Ecology & Management presented on May 6, 2020.

Title: The Ecological Recovery of Saguaro National Park after Removal of Cattle Grazing and Associated Succession.

Abstract approved:

____

Ricardo Mata-Gonzalez

Abstract

In the area that is now Saguaro National Park East, grazing began in the 1880's. Because of the impact to the iconic saguaro cactus as well as all palatable plant species in the area, ecological damage in the park were determined to be so great that anti-grazing conservationists challenged the right of grazing to continue in what was Saguaro National Monument. Ultimately, this group won a court case eliminating grazing in 1978. The Rincon Mountains, located within the park are one of many Madrean Sky Island ecosystems connecting the Rocky Mountains to the Sierra Madre mountain ranges to the south in Mexico. This area is one of the most biodiverse locations on the planet, with over 6,000 plant species (USFS, N.D.). This area is also poorly understood when considering succession and the impacts of disturbance to compositional guilds of plant species. Surveys of ten plots began in 1976 and were replicated in 2007 and 2018 in an effort to understand vegetation changes as affected by grazing management, as well as fire disturbance. The study plots were arranged into intensely grazed and lightly grazed to compare the

composition of the plant community through time. Ultimately, little significance was found when considering the composition of paired plots through time, the original aim of the study. However, plant canopy cover, density and diversity continued to increase significantly from 1976 to 2007 and 2018. Major implications of our work identified perennial grasses increasing at a significant rate by 2007 and even more so by 2018, while tree species such as the commonly identified encroacher *Prosopis velutina* decreased significantly by 2007 and stayed steady by 2018. Grass re-establishment can be directly attributed to increased tropical moisture creating uncommon survivability conditions (speaking from historical precipitation means) in recent years previous to 2007 (1996, 1998, 2000, 2003 & 2006) and dramatically increase in the years prior to 2019 (2014-2016 & 2018). Implications here identified that past fire intensity (1989, 1994 & 1999 fires, see fire history) were likely much more intense than previously thought, and supported the scientific community's knowledge that fire control woody species and supports perennial grasses re-establishment such as is occurring in our work. Our findings also documented that increasing winter minimums have allowed previously excluded, cold-sensitive species such as *Encelia farinosa* to move into the area, dominating a post-fire ecosystem. The means of succession when considering disturbance history proved quite interesting particularly when combined with climate change impacts in our research.

The Ecological Recovery of Saguaro National Park after Removal of Cattle Grazing and Associated Succession

by
Ryan James Summers

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Presented May 6, 2020
Commencement June 2020

Master of Science thesis of Ryan James Summers presented on May 6, 2020.

APPROVED:

Major Professor, representing Range Ecology and Management

Head of Department of Animal and Rangeland Sciences

Dean of the Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Ryan James Summers, Author

ACKNOWLEDGEMENTS

The author expresses sincere appreciation Yvette Gibson, Dr. Ricardo Mata-Gonzalez, and Matthew Hovland for your direction and assistance through this whole process. Also, thank you to the staff at Saguaro National Park for facilitating this research and being supportive in this process as well as Western National Parks Association for grant support. Finally, I would like to thank my wife Alexandra Summers and family. Nothing would be possible without your support and love.

CONTRIBUTION OF AUTHORS

Thank you to the contributions of Matthew Hovland, with excellent direction from Dr. Ricardo Mata-Gonzalez and Yvette Gibson.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Table Page

LIST OF APPENDICES

1. Introduction

Saguaro National Park is located at 32 degrees 11’01 North and 110 degrees 44’11 West on the eastern flank of the Sonoran Desert. The knowledge of the history of cattle grazing in North America after European contact is sometimes well-documented and sometimes not. Particularly, that of the American Southwest. Spanish missionaries first brought cattle into the Sonoran and Chihuahuan deserts during the late 16th century (Pinto, 2013). However, the area of Saguaro National Park was not thoroughly occupied by homesteaders until after the Apache Wars concluded, which allowed them to safely move into the Tanque Verde and Rincon Valleys east of Tucson Arizona in southeastern Arizona. Early homesteaders of this area ran small amounts of cattle on the desert ranges (5-10) likely causing minimal impacts (Pinto, 2013). However, in conjunction with the development of leasing systems with the Forest Service as well as terrible droughts of the 1920’s, many homesteaders sold their homesteads to larger cattle operations and ushered in the age of ecological abuse in the area. Often, cattle after this point grazed unchecked year-round as ranchers only collected roughly 75% of their cattle when it came time to move onto private land which was a requirement after the Taylor Grazing Act (Pinto, 2013). Additionally, ranchers were known to fabricate their numbers, reporting only half of their actual numbers and thus grazing intensely year-round on these properties. Moving into the 1950’s ranchers focused on intense grazing and cattle sales, ignoring modern advancements in Range Management Sciences. This led to those in park management, the Department of the Interior, and local community legally challenging the grazing rights of the ranchers as Tucson grew in size and support also grew for

Saguaro National Monument. Various western United States Senators were in league with the ranchers, constantly inspecting both the USFS and BLM when they attempted to limit overgrazing and degradation (Pinto, 2013). This began to change in the 1960's and 1970's as knowledge of impact increased and studies were conducted as such. The Department of the Interior and the National Park Service ultimately threatened to abandon the area if grazing was not removed, prompting local support from businesses and the general population which ultimately won a court case to eliminate cattle grazing from the Monument in 1978.

At that time Warren F. Steenbergh, a renowned ecologist at the park designed this long-term vegetation survey to document the recovery and aspects of recovery for Saguaro National Monument. His previous work included many different ecological studies throughout the Sonoran Desert. Concerning his work on the saguaros, he was originally hired to document the frequency and relative health of the saguaro, which led to the realization that cattle were directly impacting the parks namesake (at the time a National Monument) in a negative way. We know now that intense grazing has affected a large portion of the western United States (McClaran & Van Devender, 1995; Waser & Price, 1981) and particularly the desert regions of North America. It was for this reason that after the removal of cattle, Steenbergh began this study to document the recovery of all species in the lower-mid elevations of Saguaro National Park. Park biologist Don Swann discovered the results and intentions of this study, as it had been forgotten following Steenbergh's departure from the park and a replication of the original survey was conducted (2007). Steenbergh's aim was to document the compositional community of plants during recovery, pairing lightly grazed plots (>0.50 miles from water) with heavily grazed plots (adjacent to water). Research has widely shown much higher intensity grazing next to these water sources (Senft et. al., 1985) (Hart et. al., 1993) as these large ungulates have trouble navigating the steep terrain and harsh desert conditions. However, it is important to note that frequency of grazing is not known. No report was published previously as the intention of this report nor the grazing history of the area was not known until Robin Pint (University of Arizona) conducted a comprehensive historical study in 2013. Data will be presented from all three surveys (1976, 2007 & 2018) in this report and the change through time with evidence of past disturbance effects upon these plots when combined with a changing climate is the focus of this report.

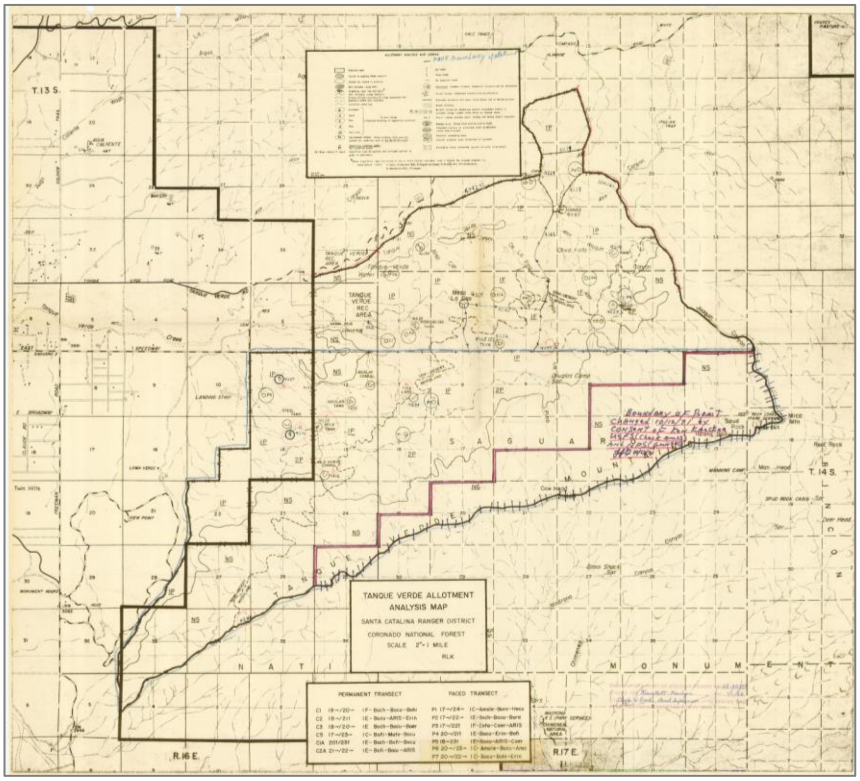


Figure 1. Tanque Verde Grazing Allotment Map at the Rincon Mountain District of Saguaro National Park showing the Tanque Verde Allotment (center, north of fence) The Rincon Valley Allotment (bottom, south of fence) and the Cactus Forest Allotment (bottom left of image, encompassing the scenic loop drive)

The area of Saguaro National Park and the Madrean Sky Islands of New Mexico, Mexico and Arizona are essential for overall biodiversity of the region. Over 6,000 species of flora exist in this area (USFS, N.D.) of the border highlands regions of this area. Countless migratory bird species use this corridor, as well as dozens of threatened or endangered species (USFS, N.D.) such as the Mexican garter snake (*Thamnophis eques*), yellow-billed cuckoo (*Coccyzus americanus*), Jaguar (*Panthera onca),* black-tailed prairie dog (*Cynomys ludovicianus*) and many more. The conservation of this ecological resource and the need to learn about succession of the vegetation of this area upon grazing cessation and in the face of climate change highlight the need for these types of studies in the Madrean Sky Islands such as the park's Rincon Mountains.

1.1 Climate

The climate of Saguaro National Park and the overall Sonoran Desert is harsh and extremely variable. High temperatures in June-September can soar from 37-43 degrees (Celsius) with humidity often in the 5-10% range causing extreme evapotranspiration. In fact, precipitation only exceeds evapotranspiration during average to above-average precipitation in December-February when highs average 20 degrees (Celsius) and lows average 4 degrees (Celsius). This rarely happens as the bimodal mode of monsoon and winter precipitation can exceed 2000% from year to year (NPS, N.D.). The precipitation chart (Fig.2) is a combined average in precipitation during this period between the Santa Rita Experimental Range (University of Arizona) and the Tucson International Airport. These two stations are the only publicly accessible stations immediately surrounding the Tucson area that were recorded prior to 1994 and create an excellent average of a lower and hotter location when compared to our study sites (Tucson International Airport) and a cooler, wetter area (with similar elevation) in the Santa Rita Experimental Range.

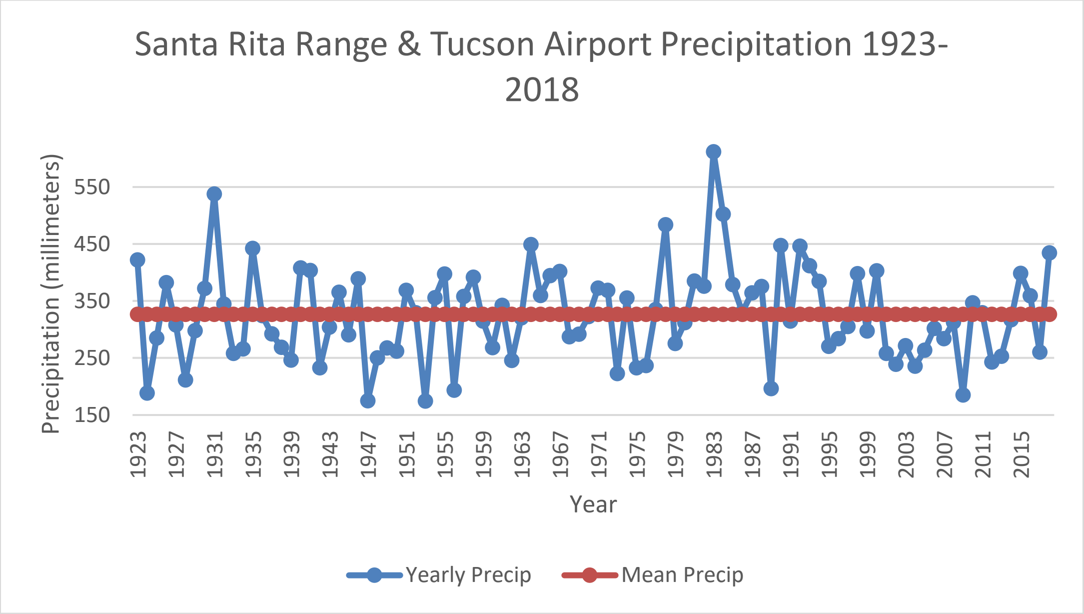


Figure 2. Yearly and Mean Precipitation between the Santa Rita Experimental Range (The University of Arizona) and Tucson International Airport

The mean precipitation for this period from 1923-2018 was 326mm. From 1923-1977 the mean precipitation was 318mm and after cattle grazing removal (1978-2018) was 338mm. The wettest period was 1964-1994 and averaged 362mm of precipitation during that phase. The following dry period (1995-2013) averaged 289mm with above average precipitation occurring after that. The most drastic trend in this region concerning climate change issues is the increase in winter minimums (Gluek, 1997) which create a variety of elevation migration among species as well as changing traditional winter snow events to rain events as with many locations in the west (NOAA, N.D.). For instance, winter minimums during the 1900's were often in the -12 to -8 (Celsius) range at Tucson International Airport and now minimum low temperatures below freezing are becoming rare (Glueck, 1997) (Saguaro National Park V.C., 2019). Tucson International Airport is as mentioned warmer and drier, so historical lows in the 3,200-4,300 foot elevation range were certainly much cooler and likely in the -15 to -12 (Celsius) range during most winter. Bimodal precipitation occurs from December-March where cold fronts from either the North or South Pacific hit the area, bringing relatively uniform precipitation, which is almost always in the form of rain. The second rainy season is during the North American Monsoon from late June through mid-September. Frequency can certainly be increased as far as days of precipitation (relative to winter), but is far more variable with extreme thunderstorm cells often only being 1 square mile wide. This exponentially increases precipitation variability, requiring decades to create proper means on the desert floor overall.

2. Methodology

2.1 Vegetation

Using Canfield's (1941) methodology, each of the ten plots in this study were 0.1 h.a (20 x 50m) (Fig.3). Starting with the upslope (highest) corner of the plot, 21-20 meters transects were used to document cover. Each plant was measured from where it intersected the tape measure (in) until when the tape measure left it (out) unless there was a break for more than 0.05 meters (such as is common with *Opuntia spp.*). Overstory, understory and any plants in between were documented separately on transects for canopy cover. Individuals such as those with more than 0.05 meters in between perennial biomass were also recorded as different canopy entries. Height was documented for all species that intersected the line and no measurement past the 20-m transect were recorded-nor before the “0” on the tape measure. Density was calculated by ten 20 x 5m subplots within the plot (Fig.3) where species above 0.25m in height were totaled by plot. These density sub-plots were labeled A-J. Additionally, only perennial species were recorded for the purpose of stability and long-term trends.

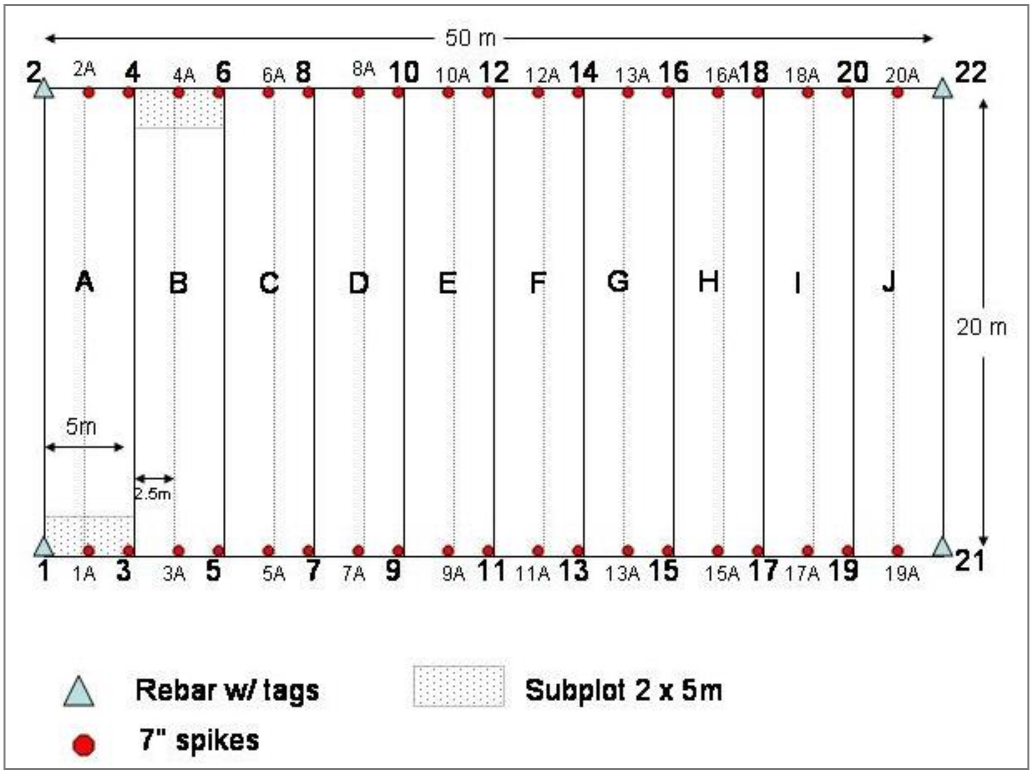


Figure 3. General Plot layout

2.2 Fire History

Normal Fire intervals of the lower Sonoran Desert are quite widespread (USFS, N.D.) at every 50-100 years with a low-moderate intensity. The overall makeup of the vegetation has limited connectivity. However, in the elevational locations of this survey the fire interval is normally 40 years (lower) to 10 year (grasslands/ higher elevation plots). After a historically wet period from 1964-1994, multiple fires occurred in the Sonoran Desert grassland zones that burned through all of the plots from this survey (NPS, N.D.).

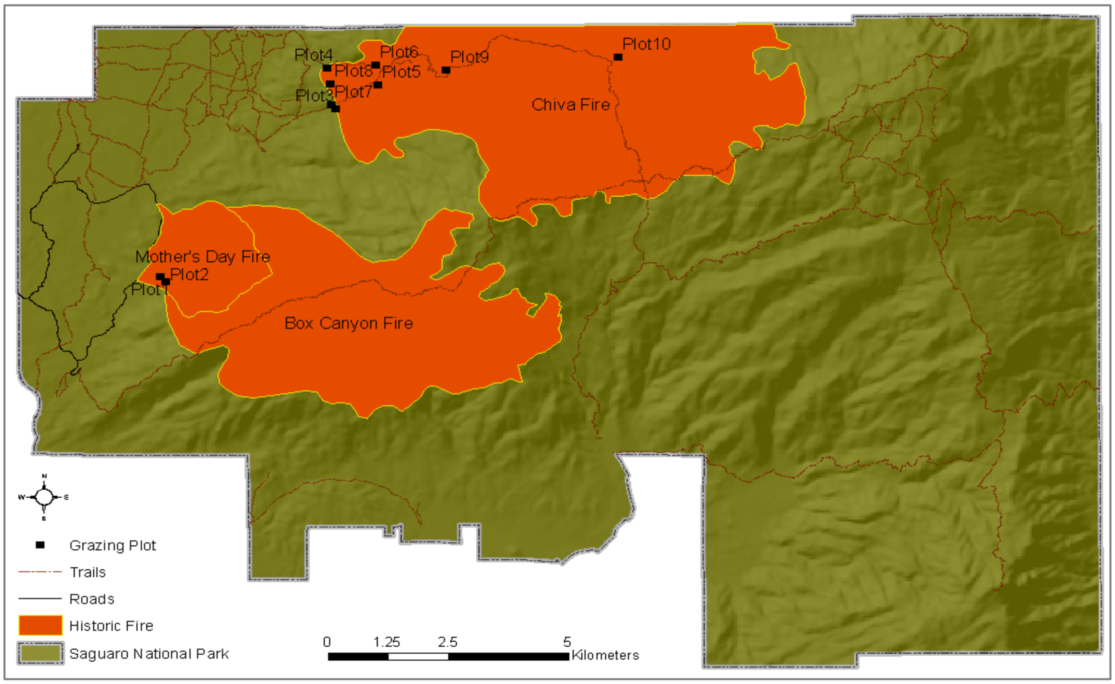


Figure 4. Location of grazing plots surveyed in 1976, 2007 and 2018 their exposure to the Chiva (1989), Mother's Day (1994), and Box Canyon (1999) fires at the Rincon Mountain District of Saguaro National Bottom (bottom). All of our plots burned at least once between 1989 and 1999.

The intensity of these fires are not known, nor the intensities mapped against each other for the sake of relativity (and to compare future vegetation developments or succession). Certain results from these fires were obvious (see discussion) while many remain uncertain as a result of the lack of intensity mapping. While fire return intervals on the Oak & Juniper Savanna (~4,500-6,500 feet) are typically every 5-10 years (USFS, N.D.) intensities are usually low and do not spread to the desert thorn-scrub transition zone that many of these plots occupy. However, as mentioned 1964-1994 were extremely wet and cool, creating extensive biomass in areas that are not typical of these elevational zones. These fires were reported to be a result of overabundance of biomass in combination with invasive grasses such as red brome (*Bromus rubens*), buffelgrass (*Cenchrus ciliare*), and crimson fountain grass (*Pennisetum setaceum*). These fires were critical in the discovery of these invasive grasses which burn far hotter than native grasses and prompted a massive invasive species restoration program at the park.

2.3 Soils

A new element we did incorporate was soil nutrient analysis. It is often reported that intense grazing removed a large amount of topsoil from erosive forces, thus removing many essential nutrients that are in short order here in the Sonoran Desert. We took three large soil samples from each plot, being in completely randomized microclimate sections of the plot. We looked at nitrogen, phosphorus and organic carbon content. Different micro-habitats were targeted such as drainage areas, areas bordering bedrock, and terrestrial areas in between. Soil cores were dug up down to a depth of 30cm (when possible with bedrock constraints and analyzed by the Central Analytical Lab at Oregon State University.

3. Analysis

We compared species guild composition changes, individual species, and percentage shifts through the three surveys using statistical advances and recommendations used by (Reed-Dustin et. al., 2016) based upon (Stroup, 2014). We analyzed possible shifts in plant community composition and associated environmental variables by creating non-metric multi-dimensional scaling ordination plots using the “vegan” package in R statistical software. The environmental variables we tested as drivers of plant community composition included precipitation, temperature, slope, elevation, grazing severity, soils, and burn severity. We analyzed absolute plant cover and density of plant functional guilds, as well as dominant species, between survey periods by creating generalized linear models (GLMs) using the “stats” package, and then running multiple comparisons (Tukey), adjusting for a false discovery rate (FDR), using the “multicomp” package in R. We fit cover data (bounded between 0 and 1) using a quasibinomial distribution, and density data (non-negative integer) using a quasipoisson distribution. When analyzing individual species data we reverted the distributions to gaussian, as the low sample sizes left our initial models over-penalizing (over-inflated variance) years with low cover or density. Differences between years were considered significant when adjusted p-values were less than 0.05.

3.1 Climate

We also looked at all available records of temperature and precipitation from stations in the surrounding area which included only the Santa Rita Experimental Range and Tucson International Airport prior to 1994. We utilized the PRISM Climate Group to account for temperature and precipitation across the plots by averaging annual means for two years previous to each survey year (1976, 2007, 2018). The primary focus of this analysis was to look at historical versus modern trends in the form of tropically influenced rain increases in autumn that we have seen in recent decades (see discussion).

4. Hypotheses & Objectives

The overall objective of this study was to ascertain whether or not paired plots showed significance concerning vegetation community composition after 41 years of succession while determining state of succession based upon disturbance & climate controls and the resulting vegetation community. Our hypotheses coming into this project were as follows;

(1) Cover, density and diversity would increase as recovery and succession continue.

(2) Woody Species would increase compared to perennial bunch grasses based upon climate change and associated drought aiding deep rooted species that require less frequent precipitation.

(3) Composition of vegetation between paired plots adjacent to water and >0.5 miles from water would show little difference, if any.

5. Results

5.1 Hypotheses Results

Hypothesis #1 was supported in that overall, there was a significant increase in plant cover and density between 2007 and 2018 (Fig.5), and a significant increase in plant density between all survey years (Table 1). Plant biodiversity (Shannon index) also increased between each survey period (Fig.6). The increase in plant cover and density was mainly driven by significant increases in ferns, graminoids, and subshrubs, with a near significant increase in shrub density between 2007 and 2018 (p=0.07, Table 1). In fact, the only decrease that was near significant occurred in tree density between 1976 and 2018 (p=0.06, Table 1), when mean density dropped from 17.32 to 7.05.

Table 1. Output of generalized linear models (GlM multiple comparison (Tukey) for differences in cover and density of plant functional guilds between survey years. Significant p-values (<0.05) are in bold

		Est. Cover	**Std. Error**	**Pr(>|z|)**	**Est. Density**	**Std. Error**	**Pr(>|z|)**
All Guilds	**2007-1976**	-0.21	0.17	0.27	1.00	0.28	**<0.001**
	2018-1976	0.50	0.16	**0.002**	1.68	0.26	**<0.001**
	2018-2007	0.71	0.17	**<0.001**	0.69	0.18	**<0.001**
Ferns	**2007-1976**	2.23	0.95	**0.03**	16.63	1177.33	0.99
	2018-1976	2.49	0.94	**0.03**	18.37	1177.33	0.99
	2018-2007	0.25	0.40	0.52	1.75	0.52	**0.002**
Forbs	**2007-1976**	0.81	0.47	0.36	2.37	1.21	0.07
	2018-1976	0.63	0.49	0.29	2.80	1.19	0.06
	2018-2007	-0.18	0.39	0.64	0.43	0.45	0.34
Graminoids	**2007-1976**	0.91	0.50	0.07	5.00	2.13	**0.02**
	2018-1976	2.73	0.43	**<0.001**	5.58	2.13	**0.01**
	2018-2007	1.82	0.29	**<0.001**	0.58	0.22	**0.01**
Shrubs	**2007-1976**	-0.50	0.32	0.18	-0.24	0.35	0.50
	2018-1976	0.11	0.27	0.68	0.48	0.30	0.15
	2018-2007	0.62	0.32	0.15	0.72	0.32	0.07
Subshrubs	**2007-1976**	2.11	0.88	**0.02**	2.58	1.44	**0.07**
	2018-1976	2.50	0.86	**0.01**	3.58	1.41	**0.03**
	2018-2007	0.38	0.37	0.31	1.00	0.45	**0.04**
Succulents	**2007-1976**	-0.52	0.40	0.43	-0.72	0.65	0.40
	2018-1976	-0.41	0.39	0.43	0.29	0.49	0.56
	2018-2007	0.11	0.43	0.81	1.00	0.62	0.32
Trees	**2007-1976**	-0.41	0.37	0.40	-0.67	0.40	0.13
	2018-1976	-0.65	0.40	0.31	-1.05	0.45	0.06
	2018-2007	-0.24	0.43	0.57	-0.37	0.51	0.46
Vines	**2007-1976**	0.73	0.92	0.43	-0.25	0.79	0.75
	2018-1976	1.39	0.85	0.30	0.56	0.66	0.59
	2018-2007	0.66	0.65	0.43	0.81	0.71	0.59

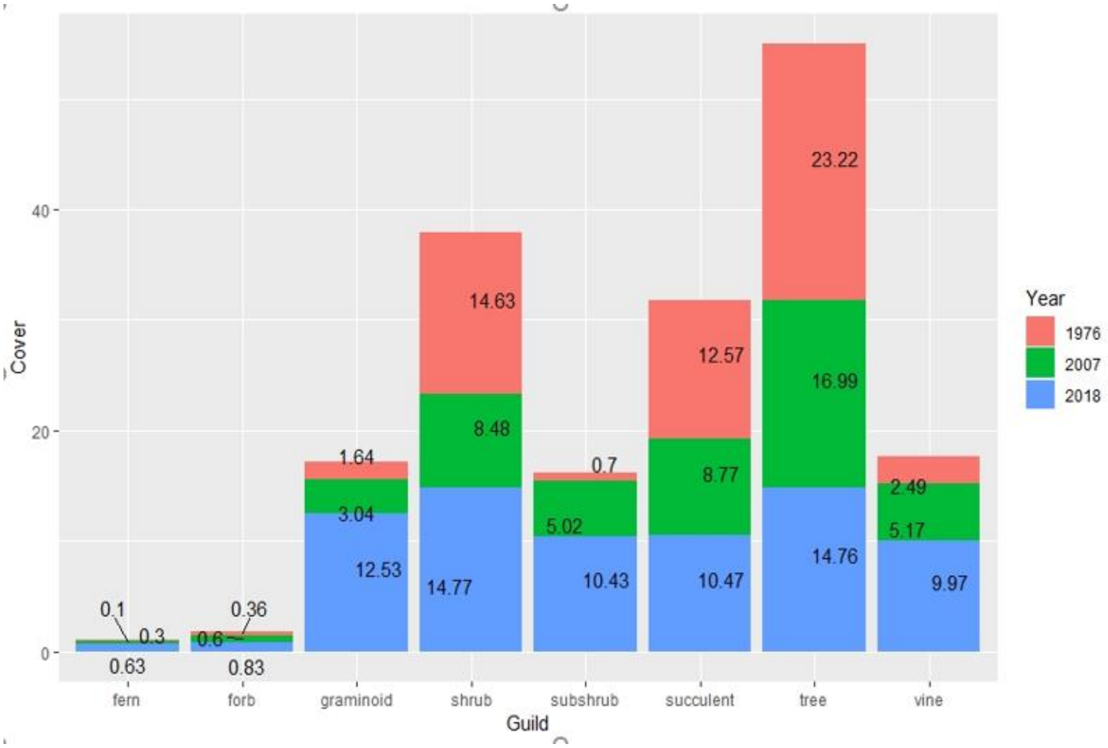


Figure 5. Mean absolute canopy cover (%) for the five dominant vegetation guilds at different years of assessment

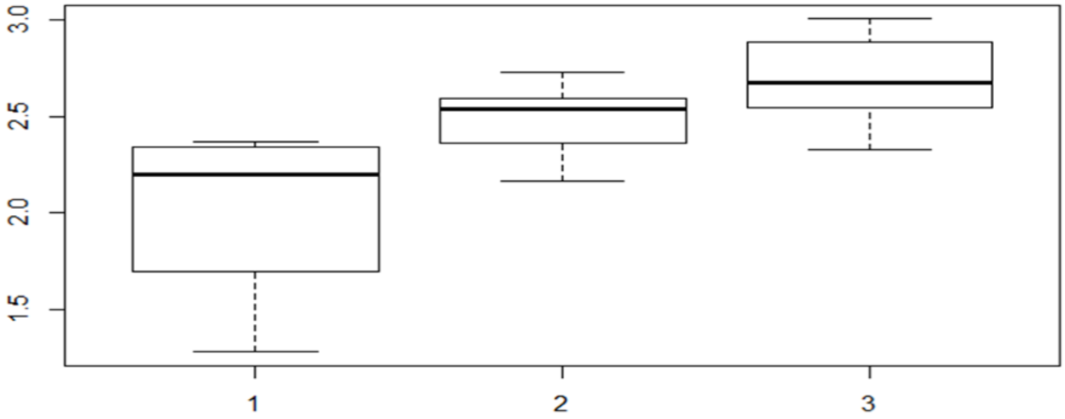


Figure 6. Boxplots illustrating Shannon Diversity for each survey period (1976, 2007, 2018) calculated with cover data

Hypothesis #2 was not supported as neither shrubs nor trees increased significantly from 2007-2018 or 1976-2007 (Table 1) and indeed tree density did nearly decrease significantly from 1976-2018 (p=0.06). While graminoids on the other hand significantly increased from 1976-2018 both concerning density (p=0.01) and cover (p=0.02) with even the small gap from 2007-2018 yielding significant results in cover (p<0.001). Clearly, perennial grasses increased far more significantly than woody species in this study.

Hypothesis #3 was partially supported with significant differences being limited; however, vines (p=0.012) did show significance between paired plots when comparing those adjacent to water and >0.5 miles from water. Subshrubs are close to significance in difference (p=0.06) with the rest of the results seen below (Fig.7).

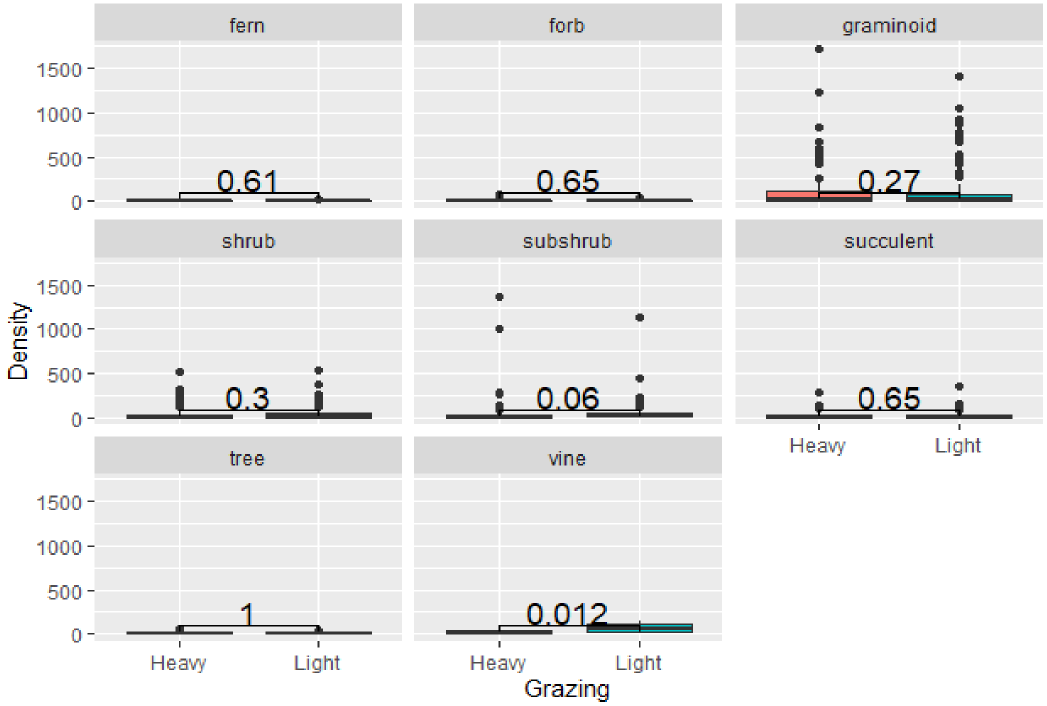


Figure 7. Density of plant guilds as related to grazing levels at Saguaro National Park after cessation of grazing for 41 years. Plots adjacent to water were considered heavy grazing while their corresponding paired plots far from water (over 800 meters) were considered light grazing. P>0.05 indicated no significant differences between them.

5.2 Individual Species

Individual species presented many interesting results as well, albeit with less statistical significance from habitat limitations through the variety of micro-climates these plots had to offer (i.e., species increased in small numbers of plots). However, a few different dominator indicator species are listed (Table 2) showing some levels of significance and cover/ density changes. *Ericameria laricifolia* (a trademark increaser under grazing pressure) decreased significantly from 1976-2007 in both mean density (p<0.001) and cover (p<0.001), however, remained relatively unchanged between 2007 and 2018. Another important species for reasons of encroachment (see discussion) is *Encelia farinosa*, which increased in total cover and density between 2007 and 2018 (Fig.8) but not significantly across all plots (Table 2). *Prosopis velutina* is another species that decreased markedly from 1976-2007 in total density (Fig.9) but not mean density at a significant rate (p=0.243). We will discuss the importance of *P. velutina* for biodiversity in the discussion section. Species that saw significant increases from 1976-2018 among the perennial grasses included native *Bouteloua repens* in density (p=0.0105) and cover (p=<0.0061) with the naturalized species *Eragrostis lehmanniana* increasing from 0.3 to 8.5 mean percent cover between 2007 and 2018 (p=0.002) While vines as an overall guild did have significant difference between paired plots (p=0.012), the main driver of that guild *Cottsia gracilis* did increase in total cover, although not significantly across all plots. (Table 2).

5.3 Drivers of Plant Community Structure

The increase in cover and density by dominant species of this region in limited numbers of plots suggests environmental variability between plots. Soils analysis revealed soils at the site were slightly acid, with an average pH of 6.87, with sandy textures, averaging 67% sand. We tested for correlations between plant community structure and precipitation, temperature, slope, elevation, soil characteristics (organic matter, texture, pH), time since fire, and grazing intensity. We produced an ordination with the significant environmental variables fit atop plant communities grouped by plot, and reveled the influence of slope and elevation on plant community structure between plots (Fig.10). While precipitation and temperature are also significant variables, they were greater drivers of plant community through time (Fig.11, 12).

Table 2. Mean absolute canopy cover and density of dominant species of importance. Values that share a letter are not significantly different between survey years.

	Cover %			**Density**		
Species	**1976**	**2007**	**2018**	**1976**	**2007**	**2018**
Bouteloa repens	1.038a	1.301a	7.092b	0a	456.2b	573.8b
Calliandra eriophylla	0.322a	3.148ab	5.451b	6.5a	86.4a	464.2b
Carlowrightia arizonica	0.0783a	0.043a	0.903a	0.4a	2.2a	66.8b
Dalea pulchra	0.027a	1.591ab	4.343b	2.1a	58.5ab	97.6b
Encelia farinosa	1.1a	2.006a	5.187a	36.7a	49.2a	138.4a
Eragrostis lehmanniana	0a	0.316a	8.562b	0a	167.4ab	457.9b
Ericameria laricifolia	11.155b	0.788a	0.891a	157.7b	12.7a	10.4a
Fouquieria splendens	8.366a	1.678b	1.61b	61.8b	17a	22.4a
Cottsia gracilis	0.418a	0.959a	1.88a	28.6a	20.8a	49.8a
Muhlenbergia ermersleyi	0.189a	1.282a	2.666a	4.3a	112.4a	89.8a
Opuntia phaecantha	2.823a	4.492a	4.84a	60a	62.5a	127.1a
Parkinsonia microphylla	4.905b	0.931a	0.805a	18.2b	4.8a	4.8a
Prosopis velutina	6.136a	5.02a	5.035a	9.1a	3.8a	7a

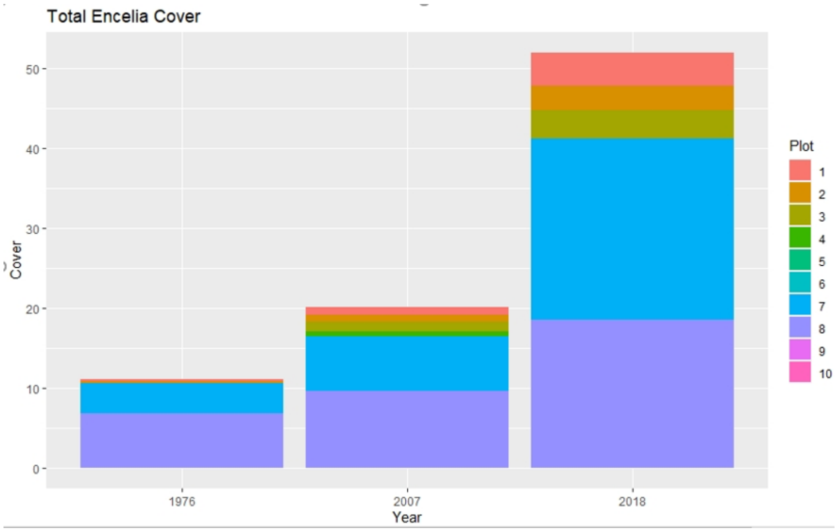


Figure 8. *Encelia farinosa* absolute canopy cover totals by year (1976, 2007, 2018) with color-coded correspondence to plots further emphasizing the expansion into higher elevation plots and relative dominance within similar plots.

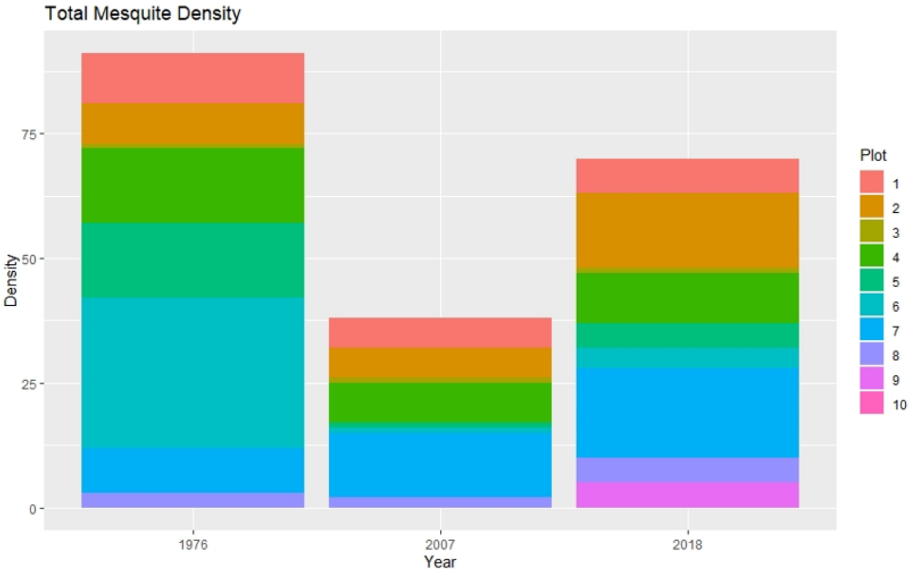


Figure 9. *Prosopis velutina* total density amounts by year (1976, 2007, 2018) with color-coded correspondence to plots further emphasizing reduction in density from plots previously with higher populations.

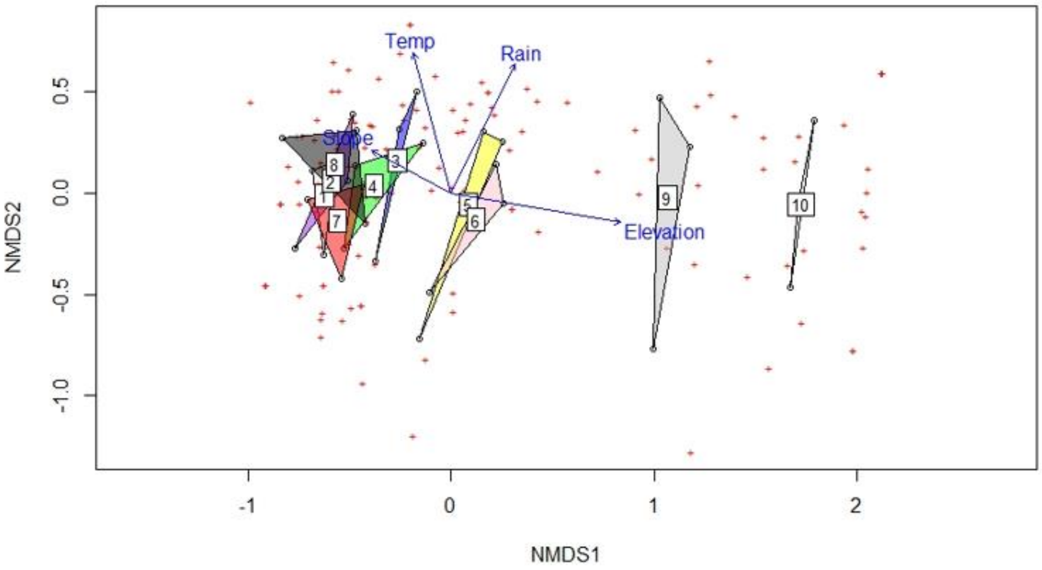


Figure 10. NMDS ordination of plant community structure grouped by plot with significant environmental variables of mean average annual temperature and precipitation, slope and elevation. Non-significant variables included soils, grazing, intensity, time since burn, and aspect. The x-axis represents relative importance considering individual plots and the y-axis represents relative importance of the overall community through time.

5.4 Climate

Upon our analysis of both the PRISM climate group as well as weather stations at the Santa Rita Experimental Range and Tucson International, we noticed some interesting trends pre-survey and overall. For instance, overall precipitation has not, in fact decreased as predicted in climate models with amounts of precipitation increasing in each successive survey (Fig. 10). This agrees with overall precipitation trends that vary greatly in this ecoregion. Additionally, mean temperatures increased (as expected) before each successive survey in this study (Fig.11). The most interesting aspect from studying historical data (Tucson International Airport) was the trend in increased winter minimums, which have risen at least from -12 Celsius to -4 in the past 100+ years (Appendix 9.3). This could, and likely has led to interesting upward migration in elevation (see discussion on *E. farinose and winter minimums*).

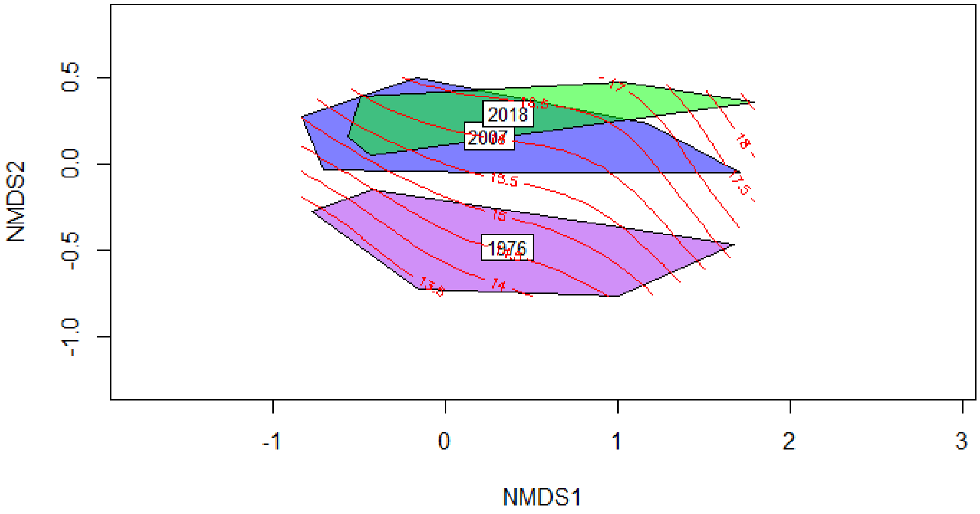


Figure 11. Non-metric multi-dimensional scaling ordination of plant communities (based on cover). Communities are separated into polygons by survey year, and mean annual precipitation for the survey area (average of the year prior to and survey year; source-PRISM) is overlaid as "topographic" lines. The y-axis represents average precipitation as "0" with the x-axis representing the year of the survey as "1"

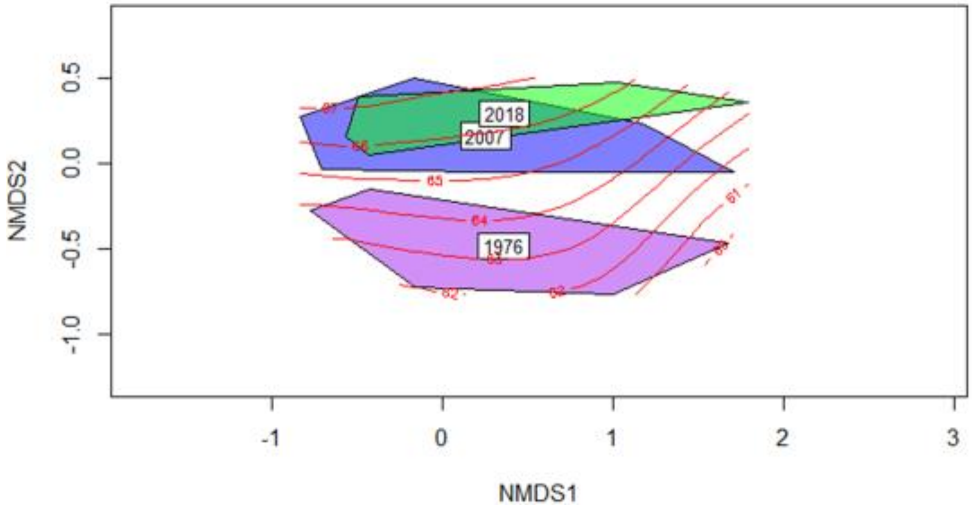


Figure 12. Non-metric multi-dimensional scaling ordination of plant communities (based on cover). Communities are separated into polygons by survey year, and mean annual temperature for the survey area (average of the year prior to and survey year; source-PRISM) is overlaid as "topographic lines". The y-axis represents average temperature as "0" with the x-axis representing the year of the survey as "1".

5.5 Soils

Soils did not reveal significant differences in composition between paired plots (table 3). This further confirms that slope and elevation are the main drivers in compositional differences between plots (Fig.10).

Table 3. Mean percentages of Carbon (C), Nitrogen (N), Sand, Silt, Clay and pH through plots 1-8 (paired plots) with samples dug from 0-30cm in depth.

Plot	C	N	Sand	Silt	Clay	pH
1	0.923333	0.076333	63.61252	23.81495	12.57253	6.58
2	0.698333	0.056667	66.91742	21.8324	11.25017	7.036667
3	0.867667	0.078333	66.90998	21.83749	11.25252	7.216667
4	0.806333	0.074333	66.99595	21.78376	11.22029	6.856667
5	0.966	0.093	65.71099	21.76014	12.52887	6.986667
6	0.609667	0.054667	70.31773	16.48733	13.19495	6.923333
7	0.693667	0.061	69.57264	17.20176	13.2256	6.983333
8	0.731333	0.061333	71.62588	16.49486	11.87926	6.453333

6. Discussion

6.1 Cover and Density

The largest takeaways from this study are clearly that the overall cover and density of the Saguaro National Park semi-grassland and desert thorn-scrub communities have increased steadily, if not quickly since the removal of cattle grazing. Particularly, perennial bunchgrass increases since 2007 and density as well. Controls of vegetation density and cover include climate, herbivory, soil nutrients and disturbance. Given our results, it would indicate that some combination of very desirable climate conditions has occurred while herbivory is reduced, soil nutrients are present and disturbance has been limited since the removal of grazing aside from fire. An increase in vegetation can be seen as a win for passive restoration of the park; however, an altered reference state of invasive grasses and encroaching shrubs now occurs. Additionally, during times of drought after the last five years of relative precipitation abundance, fire will likely become an issue when large amounts of dead organic matter begin to accumulate. While Saguaro National Park certainly has an ongoing invasive treatment effort, even native species increasing to the extent that they are currently brings about fire concerns with the knowledge that large herbivores are extremely lacking in the park. Why then, has this ecosystem recovered during increasing global temperatures and increasing local temperatures?

6.2 Climate

The climate of the Sonoran Desert has been thoroughly documented and highlighted by variability, heat and unforgiveable growing conditions. As a historical mean, 163mm of precipitation occurs during the winter rainy season (December-April) and 163mm of precipitation occurs during the monsoon season (June-September) (Saguaro National Park Visitors Center, 2019). This bimodal system of precipitation is why the Sonoran Desert is known as the wettest desert in the world (NOAA, N.D.) (NPS, N.D.). Naturally, the plants of the area have evolved to tolerate these large variations in temperature and precipitation, as well as capitalize on which ever season provides adequate moisture. However, overall precipitation has not fallen off as popular opinion has stated rather, timing, frequency, and evapotranspiration from reduced cloud cover and warmer temperatures has occurred. Additionally, monsoon moisture has been the primary precipitation input during this drought period versus winter rains during the previous periods (1960’s-early 1990’s). Our largest finding from our incorrect assumption that shrubs would increase compared to graminoids indicates that frequency of rainfall must be stable enough to germinate and support bunchgrass survival in recent years brought on by terrific tropical moisture in the autumn.

6.3 Perennial Bunchgrass Establishment & Survival

The vast majority of the grass species in Saguaro National Park and the Chihuahuan/ Sonoran Desert overall are C4 species. Overall, these species germinate in confluence with the North American Monsoon season that typically last from late June through mid-September in the northern Madrean Sky Islands (NOAA, N.D.). Germination is typically very reliable in July and August, unless there is an extremely low outlier year for precipitation, such as 1926 (Roundy & Biedenbender, 1996). The main problem with germination of these species is survival and prolonged wet soils that last through September and October, allowing a full root system to develop and store water for the inevitable dry seasons that routinely occur (Coronado et. al., 2005). Looking at the work of Coronado et. al. (2005) we confirm that these September and October rains in the southern deserts (Sonoran and Chihuahuan) are absolutely critical to the germination that typically occurs during normal North American Monsoon season precipitation (Fehmi et. al., 2014) and survival of these species. We can confirm that most years lack these frequent rainfall events that allow for full development of mature individuals (Coronado et. al., 2005). However, many years previous to this round of vegetation surveyed were banner years for seedling establishment and survival (specifically 2014-2016 & 2018-2019).

Using 2018 as an example, the year previous to the majority of the data collection for the focus of this study. The second half of June saw 1-4’’ of rain based upon tropical activity. This storm likely caused flowering and seeding of perennial bunch grasses in Saguaro National Park, which precluded typical monsoon moisture that began in the first week of July. Rain amounts were average to strong through early September, and were more frequent rather than intense storms as can occur in some years. Following this a series of strong October tropical storms off the coast of Mexico were picked up by early season cold fronts dipping south through Arizona. November of 2018 was dry; however, winter storms were constant and far above average rainfall occurred throughout Arizona into 2019 when much of this survey was conducted. Clearly, the large increase in cover is at a higher interval than the rise in density because of this extended period of high frequency and well above average rainfall. This is typical of arid area perennial bunchgrasses (Fehmi et. al., 2014) as far as well above average size during excellent, extended growing seasons.

Additionally, given the discussion on tree species in the next section, one could surmise that in fact these species likely did not re-populate (as least in the majority) from onsite sources including seedbank and re-sprouting. In fact, if the fires that touched these plots seem to have been intense enough to eliminate most *Prosopis velutina* and *Parkisonia microphylla* life (see the following section) that the seed bank likely was mostly destroyed as well as any perennial grasses living at the time of the fire. Grass seed in the area can often be dispersed from far distances in short periods via aeolian transport or rodent storage and connected, unburnt areas from the Cactus Forest as well as the Tanque Verde Ridge were located on all sides of these burns. It would seem that given the implied fire intensity that these areas are likely the source of re-establishment and propagation. However, any surviving grasses and seed bank clearly helped re-establishment as a more minor level than aeolian transport from bordering unburnt communities. For instance, species such as *Digitaria californica* has been known to have viability rates of 20-30 years (or more) in the soil seed bank (Tiedemann & Pond, 1967). Additionally, in the face of intense grazing species such as *Bouteloua repens* has been recorded to more than double its seed output on a yearly basis (Canfield, 1957). Many perennial grass species in the area also achieve extremely long lifespans including *Bouteloua eriopoda* which may live well over 25 years in the right conditions (Canfield, 1957) (Peters, 2002). However, the lack of *B. eriopoda* in this study compared to the 1976 survey shows the weakness this species has, reproducing primarily from stolons, and thus not re-colonizing as quickly as related species in burned areas. Clearly, between aeolian transport, rodent seed transport, and surviving seed bank/ individuals enough seed was able to re-establish the area to its current productive state.

6.4 *Prosopis velutina* Biodiversity & Importance

P. velutina, as well as other from the *Prosopis* genus have often been grouped with *Juniperus spp.* as an encroacher that limits forage production (Pease et. al., 2003) (Cox et. al., 1993). Specifically, the comparable Santa Rita Experimental Range has worked on reducing the spread of this species (Pease et. al., 2003) mainly for forage production for cattle grazing. It is likely that this species has been given a relatively poor impression based upon the southwestern cattle grazing lifestyle that has occurred in the North American desert since the 1600's. However, it appears that *P. velutina* and associated *P. glandulosa* in the Chihuahuan desert may actually drive biodiversity and create habitat for many excellent forage species (Golubov, 2001). Some of these are previously mentioned *Carlowrightia arizonica, Setaria spp.,* *Digitaria californica,* as well as dozens of other graminoids and herbaceous species at Saguaro National Park. In ecological circles, we know this species and other legumes such as *Parkisonia spp.* to be called “life islands” because of the overall amount of biodiversity they create, often bordering lifeless patches of soil outside of their zone of influence (Golubov, 2001). *P. velutina,* as a member of Leguminosae family is renowned for nitrogen fixation in its roots-which is generally lacking in the soil profile in the desert areas and the most important macro-nutrient for plant growth (Larcher, 2003). Furthermore, *P. velutina* allows filtered light that allows light-sensitive species to avoid intense infrared rays that are constant in this ecoregion. Species such as *Celtis spp., Ziziphus spp., and Lycium spp.* are all extremely important edible berries that rely upon not only the nitrogen fixation from *P. velutina* but also the hydraulic lift that this extremely deep-rooted species supplies and re-distributes through the upper layers of soil during the overnight hours (Larcher, 2003). This is not to mention the direct nurse tree relationship *P. velutina* as well as *Parkinsonia spp.* have in facilitating germination and growth of this park’s namesake the saguaro (*Carnegiea gigantean*) as a nurse plant (NPS, N.D.). It is for all of these reasons we have concern when considering the lack of abundance of *P. velutina* and are required to address the issues and possible causes.

6.5 Santa Rita Experimental Range Comparison of *P. velutina* & Soils

As previously stated, the Santa Rita Experimental Range is an excellent comparison to this long-term study in terms of elevation, climate and species composition. Nine of our ten study plots are from 3200-4300 feet in elevation and all exist on the northern slopes of Tanque Verde Ridge in Saguaro National Park (although some split orientation as mentioned). Both locations (the Santa Rita Range and Saguaro National Park) are on terrestrial surfaces, away from Riparian impacts. Similarly, the Santa Rita Experimental Range covers roughly 2,900-5,200 feet on the northern piedmont of the Santa Rita Mountains near Madera Canyon. These areas are only 30 miles apart and only differ in climate with localized monsoon thunderstorms which equalize precipitation amounts on a longer-term scale. It is for this reason we will discuss differences in density between these two locations. Cattle still openly graze the Santa Rita Range. This knowledge is important as a variable when considering differing densities and canopy cover percentages of *P. velutina.*

Of the 8 plots within the typical elevation range of *P. velutina* a total density of 65 was found in this survey. That density averages 78 individuals per h.a. While plot 9 has begun to see *P. velutina* encroachment, we will focus on the lower 8 plots where this species is common through the Madrean Sky Islands. Concerning the Santa Rita Range at elevations of 2950-4100 feet, *P. velutina* averages from 200-450 individuals per h.a. (McClaran, 2003). While a density increase hints at more *P. velutina* establishment from 2007-2019 is noteworthy, it is still only a fraction of that of the Santa Rita Range. The University of Arizona also conducts routine soils analysis seen such as (McClaran et. al., 2007). Our soil results (see results) were similar as far as pH (slightly acidic, 6.3-7.0) and C/N ratio (11.53 from 0-23.5cm). This further emphasizes that our soil pH and nutrients are not a factor for the relative abundance of native grasses, exotic grasses, or *P. velutina* in any manner.

We also know that this species can easily re-sprout after even moderate fire, as long as the basal areas is 1.5 c.m. wide or more (Bock et. al., 2007). Knowing the original density of the species was much higher in cover and density in 1976 compared to 2018 while combining our knowledge of *P. velutina* re-sprouting post-fire (and the intensity they are able to survive) it would lead us to conclude that the fires of 1989, 1994 and 1999 (or at least two of them) were extremely intense. This likely killed most plant life and most of the seed bank on each one of these plots. Law enforcement rangers who witnessed and worked on the Mother's Day Fire (1994) detailed that indeed "the fire was extremely intense, clearing whole hillsides of vegetation in a matter of hours" (Rich Hayes, 2019). *Parkisonia spp.* have had a similar response as well (see results) hinting that they too were nearly wiped out during these fires. However, the relative drought of 1995-2013 likely has slowed down recovery and succession, with only recent rains theoretically beginning the ecosystem shift from mid-late seral succession in the park. This is not only supported by delayed climax community of *P. velutina* and *Parkisonia spp.*, but also in the *Encelia farinosa* dominated state, which is known as an early-mid seral dominator in its historic habitat (USFS, N.D.).

6.6 Historic Reference State, Alterations & *Encelia farinosa*

When considering the results from this survey, it is clear that overall recovery is occurring. Referring to the NRCS Ecological Site Description, nearly all of the perennial species mentioned were found in our 2019 survey (Appendix 9.2). However, the dominance of both *Encelia farinosa* and *Eragrostis lehmanniana* are not included in this previous established baseline ESD. These two species are quite different in terms of source and impact. *E. lehmanniana* is a very common invasive grass species in the desert southwest ecoregion, brought into the area in the early-mid

20th century for cattle forage after native grasses had been consumed (NPS, N.D.). These days, *E. lehmanniana* is considered naturalized by most land managers because of its relative palatability and lack of biodiversity reduction in combination with a lack of fire proclivity when compared to *Cenchrus ciliare* and *Pennisetum setaceum.* Also, judging by its spread in this study, it would be impossible to eradicate or even positively impact its current population size and growth. However, *E. farinosa* is a native to the hotter southwestern Sonoran Desert, categorizing this species as an encroacher in Saguaro National Park East with the elevation of winter minimums over the last 100 years.

As we have discussed, a vast increase in density and cover of *E. farinosa* has occurred below roughly 3,600 feet in Saguaro National Park East. *E. farinosa* was not a dominant species at our plot locations during the 1976 survey conducted by Warren Steenberg. This is directly correlated to how cold low temperature maximums used to be in the 3,200-3,600 foot range of Saguaro National Park were, and now how limited freezing temperatures occur at this elevation annually. *E. farinosa* is known to be top-killed during temperatures just below freezing, and as temperatures move into the teens (F) it kills the entire plant. The *Encelia* genus is also well known for introduction allelopathic germination prohibiting and toxic compounds into the soil allowing it form monocultures (Gray & Bonner, 1948). *E. farinosa* has not been seen in such elevations previously through the ice ages discovered by dating packrat middle *E. farinosa* segments fossilized by packrat urine (McAuliffe & Devender, 1998). *E. farinosa* is historically a species seen dominating the southwestern Arizona deserts and only recently established itself at Saguaro

National Park as viewed by our first survey (1976) and interglacial phylogenetic research from packrat middens (Fehlberg & Ranker, 2009). The biodiversity and large increase in cover is a positive sign of ecosystem health, but the encroachment of this species certainly is concerning. Climate change, specifically the large deviation from historical overnights lows (Appendix 9.3) is directly responsible for this large encroachment of this species. We would compare, for the sake of reference this situation to *Juniperus spp.* encroachment throughout the west. Juniper severely limits biodiversity in a different manner, by reducing sunlight, creasing erosion, and reducing capture of organic matter. The biodiversity impact of *Encelia farinosa* is different, focusing on germination prevention and eliminating individuals growing within its sphere of influence. Nevertheless, this species is certainly encroaching with assistance from climate change and facilitated by disturbance, causing similar biodiversity reduction. The positive news, depending on one's viewpoint is that *E. farinosa* is an early-mid seral species in its historical habitat, hinting that as succession continues and a climax community develops that this species should return to more moderate numbers compared to the current state of the ecosystem.

6.7 The Rise and Fall of Unpalatable Species

As the focal point of many grazing studies, we know that unpalatable species (increasers) thrive during times of intense grazing, limiting seed production from palatable species and giving unpalatable species such as *Ericameria lacirifolia* a competitive advantage. This was clearly the case in this study. Palatable species such as *Calliandra eriophylla, Cottsia gracilis* and indeed all perennial grasses gained significant ground and the relative densities, frequencies and canopy covers increased when compared to unpalatable species. The overall composition of that is a palatable species in the Sonoran Desert is however-relatively limited. Fauna here in the desert will consume nearly everything aside from *Cylindropogon spp., Fouqueiria splendens, Isocoma tenuisecta* and the previously mentioned *Ericameria lacirifolia.* Species such as *Opuntia spp.* and *Prosopis* cannot be viewed as unpalatable as desert fauna have evolved co-dependencies with many of the seemingly unpalatable flora.

6.8 Species Biodiversity

We have seen diversity increase much more dramatically in the 2007 survey and then again to a more minor extent in the 2018 survey. Indeed, very few places offer the biodiversity of the Madrean Sky Island slopes and mountain ranges (USFS, N.D.) with roughly 6,000 species of plants near the United States-Mexico border. Naturally, as succession occurs biodiversity will slow down towards a climax community until disturbance once again impacts the ecosystem. As previously mentioned, it is interesting that even though intense grazing occurred in the 1950's and 1960's, as well as to a lesser extent during the 1970's (Pinto, 2013) a relatively large amount of biodiversity existed during the first survey. This is likely a result of above-average precipitation in the late 1960's and into the 1970's. The small increase in biodiversity in our 2018 survey would suggest that Saguaro National Park is nearing what would be a considered a late-seral community, albeit in an altered reference state when compared to pre-grazing conditions. The reason for this is the passive restoration of the park and presence of invasive species such as *Cenchrus ciliare, Pennisetum setaceum, Eragrostis lehmanniana, Bromus rubens, Eragrostis curvula,* and *Melinis repens.* Additionally, the relative dominance of *Encelia* *farinosa* below roughly 3,600 feet is a cause for concern as well as an encroaching species. Nearly all of the species aside from *E. lehmanniana* cause a threat to biodiversity both by creating monocultures and by invoking intense, frequent wildfires such as those in the park during the 1980's and 1990's. While wildfire is a natural component of the middle desert elevations (USFS, N.D.) *P. setaceum* and *C. ciliare* particularly offer much increased fire temperature and overall fuel loads when compared to native species (NPS, N.D.). These species are also fire-tolerant, re-sprouting and out-competing native species during secondary succession post-fire. All of the plots in this study either contained multiple individuals of the invasive species or had them very nearby. The saguaro cacti (*Carnigea gigantea)* has no fire adaptations (NPS, N.D.) and thus the namesake for this park could be extremely threatened in the future. For biodiversity to continue in this area, alternative treatments will need to implemented and utilized in Saguaro National Park and the entire Madrean Sky Island corridor, as well.

6.9 Overcrowding of Vegetation and Herbivore Associations

As we have answered the question of recovery for the Saguaro ecosystems, we also need to pose the question as to if there is too much vegetation as a result a lack of large herbivores in the area. Saguaro National Park biologists have documented a sharp and even drastic decline in the one remaining large herbivore mule deer (*Odocoileus hemionus*) (Swann, 2019) while desert bighorn sheep (*Ovis canadensis nelsoni*) were extirpated by the late 1950's (NPS, N.D.). Biologist Don Swann documented dramatic decreases in mule deer in the park since the 1970's, not having sources through the 1980's and 1990's (unknown reasoning). Since the late 2000's, mule deer have essentially become a rare species (1-2 individuals sited per survey year) coinciding with the continued increase of vegetation at Saguaro National Park. Other studies have detailed ideal mule deer habitat (Bender et. al., 2007) as well as the parks' own work (Swann, 2019) and found that mule deer prefer open, visible habitat to avoid predators such as *Puma concolor.* This certainly explains the low numbers of *O. hemionus* from at least the western side of the Rincon Mountains and why white-tailed coues deer (*Odocoileus virginianus couesi)* have begun to further establish at lower elevations. This species strongly prefers to hide with their much-reduced size relative to *O. hemionus*, explaining why this species has taken over in the much denser vegetation community that now exists. In that light, even if current vegetation cover and density are at a healthy level, future vegetation increase may see extreme drought, causing massive wildfire seasons in the park with the limited large herbivore species grazing the perennial grasses.

7. Conclusion & Recommendations

While the future impacts of climate change and anthropogenic disturbance are certainly not known, we have revealed quite a number of patterns and changes during the past 41 years of succession and disturbance with the cessation of grazing in Saguaro National Park. While succession since fire certainly has been occurring, dominance of recent encroacher *E. farinosa* and a lower number of tree species tells us that this ecosystem continues evolving towards a more stable, climax community. Climate results will continue to drive this and every ecosystem, and tracking recent increased tropical activity in autumn with associated increases in perennial grasses is absolutely critical to understanding not only composition, but fire ecology as well. A continued invasive species removal program is critical to avoiding such unnaturally intense fires as those from 1989-1999, which likely killed of the vast majority of species in our study plots. Additionally, natural herbivores that consume large amounts of perennial bunchgrasses such as *Ovis canadensis nelsoni* must be encouraged to return to the park to consume this increase in fine fuels. Either that, or some sort of seasonal grazing system should be considered to reduce the increasing possibility of unnaturally hot fires from buildup of native and naturalized (*E. lehmanniana*). These semi-desert grasslands and oak savannas simply are not ecologically functional (when considering past composition) without the presence of large, grass-targeting herbivores. For the time being, increased infiltration will aid affected by sediment during past intense fires in containing perennial water sources for both flora and fauna of the area-including springs and tanajas.

8. Appendix

8.1 Plot locations

Plot Number	Location	UTM X	UTM Y
01	Near loop drive, Rincon Mountain Overlook	527683	3560904
02	Near loop drive, Rincon Mountain Overlook	527792	3560799
03	Immediately adjacent to Mica tank, NW slope	531325	3564717
04	Douglas Springs Trail nearby Mica tank, NW slope	531147	3565631
05	Near Aguila Tank, N slope	532216	3565265
06	Douglas Springs Trail nearby Aguila Tank, N slope	532169	3565702
07	Adjacent to Mica Tank, S slope	531230	3564809
08	Douglas Springs Trail nearby Mica tank, S slope	531210	3565272
09	Douglas Springs Trail nearby Tina Larga Tank	533634	3565589
10	Near Douglas Springs Campground, 4800 ft	537224	3565891

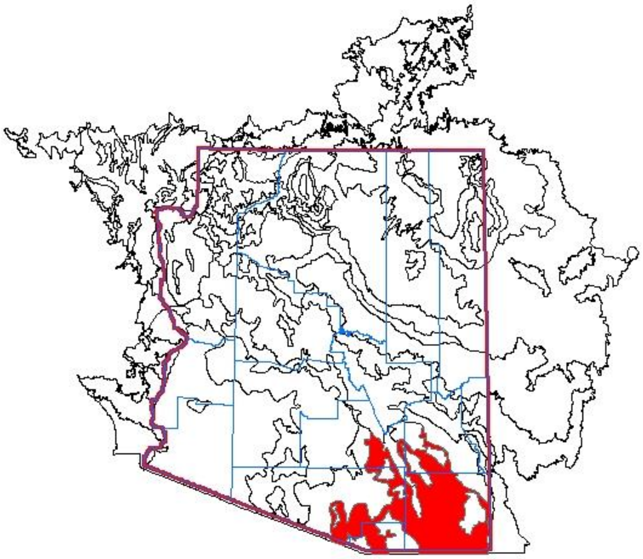
Table 1: The plot numbers along with their general location, and a GPS coordinate point.

8.2 United States Department of Agriculture Natural Resources Conservation Service Ecological Site Description

Section l: Ecological Site Characteristics

Ecological Site Identification and Concept

Site name: **Shallow Hills 12-16" p.z.**
/ eriogonum wrightii - calliandra eriophylla / bouteloua curtipendula - artemisia ludoviciana
(/ bastardsage - fairyduster / sideoats grama - white sagebrush)
Site type: Rangeland
Site ID: R041XC306AZ
Major land resource area (MLRA): 041-Southeastern Arizona Basin and Range



AZ 41.3 – Chihuahuan – Sonoran Semidesert Grasslands

Elevations range from 3200 to 5000 feet and precipitation ranges from 12 to 16 inches per year. Vegetation includes mesquite, catclaw acacia, netleaf hackberry, palo verde, false mesquite, range ratany, fourwing saltbush, tarbush, littleleaf sumac, sideoats grama, black grama, plains lovegrass, cane beardgrass, tobosa, vine mesquite, threeawns, Arizona cottontop and bush muhly. The soil temperature regime is thermic and the soil moisture regime is ustic aridic. This unit occurs within the Basin and Range Physiographic Province and is characterized by numerous mountain ranges that rise abruptly from broad, plain-like valleys and basins. Igneous and metamorphic rock classes dominate the mountain ranges and sediments filling the basins represent combinations of fluvial, lacustrine, colluvial and alluvial deposits.

Plant Community Photos — Historic Climax Plant Community

Historic Climax Plant Community

Collapse Description

Description — Historic Climax Plant Community

The potential plant community on this site is dominated by warm season perennial grasses. Several species of low shrubs are well represented on the site, but the aspect is grassland dotted with shrubs and cacti. Larger species of shrubs are concentrated at the edges of rock outcrop areas and in canyon bottoms. Most of the grass and low shrub species are well dispersed throughout the plant

Collapse Plant Species Composition (Lbs/Acre)
Plant Species Composition (Lbs/Acre)

Grass/Grasslike				
Group	**Plant Common Name**	**Plant Scientific Name**	**Annual Production Pounds Per Acre**	
			Low	**High**
1: Dominant Perennial Mid Grasses			**250**	**350**
	cane beardgrass	Bothriochloa barbinodis	20	150
	sideoats grama	Bouteloua curtipendula	150	200
	arizona cottontop	Digitaria californica	20	100
	plains lovegrass	Eragrostis intermedia	10	150
	tanglehead	Heteropogon contortus	10	100
2: Suffrutescent Grasses			**30**	**250**
	black grama	Bouteloua eriopoda	25	200
	bush muhly	Muhlenbergia porteri	5	50
3: Dominant Perennial Short Grasses			**55**	**150**
	sprucetop grama	Bouteloua chondrosioides	0	20
	santa rita grama	Bouteloua eludens	0	35
	blue grama	Bouteloua gracilis	0	20
	hairy grama	Bouteloua hirsuta	25	80
	slender grama	Bouteloua repens	15	80
	fall witchgrass	Digitaria cognata	1	20
	curly mesquite	Hilaria belangeri	5	35
	wolftail	Lycurus phleoides	5	30
	arizona muhly	Muhlenbergia arizonica	0	10
4: Annual Grasses			**10**	**100**
	fragile grass	Aegopogon tenellus	0	2
	sixweeks threeawn	Aristida adscensionis	1	20
	prairie threeawn	Aristida oligantha	1	30
	sixweeks needle grama	Bouteloua aristidoides	0	5
	sixweeks grama	Bouteloua barbata	0	1
	arizona brome	Bromus arizonicus	0	2
	feather fingergrass	Chloris virgata	0	2

	southwestern cupgrass	Eriochloa acuminata var. acuminata	0	2
	mexican lovegrass	Eragrostis mexicana	0	2
	desert lovegrass	Eragrostis pectinacea var. miserrima	0	2
	tufted lovegrass	Eragrostis pectinacea var. pectinacea	0	2
	sweet tanglehead	Heteropogon melanocarpus	0	20
	mexican sprangletop	Leptochloa fusca ssp. uninervia	1	30
	red sprangeltop	Leptochloa panicea ssp. brachiata	1	30
	annual muhly	Muhlenbergia fragilis	1	15
	littleseed muhly	Muhlenbergia microsperma	0	5
	witchgrass	Panicum capillare	0	5
	mexican panicgrass	Panicum hirticaule	1	30
	bigelow bluegrass	Poa bigelovii	0	5
	arizona signalgrass	Urochloa arizonica	0	5
	gray fescue	Vulpia microstachys var. ciliata	1	20
	twoflower fescue	Vulpia microstachys var. microstachys	1	20
	sixweeks fescue	Vulpia octoflora	1	20
5: Perennial threeawns			**10**	**45**
	poverty threeawn	Aristida divaricata	0	2
	havard threeawn	Aristida havardii	0	2
	wooton threeawn	Aristida pansa	0	2
	purple threeawn	Aristida purpurea	0	10
	red threeawn	Aristida purpurea var. longiseta	0	10
	blue threeawn	Aristida purpurea var. nealleyi	0	5
	parish threeawn	Aristida purpurea var. parishii	0	10
	wright threeawn	Aristida purpurea var. wrightii	0	10
	singleawn threeawn	Aristida schiedeana var. orcuttiana	0	15
	spidergrass	Aristida ternipes	5	30
	mesa threeawn	Aristida ternipes var. gentilis	0	15
6: Miscellaneous Perennial grasses			**10**	**60**
	purple grama	Bouteloua radicosa	0	2
	rothrock grama	Bouteloua rothrockii	0	5
	silver bluestem	Bothriochloa saccharoides	0	5
	sedge	Carex	0	2
	fluffgrass	Dasyochloa pulchella	0	2
	sourgrass	Digitaria insularis	0	2

	woolly bunchgrass	Elionurus barbiculmis	0	2
	bottlebrush squirreltail	Elymus elymoides	1	10
	spike pappusgrass	Enneapogon desvauxii	0	2
	prairie junegrass	Koeleria macrantha	0	5
	green sprangletop	Leptochloa dubia	1	20
	kunth smallgrass	Microchloa kunthii	0	5
	bamboo muhly	Muhlenbergia dumosa	0	5
	bullgrass	Muhlenbergia emersleyi	1	15
	cliff muhly	Muhlenbergia polycaulis	0	27
	deergrass	Muhlenbergia rigens	0	2
	mesa muhly	Muhlenbergia tenuifolia	0	2
	bulb panicgrass	Panicum bulbosum	0	2
	hall panicgrass	Panicum hallii	0	10
	vine mesquite	Panicum obtusum	0	5
	tobosa	Pleuraphis mutica	0	2
	texas bluestem	Schizachyrium cirratum	0	5
	southwestern bristlegrass	Setaria scheelei	1	5
	plains bristlegrass	Setaria vulpiseta	0	5
	sand dropseed	Sporobolus cryptandrus	0	10
	mexican gamagrass	Tripsacum lanceolatum	0	5
	slim tridens	Tridens muticus	0	10
	crinkleawn	Trachypogon spicatus	0	10
Forb				
Group	**Plant Common Name**	**Plant Scientific Name**	**Annual Production Pounds Per Acre**	
			Low	**High**
7: Perennial Forbs			**10**	**100**
	palmer indianmallow	Abutilon palmeri	0	5
	pink perezia	Acourtia wrightii	0	5
	san felipe dogweed	Adenophyllum porophylloides	0	2
	trailing four o'clock	Allionia incarnata	1	5
	largeflower onion	Allium macropetalum	0	2
	slimleaf bursage	Ambrosia confertiflora	1	10
	desert anemone	Anemone tuberosa	1	5

	tarragon	Artemisia dracunculus	0	5
	white sagebrush	Artemisia ludoviciana	1	15
	new mexico silverbush	Argythamnia neomexicana	0	1
	stiffarm rockcress	Arabis perennans	1	5
	indianroot	Aristolochia watsonii	0	1
	shrubby ayenia	Ayenia microphylla	1	5
	hairyseed bahia	Bahia absinthifolia	0	1
	desert marigold	Baileya multiradiata	0	2
	scarlet spiderling	Boerhavia coccinea	0	5
	wishbone vine	Boerhavia scandens	1	10
	arizona carlowrightia	Carlowrightia arizonica	0	5
	desert mariposa lily	Calochortus kennedyi	0	1
	sego lily	Calochortus nuttallii	0	1
	Indian paintbrush	Castilleja	0	2
	baby aster	Chaetopappa ericoides	0	1
	whitemouth dayflower	Commelina erecta	0	5
	leatherweed croton	Croton pottsii	0	1
	cooley bundleflower	Desmanthus cooleyi	0	2
	desert larkspur	Delphinium parishii	0	1
	bluedicks	Dichelostemma capitatum	1	5
	spreading dyschoriste	Dyschoriste schiedeana var. decumbens	0	1
	spreading fleabane	Erigeron divergens	0	10
	trailing fleabane	Erigeron flagellaris	0	10
	hairy evolvulus	Evolvulus arizonicus	0	1
	arizona snakecotton	Froelichia arizonica	0	2
	oenothera	Oenothera	0	5
	gooding mock verbena	Glandularia gooddingii	0	5
	desert wild cotton	Gossypium thurberi	1	10
	hairy false goldenaster	Heterotheca villosa var. minor	0	5
	coulter hibiscus	Hibiscus coulteri	0	5
	yellow cutleaf	Hymenopappus filifolius var. lugens	0	5
	trans-pecos thimblehead	Hymenothrix wislizeni	0	10
	slender janusia	Janusia gracilis	1	15
	ragged jatropha	Jatropha macrorhiza	0	1
	longflower tubetongue	Justicia longii	0	2
	san pedro daisy	Lasianthaea podocephala	0	1
	narrowleaf puccoon	Lithospermum incisum	0	1
	lewis blue flax	Linum lewisii	0	5

	carrotleaf desertparsley	Lomatium dissectum	0	1
	greene deervetch	Lotus greenei	0	2
	red and yellow deervetch	Lotus rigidus	0	15
	wright deervetch	Lotus wrightii	0	5
	climbing snapdragon	Maurandella antirrhiniflora	0	2
	Huachuca Mountain rocktrumpet	Mandevilla brachysiphon	0	5
	wild bushbean	Macroptilium gibbosifolium	0	2
	parry false dalea	Marina parryi	0	5
	spiny goldenhead	Machaeranthera pinnatifida	1	5
	plains blackfoot daisy	Melampodium leucanthum	0	2
	wishbone four o'clock	Mirabilis laevis var. villosa	0	5
	desert tobacco	Nicotiana obtusifolia	0	5
	schott yellowhood	Nissolia schottii	0	10
	tufted evening-primrose	Oenothera caespitosa	0	1
	love-in-a-mist	Passiflora foetida	0	1
	parry penstemon	Penstemon parryi	1	5
	desert penstemon	Penstemon pseudospectabilis	0	5
	narrowleaf bean	Phaseolus angustissimus	0	1
	orange talinum	Phemeranthus aurantiacus	0	1
	ivyleaf groundcherry	Physalis hederifolia	0	1
	yerba de venado	Porophyllum gracile	0	5
	velvetseed milkwort	Polygala obscura	0	2
	shrubby purslane	Portulaca suffrutescens	0	2
	wright cudweed	Pseudognaphalium canescens ssp. canescens	0	5
	twinleaf senna	Senna bauhinioides	0	1
	desert senna	Senna covesii	0	2
	lemmon grounsel	Senecio lemmonii	0	5
	showy senna	Senna lindheimeriana	0	1
	new mexico sida	Sida neomexicana	0	2
	rocky mountain checker-mallow	Sidalcea neomexicana ssp. thurberi	0	1
	silverleaf nightshade	Solanum elaeagnifolium	0	1
	desert globemallow	Sphaeralcea ambigua	0	15
	gooseberryleaf globemallow	Sphaeralcea grossulariifolia	0	2
	brownplume wirelettuce	Stephanomeria pauciflora	0	15
	big talinum	Talinum paniculatum	0	1
	coulter wrinklefruit	Tetraclea coulteri	0	1

	hairy tetramerium	Tetramerium nervosum	0	5
	branched noseburn	Tragia ramosa	1	5
	american vetch	Vicia americana	0	5
	slim vetch	Vicia ludoviciana	0	5
8: Annual Forbs			**10**	**100**
	new mexico copperleaf	Acalypha neomexicana	0	5
	carelessweed	Amaranthus palmeri	0	10
	western fiddleneck	Amsinckia tessellata	0	5
	astralagus	Astragalus	0	20
	wheelscale saltbush	Atriplex elegans	0	1
	fewflower beggartick	Bidens leptocephala	0	10
	coulter spiderling	Boerhavia coulteri	0	5
	hairy bowlesia	Bowlesia incana	0	1
	redmaids	Calandrinia ciliata	0	2
	chenopodium	Chenopodium	0	20
	partridge sensitive pea	Chamaecrista nictitans	1	15
	new mexico thistle	Cirsium neomexicanum	0	5
	golden corydalis	Corydalis aurea	0	1
	rattlesnake carrot	Daucus pusillus	0	2
	western tansymustard	Descurainia pinnata	1	10
	wedgeleaf draba	Draba cuneifolia	0	2
	western wallflower	Erysimum capitatum	0	1
	miniature woollystar	Eriastrum diffusum	0	1
	sorrel buckwheat	Eriogonum polycladon	0	5
	bull filaree	Erodium texanum	0	1
	mexican gold poppy	Eschscholzia californica ssp. mexicana	0	45
	spurge	Euphorbia	0	1
	star gilia	Gilia stellata	0	2
	pearly ballclover	Gomphrena nitida	0	2
	annual goldeneye	Heliomeris longifolia var. annua	1	50
	longleaf goldeneye	Heliomeris longifolia var. longifolia	0	5
	camphorweed	Heterotheca subaxillaris	0	5
	cutleaf morning glory	Ipomoea costellata	0	5
	redstar	Ipomoea coccinea	0	2
	thurber morning glory	Ipomoea thurberi	0	5
	orange caltrop	Kallstroemia grandiflora	0	5
	warty caltrop	Kallstroemia parviflora	0	2
	hairypod pepperweed	Lepidium lasiocarpum	0	2

	poorman pepperweed	Lepidium virginicum var. medium	0	5
	foothill deervetch	Lotus humistratus	0	10
	maresfat	Lotus salsuginosus var. brevivexillus	0	10
	arizona lupine	Lupinus arizonicus	0	5
	mojave lupine	Lupinus sparsiflorus	0	5
	fendler desert-dandelion	Malacothrix fendleri	0	2
	yellow tansyaster	Machaeranthera gracilis	1	10
	big purple tansyaster	Machaeranthera tanacetifolia	1	10
	whitestem stickleaf	Mentzelia albicaulis	0	5
	longtube four o'clock	Mirabilis longiflora	0	5
	arizona mountain mint	Monardella arizonica	0	1
	minerslettuce	Montia	0	5
	green carpetweed	Mollugo verticillata	0	1
	spring evening-primrose	Oenothera primiveris	0	1
	Florida pellitory	Parietaria floridana	0	2
	pectocarya	Pectocarya	0	2
	phacelia	Phacelia	0	10
	lipstick plant	Plagiobothrys arizonicus	0	2
	desert indianwheat	Plantago ovata	0	5
	woolly indianwheat	Plantago patagonica	0	5
	straighttube devilsclaw	Proboscidea althaeifolia	0	1
	annual devilsclaw	Proboscidea parviflora	0	1
	desert-chicory	Rafinesquia neomexicana	0	1
	chia	Salvia columbariae	0	2
	sawtooth sage	Salvia subincisa	0	5
	prostrate sida	Sida abutifolia	1	5
	streamside bur cucumber	Sicyos ampelophyllus	0	5
	sleepy silene	Silene antirrhina	0	5
	cutleaf bur cucumber	Sicyos laciniatus	0	5
	lacepod mustard	Thysanocarpus curvipes	0	2
	woolly tidestromia	Tidestromia lanuginosa	0	5
9: Perennial ferns			**5**	**20**
	cheilanthes	Cheilanthes	1	5
	notholaena	Notholaena	0	5
	pellaea	Pellaea	1	10
	spikemoss	Selaginella	1	20
Shrub/Vine				

Group	Plant Common Name	Plant Scientific Name	Annual Production Pounds Per Acre	
			Low	High
10: Dominant Half Shrubs			**100**	**150**
	orange indianmallow	Abutilon incanum	0	30
	prairie acacia	Acaciella angustissima	0	15
	yerba de pasmo	Baccharis pteronioides	0	10
	coulter brickellbush	Brickellia coulteri	0	10
	false mesquite	Calliandra eriophylla	10	80
	Gregg's prairie clover	Dalea greggii	10	40
	shrubby buckwheat	Eriogonum wrightii	20	70
	range ratany	Krameria erecta	1	10
	spreading ratany	Krameria lanceolata	0	10
	rough menodora	Menodora scabra	0	25
	california trixis	Trixis californica	1	10
11: Miscellaneous Shrubs			**10**	**50**
	whitethorn acacia	Vachellia constricta	0	5
	whitethorn acacia	Vachellia constricta	0	2
	catclaw acacia	Senegalia greggii	1	10
	milfoil wattle	Mariosousa millefolia	0	2
	mintbush lippia	Aloysia wrightii	0	5
	canyon ragweed	Ambrosia ambrosioides	0	1
	desert-honeysuckle	Anisacanthus thurberi	0	5
	pointleaf manzanita	Arctostaphylos pungens	0	2
	fourwing saltbush	Atriplex canescens	0	5
	shortleaf baccharis	Baccharis brachyphylla	0	1
	sweetbush bebbia	Bebbia juncea var. aspera	0	2
	california brickellbush	Brickellia californica	0	5
	desert hackberry	Celtis ehrenbergiana	0	5
	javelina bush	Condalia ericoides	0	2
	samota	Coursetia glandulosa	0	15
	knifeleaf snakewood	Condalia spathulata	0	5

	mexican crucillo	Condalia warnockii	0	5
	mexican crucillo	Condalia warnockii var. kearneyana	0	2
	ragged rockflower	Crossosoma bigelovii	0	2
	sotol	Dasylirion wheeleri	1	15
	hopseed bush	Dodonaea viscosa	0	10
	rayless brittlebush	Encelia frutescens	0	5
	rough mormon tea	Ephedra aspera	0	2
	coralbean	Erythrina flabelliformis	1	10
	tahitian kidneywood	Eysenhardtia orthocarpa	1	25
	apache plume	Fallugia paradoxa	0	5
	cliff fendlerbush	Fendlera rupicola	0	2
	desert olive	Forestiera shrevei	0	5
	ocotillo	Fouquieria splendens	1	25
	starry bedstraw	Galium stellatum	0	1
	desert lavender	Hyptis emoryi	1	15
	limberbush	Jatropha cuneata	0	5
	chuparosa	Justicia californica	0	5
	jacobina	Justicia candicans	0	5
	winterfat	Krascheninnikovia lanata	0	5
	lycium	Lycium	0	5
	watson lysiloma	Lysiloma watsonii	0	2
	algerita barberry	Mahonia trifoliolata	0	5
	wait-a-bit	Mimosa aculeaticarpa var. biuncifera	1	10
	velvetpod mimosa	Mimosa dysocarpa	1	10
	graham mimosa	Mimosa grahamii	0	2
	sacahuista	Nolina microcarpa	0	15
	blue palo verde	Parkinsonia florida	0	10
	whitestem paperflower	Psilostrophe cooperi	0	1
	turbinella oak	Quercus turbinella	0	10
	skunkbush sumac	Rhus trilobata	0	5
	evergreen sumac	Rhus virens var. choriophylla	0	2
	western soapberry	Sapindus saponaria var. drummondii	0	2
	jojoba	Simmondsia chinensis	0	15
	yellow trumpetbush	Tecoma stans	0	2
	mountain goldeneye	Viguiera cordifolia	0	5
	triangleleaf goldeneye	Viguiera parishii	0	5
	schott false mesquite	Zapoteca formosa var. schottii	0	5
	graythorn	Ziziphus obtusifolia	0	1

12: Increaser Shrubs			**10**	**45**
	desert broom baccharis	Baccharis sarothroides	0	2
	turpentine bush	Ericameria laricifolia	0	20
	broom snakeweed	Gutierrezia sarothrae	1	20
	sticky selloa	Gymnosperma glutinosum	0	5
	burroweed	Isocoma tenuisecta	0	2
13: Succulents			**15**	**55**
	desert agave	Agave deserti	0	2
	palmer agave	Agave palmeri	1	10
	smallflower agave	Agave parviflora	0	5
	schott agave	Agave schottii	0	10
	saguaro	Carnegiea gigantea	0	5
	buckhorn cholla	Cylindropuntia acanthocarpa	0	1
	jumping cholla	Cylindropuntia fulgida	0	2
	christmas cholla	Cylindropuntia leptocaulis	0	1
	cane cholla	Cylindropuntia spinosior	0	5
	staghorn cholla	Cylindropuntia versicolor	0	2
	fendler hedgehog cactus	Echinocereus bonkerae	0	1
	scarlet hedgehog cactus	Echinocereus coccineus	0	1
	engelmann hedgehog cactus	Echinocereus engelmannii	0	1
	fendler hedgehog cactus	Echinocereus fendleri ssp. fendleri	0	1
	rainbow cactus	Echinocereus pectinatus	1	2
	spinystar cactus	Escobaria vivipara	0	1
	fishhook barrel cactus	Ferocactus wislizeni	0	2
	fishhook pincushion cactus	Mammillaria grahamii	0	1
	cream pincushion cactus	Mammillaria heyderi	0	1
	dollarjoint pricklypear	Opuntia chlorotica	0	2
	engelmann pricklypear	Opuntia engelmannii	1	20
	redjoint pricklypear	Opuntia macrocentra var. macrocentra	0	2
	brownspine pricklypear	Opuntia phaeacantha	0	5
	santa rita pricklypear	Opuntia santa-rita	0	2
	banana yucca	Yucca baccata	0	2
	soaptree yucca	Yucca elata	0	2
		Tree		
Group	**Plant Common Name**	**Plant Scientific Name**	**Annual Production**	

			Pounds Per Acre	
			Low	**High**
14: Trees			**10**	**40**
	oneseed juniper	Juniperus monosperma	0	10
	honey mesquite	Prosopis glandulosa var. torreyana	0	5
	velvet mesquite	Prosopis velutina	0	10
	arizona white oak	Quercus arizonica	0	5
	emory oak	Quercus emoryi	0	5
	mexican blue oak	Quercus oblongifolia	0	5
	arizona rosewood	Vauquelinia californica	0	10

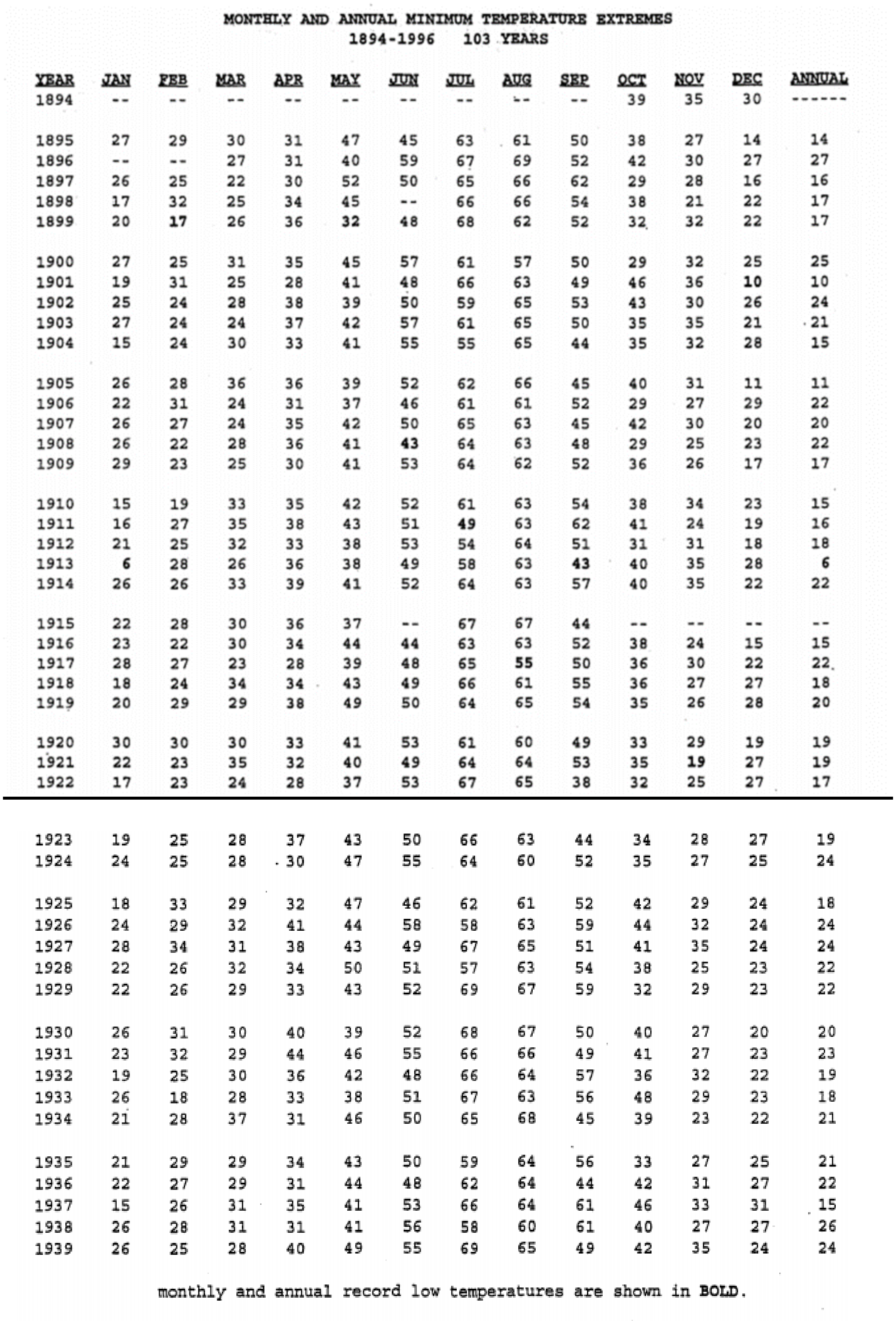
community.
In the absence of wildfire and/or with overgrazing, shrubs increase to dominate the plant community. Well developed gravel and cobble covers protect the soil from erosion and protect forage species from heavy use. Natural fire was an important factor in development of the potential plant community.
Natural fire frequencies were about once every ten years. Fires helped maintain a balance between grasses, forbs and shrubs.
With continuous heavy grazing palatable forage species diminish in the plant community and can be replaced by shrubs and succulents. Areas of rock outcrop are little grazed and hold remnant perennial forage species to help reseed the slopes below once grazing is managed.
The plant community described for the HCPC is at a midpoint in its fire free interval (5 to 7 years after fire).

Collapse Plant Community Tables
Tables — Historic Climax Plant Community

Collapse Annual Production (Lbs/Acre)
Annual Production (Lbs/Acre)

Plant Type	Low	Representative Value
Grass/Grasslike	360	700
Forb	25	50
Shrub/Vine	130	150
Tree	10	15

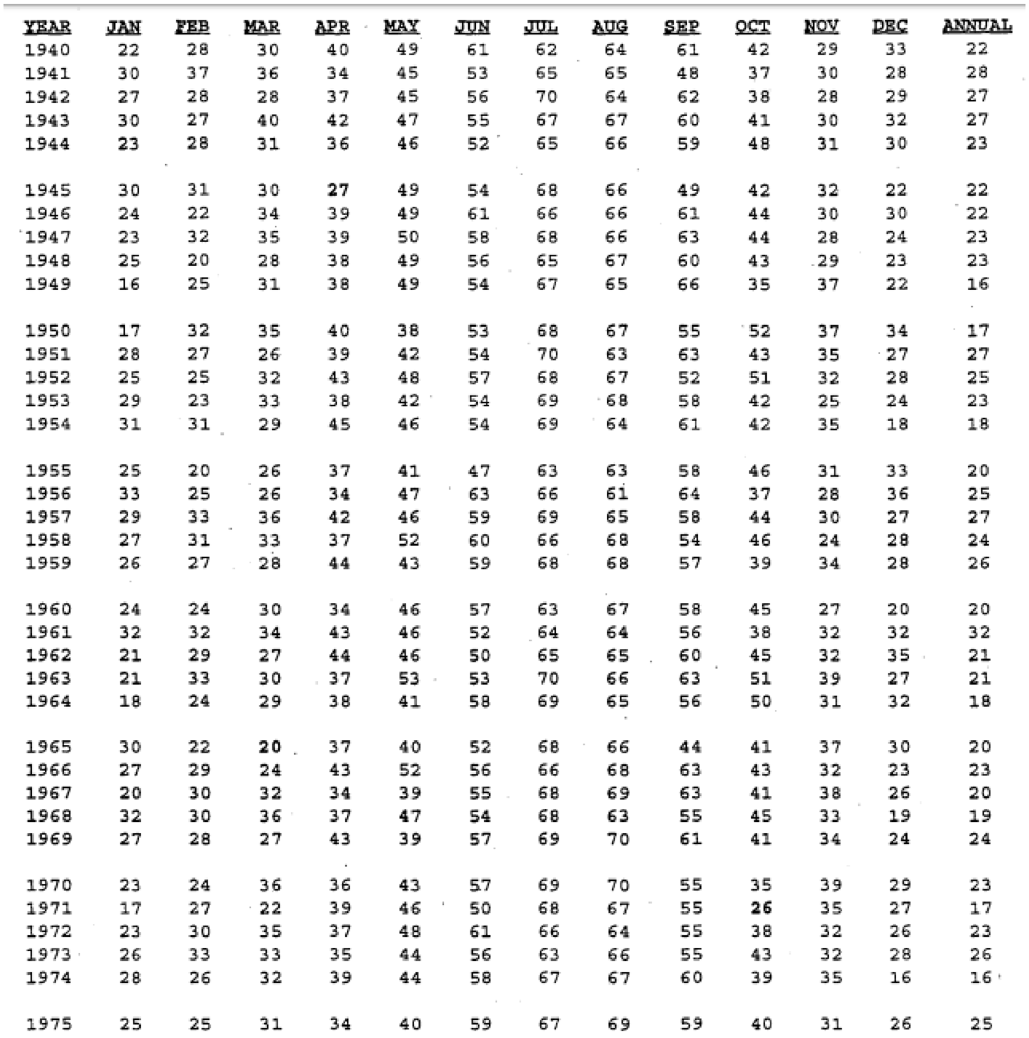
8.3 Historical Winter Minimum History



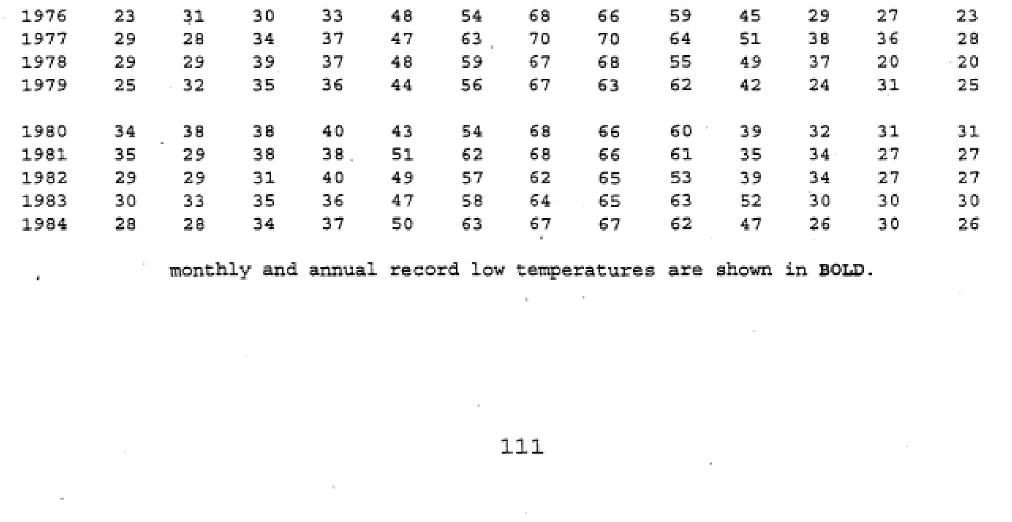
MONTHLY AND ANNUAL MINIMUM TEMPERATURE EXTREMES
1894-1996 103 YEARS

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1894	--	--	--	--	--	--	--	--	--	39	35	30	------
1895	27	29	30	31	47	45	63	61	50	38	27	14	14
1896	--	--	27	31	40	59	67	69	52	42	30	27	27
1897	26	25	22	30	52	50	65	66	62	29	28	16	16
1898	17	32	25	34	45	--	66	66	54	38	21	22	17
1899	20	**17**	26	36	**32**	48	68	62	52	32	32	22	17
1900	27	25	31	35	45	57	61	57	50	29	32	25	25
1901	19	31	25	28	41	48	66	63	49	46	36	**10**	10
1902	25	24	28	38	39	50	59	65	53	43	30	26	24
1903	27	24	24	37	42	57	61	65	50	35	35	21	21
1904	15	24	30	33	41	55	55	65	44	35	32	28	15
1905	26	28	36	36	39	52	62	66	45	40	31	11	11
1906	22	31	24	31	37	46	61	61	52	29	27	29	22
1907	26	27	24	35	42	50	65	63	45	42	30	20	20
1908	26	22	28	36	41	**43**	64	63	48	29	25	23	22
1909	29	23	25	30	41	53	64	62	52	36	26	17	17
1910	15	19	33	35	42	52	61	63	54	38	34	23	15
1911	16	27	35	38	43	51	**49**	63	62	41	24	19	16
1912	21	25	32	33	38	53	54	64	51	31	31	18	18
1913	**6**	28	26	36	38	49	58	63	**43**	40	35	28	**6**
1914	26	26	33	39	41	52	64	63	57	40	35	22	22
1915	22	28	30	36	37	--	67	67	44	--	--	--	--
1916	23	22	30	34	44	44	63	63	52	38	24	15	15
1917	28	27	23	28	39	48	65	**55**	50	36	30	22	22
1918	18	24	34	34	43	49	66	61	55	36	27	27	18
1919	20	29	29	38	49	50	64	65	54	35	26	28	20
1920	30	30	30	33	41	53	61	60	49	33	29	19	19
1921	22	23	35	32	40	49	64	64	53	35	**19**	27	19
1922	17	23	24	28	37	53	67	65	38	32	25	27	17
1923	19	25	28	37	43	50	66	63	44	34	28	27	19
1924	24	25	28	30	47	55	64	60	52	35	27	25	24
1925	18	33	29	32	47	46	62	61	52	42	29	24	18
1926	24	29	32	41	44	58	58	63	59	44	32	24	24
1927	28	34	31	38	43	49	67	65	51	41	35	24	24
1928	22	26	32	34	50	51	57	63	54	38	25	23	22
1929	22	26	29	33	43	52	69	67	59	32	29	23	22
1930	26	31	30	40	39	52	68	67	50	40	27	20	20
1931	23	32	29	44	46	55	66	66	49	41	27	23	23
1932	19	25	30	36	42	48	66	64	57	36	32	22	19
1933	26	18	28	33	38	51	67	63	56	48	29	23	18
1934	21	28	37	31	46	50	65	68	45	39	23	22	21
1935	21	29	29	34	43	50	59	64	56	33	27	25	21
1936	22	27	29	31	44	48	62	64	44	42	31	27	22
1937	15	26	31	35	41	53	66	64	61	46	33	31	15
1938	26	28	31	31	41	56	58	60	61	40	27	27	26
1939	26	25	28	40	49	55	69	65	49	42	35	24	24

monthly and annual record low temperatures are shown in **BOLD**.

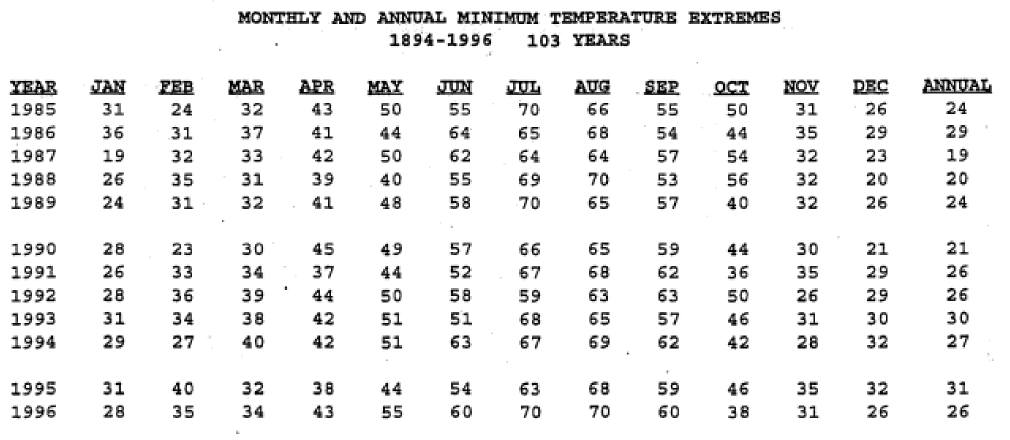


YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1940	22	28	30	40	49	61	62	64	61	42	29	33	22
1941	30	37	36	34	45	53	65	65	48	37	30	28	28
1942	27	28	28	37	45	56	70	64	62	38	28	29	27
1943	30	27	40	42	47	55	67	67	60	41	30	32	27
1944	23	28	31	36	46	52	65	66	59	48	31	30	23
1945	30	31	30	27	49	54	68	66	49	42	32	22	22
1946	24	22	34	39	49	61	66	66	61	44	30	30	22
1947	23	32	35	39	50	58	68	66	63	44	28	24	23
1948	25	20	28	38	49	56	65	67	60	43	29	23	23
1949	16	25	31	38	49	54	67	65	66	35	37	22	16
1950	17	32	35	40	38	53	68	67	55	52	37	34	17
1951	28	27	26	39	42	54	70	63	63	43	35	27	27
1952	25	25	32	43	48	57	68	67	52	51	32	28	25
1953	29	23	33	38	42	54	69	68	58	42	25	24	23
1954	31	31	29	45	46	54	69	64	61	42	35	18	18
1955	25	20	26	37	41	47	63	63	58	46	31	33	20
1956	33	25	26	34	47	63	66	61	64	37	28	36	25
1957	29	33	36	42	46	59	69	65	58	44	30	27	27
1958	27	31	33	37	52	60	66	68	54	46	24	28	24
1959	26	27	28	44	43	59	68	68	57	39	34	28	26
1960	24	24	30	34	46	57	63	67	58	45	27	20	20
1961	32	32	34	43	46	52	64	64	56	38	32	32	32
1962	21	29	27	44	46	50	65	65	60	45	32	35	21
1963	21	33	30	37	53	53	70	66	63	51	39	27	21
1964	18	24	29	38	41	58	69	65	56	50	31	32	18
1965	30	22	20	37	40	52	68	66	44	41	37	30	20
1966	27	29	24	43	52	56	66	68	63	43	32	23	23
1967	20	30	32	34	39	55	68	69	63	41	38	26	20
1968	32	30	36	37	47	54	68	63	55	45	33	19	19
1969	27	28	27	43	39	57	69	70	61	41	34	24	24
1970	23	24	36	36	43	57	69	70	55	35	39	29	23
1971	17	27	22	39	46	50	68	67	55	26	35	27	17
1972	23	30	35	37	48	61	66	64	55	38	32	26	23
1973	26	33	33	35	44	56	63	66	55	43	32	28	26
1974	28	26	32	39	44	58	67	67	60	39	35	16	16
1975	25	25	31	34	40	59	67	69	59	40	31	26	25



1976	23	31	30	33	48	54	68	66	59	45	29	27	23
1977	29	28	34	37	47	63	70	70	64	51	38	36	28
1978	29	29	39	37	48	59	67	68	55	49	37	20	20
1979	25	32	35	36	44	56	67	63	62	42	24	31	25
1980	34	38	38	40	43	54	68	66	60	39	32	31	31
1981	35	29	38	38	51	62	68	66	61	35	34	27	27
1982	29	29	31	40	49	57	62	65	53	39	34	27	27
1983	30	33	35	36	47	58	64	65	63	52	30	30	30
1984	28	28	34	37	50	63	67	67	62	47	26	30	26

monthly and annual record low temperatures are shown in **BOLD**.



MONTHLY AND ANNUAL MINIMUM TEMPERATURE EXTREMES
1894-1996 103 YEARS

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1985	31	24	32	43	50	55	70	66	55	50	31	26	24
1986	36	31	37	41	44	64	65	68	54	44	35	29	29
1987	19	32	33	42	50	62	64	64	57	54	32	23	19
1988	26	35	31	39	40	55	69	70	53	56	32	20	20
1989	24	31	32	41	48	58	70	65	57	40	32	26	24
1990	28	23	30	45	49	57	66	65	59	44	30	21	21
1991	26	33	34	37	44	52	67	68	62	36	35	29	26
1992	28	36	39	44	50	58	59	63	63	50	26	29	26
1993	31	34	38	42	51	51	68	65	57	46	31	30	30
1994	29	27	40	42	51	63	67	69	62	42	28	32	27
1995	31	40	32	38	44	54	63	68	59	46	35	32	31
1996	28	35	34	43	55	60	70	70	60	38	31	26	26

9. References

1. Bahre, Conrad J., Marlyn, Shelton L. Rangeland Destruction: Cattle and Drought in Southeastern Arizona at the Turn of the Century. 1996. Journal of the Southwest 38(1): 1-22
2. Bender, L.C., Lomas, L.A., Kamienski, T. Habitat Effects on Condition of Doe Mule Deer in Arid Mixed Woodland-grassland. 2007. Rangeland Ecology & Management 60(3); 277-284.
3. Biedenbener, Sharon H. & Roundy, Bruce A. Establishment of Native Semidesert Grasses into Existing Stands of *Eragrostis lehmanniana* in Southeastern Arizona. 1996. Restoration Ecology 4:2: 155-162.
4. Canfield, R.H. Reproduction and Life Span of Some Perennial Grasses of Southern Arizona. 1957. Journal of Range Management 10:5: 199-203.
5. Coronado, Mario Humberto Esqueda, Castillo, Alicia Melgoza, Cerecedo, Manuel Sosa, Romo, Regina Carrillo, Castro, Jorge Jimenez. Emergence and survival of native and introduce grasses in an arid environment under different wet-dry sequences in three soil types. 2005. Tec Pecu Mex Vol. 43:1: 101-115.
6. De Dios, V.R., Weltzin, J.F., Sun, W., Huxman, T.E., Williams, D.G. Windows of opportunity for *Prosopis velutina* seedling establishment and encroachment in a semiarid grassland. 2012. Perspectives in Plant Ecology, Evolution and Systematics 14: 275-282.
7. Fehlberg, S.D., Ranker, T.A. Evolutionary and phylogeography of *Encelia farinosa* (Asteraceae) from the Sonoran, Mojave, and Peninsular Deserts. 2009. Molecular Phylogenetics and Evolution 50: 326-335.
8. Fehmi, J.S., Niu, G-Y., Scott, R.L. Evaluating the effect of rainfall variability on vegetation establishment in a semidesert grassland. 2014. Environmental Monitoring Assessment 186: 395-406.
9. Geiger, E., Mau-Crimmins, T., Schussman, H. Spread of a Nonnative Grass Across Southern Arizona: Multiple Data Sources to Monitor Change. 2003. USDA Forest Service Proceedings RMRS-P-30.
10. Gluek, John R. NOAA Technical Memorandum; Climate of Tucson. 1997. National Weather Service. Retrieved from; https://www.weather.gov/media/wrh/online_publications/TMs/TM-249.pdf
11. Goergen, Erin & Daehler, Curtis C. Reproductive Ecology of a Native Hawaiian Grass (*Heterpogon contortus;* Poaceae) Versus its Invasive Alien Competitor (*Pennisetum Setaceum;* Poaceae). 2001. International Journal of Plant Science 162:2: 217-326.
12. Golubov, J., Mandujano, M.C., Egiarate, L.E. The Paradox of Mesquites (*Prosopis spp.)* Invading Species or Biodiversity Enhancers? 2001. Biological Society of Botany (Mexico) 69: 23-30.
13. Gray, Reed; Bonner, James. An inhibitor of plant growth from the leaves of *Encelia farinosa.* 1948. American Journal of Botany 35: 52-57.

14. Hart, R.H., Bissio, J., Samuel, M.J., Waggoner Jr., J.W. Grazing Systems, Pasture Size, and Cattle Grazing Behavior, Distribution and Gains. 1993. Journal of Range Management 46:81-87.
15. Jackson, Carola V. Seed Germination in Certain New Mexico Range Grasses. 1928. Botanical Gazette 86:3: 270-294.
16. McAuliffe, Joseph R., Devender, Thomas R. A 22,000-year record of vegetation change in the norther-central Sonoran Desert. 1998. Palaeogeography, Palaeoclimatology, Palaeoecology 141: 253-275.
17. McClaran, Mitchel P. A Century of Vegetation Change on the Santa Rita Experimental Range. 2003. USDA Forest Service Proceedings RMRS-P-30.
18. McClaran, M.P., Moore-Kucera, J., Martens, D.A., van Haren, J., Marsh, S.E. Soil Carbon and Nitrogen in Relation to Shrub Size and Death in a Semi-Arid Grassland. 2008. Geoderma 145:60-68.
19. McClaran, Mitchell P. & Van Devender, Thomas R. Desert Grasslands. 1995. The University of Arizona Press.
20. Mohamed, Ahmed; Holechek, Jerry; Bailey, Derek; Campbell, Carol; Demers, Michael Mohamed. Mesquite encroachment impact on southern New Mexico rangelands: remote sensing and geographic information systems approach. 2011. Journal of Applied Remote Sensing 5, p. nd.
21. National Park Service. Saguaro National Park Facts & Figures. 2019. Retrieved from; https://www.nps.gov/sagu/index.htm
22. NOAA. Climate Records. 2020. Retrieved from; https://www.currentresults.com/Yearly-Weather/USA/AZ/Tucson/extreme-annual-tucson-low-temperature.php
23. NOAA. Historical Tucson Airport Precipitation. 2019. Retrieved from; =https://www.ncei.noaa.gov/
24. NRCS. Ecological Site Descriptions. N.D. Retrieved from; https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/ecoscience/desc/
25. Pease, S., Ffolliott, P.F.,DeBano, L.F., Gottfried, G.J. Mesquite Removal and Mulching Treatment Impacts on Herbage Production and Selected Soil Chemical Properties. 2003. USDA Forest Service Proceedings RMRS-P-30.
26. Peters, Debra P.C. Recruitment Potential of Two Perennial Grasses with Different Growth Forms at a Semiarid-Arid Transition Zone. 2002. Journal of Botany 89:10: 1616-1623.
27. Pinto, Robin L. Cattle Grazing and Ecological History of Saguaro National Park Executive Summary. 2013. University of Arizona.
28. Reed-Dustin, C.M., Mata-Gonzalez, R., Rodhouse, T.J. Long-term Effects on Native and Invasive Grasses in Protected Area Sagebrush Steppe. 2016. Rangeland & Ecology Management 69:257-264.
29. Roundy, B.A., Biendenbender, S.H. Germination of Warm-Season Grasses under Constant and Dynamic Temperatures. 1996. Journal of Range Management 49(5): 425-431.

30. Saguaro National Park East. Visitors Center Precipitation 1994-2019. 2019.
31. Senft, R.L., Rittenhouse, L.R., Woodmansee, R.G. Factors Influencing Patterns of Cattle Grazing Behavior on Shortgrass Prairie Steppe. 1985. Journal of Range Management 38(1):82-87.
32. Shaidaee, G., Dahl, B.E., Hanse, R.M. Germination and Emergence of Different Age Seed of Six Grasses. 1969. Journal of Range Management 22:4: 240-243.
33. Smith, S.E., Mosher, R., Fendenheim, D. Seed Production in Sideoats Grama populations with different grazing histories. 2000. Journal of Range Management 53: 550-555.
34. Steenbergh, Warren F. Ecological Impact of Livestock Grazing at Saguaro National Monument. 1976. National Park Service Report, The University of Arizona.
35. Stroup, Walter W. Rethinking the Analysis of Non-Normal Data in Plant and Soil Science. 2014. Symposium; Statistical Concepts.