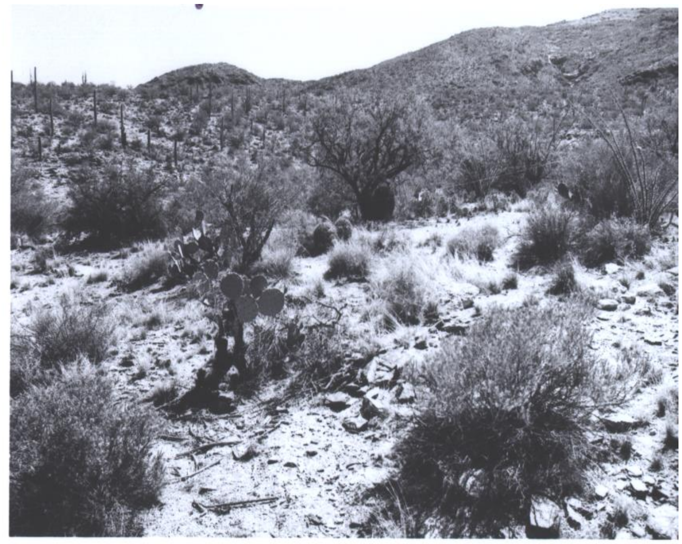
The Long-term Impact of Cattle Grazing in Saguaro National Park

Above: Plot 1 (ungrazed control). Photos taken in 1976 (L) and 2007 (R). Below: Plot 6, 2019.

Final Report, WNPA Research Project #18-09

March 2020

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Introduction

The history of cattle grazing in North America after European contact is well known, particularly in the American west. Spanish missionaries first brought cattle into what would become the Sonoran and Chihuahuan deserts during the late 16th century (Pinto, 2013). However, the area that is now Saguaro National Park was not occupied by cattle thoroughly until after the Apache Wars, when homesteaders could safely move into the Tanque Verde and Rincon Valleys of southeastern Arizona. Early homesteaders ran small numbers (25-100) of cattle on the desert ranges that likely caused 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, which ushered in an age of ecological abuse in the area. After this point cattle often grazed unchecked year-round, because ranchers only collected roughly 75% of their cattle when it came time to move onto private land, 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 intensively year-round on these properties. Even into the 1950's ranchers focused on intensive grazing and cattle sales, ignoring modern advancements in range management sciences. As knowledge of the impact of cattle grazing increased in the 1960s and 1970s, studies conducted in Saguaro National Park led to park managers, the Department of the Interior, and local community groups legally challenging the grazing rights of the ranchers.

This project in Saguaro National Park is a replicate of a 1976 study that established ten plots in formally grazed areas to provide a baseline of ecological damage and recovery following the removal of cattle grazing. Warren F. Steenbergh, a renowned ecologist at the park who had helped lead the effort to eliminate grazing, designed this long-term vegetation survey to document the recovery of the plant community. His previous work included ecological studies on the saguaro (*Carnigea gigantea*) and other Sonoran Desert plants. After Steenbergh's death the papers from his study were left in a box in the park's library, and not re-discovered until the mid-2000s. In 2007 park staff re-located the plots in the field through repeat photos and re-surveyed them (Springer et al., 2010). However, the results were not published, in part due to confusion about the park's grazing history, which was addressed in a subsequent report (Pinto 2013).

Although Steenbergh's study focused on recovery of the plant community from cattle grazing, since 1976 Saguaro National Park has experienced many other ecological influences, especially higher average temperatures and changes in fire regimes. Both factors have certainly impacted vegetation on his plots in the nearly 50 years since.

Fire. Natural wildfires in the lower Sonoran Desert are very rare due to lack of fuels to carry fire, but at higher elevations fire intervals are 10-15 years. However, during a historically wet period from 1964-1994, multiple fires with both lightening and human-caused starts occurred in Sonoran Desert grassland and desert thorn scrub zones. These fires burned through 8 of the 10 plots in this survey. During this period, conditions were extremely cool and wet, creating extensive biomass in areas that are not typical of these elevational zones. These fires were reported to be a result of this overabundance of biomass in combination with invasive grasses such as red brome *(Bromus rubens)*, buffelgrass (*Cenchrus ciliare),* and crimson fountain grass (*Pennisetum setaceum)*. Although excellent maps of these fires exist, their severity was generally not well-documented.

Climate. Figure 3 shows the combined average in precipitation between the Santa Rita Experimental Range (University of Arizona) and the Tucson International Airport. These two stations are the only stations immediately surrounding the Tucson area that were recorded prior to 1994. Combined, they provide an average of a lower and hotter location compared to our study site (Tucson International

Airport) and a cooler, wetter area with similar elevation (Santa Rita Range). Mean precipitation for the period from 1923-2019 was 12.85''. From 1923-1977 mean precipitation was 12.51''. The 1995-2013 period was fairly dry (11.36'' annually) but has been slightly higher since. Since 1978-2019, after cattle were removed from the park, mean annual precipitation has been 13.30''.

The most dramatic climate trend in the desert southwest region has been an increase in winter minimum temperatures of 10-15 F in the last 100 years (Gluek, 1997). These higher temperatures are creating new trends in elevational migration patterns, as well as changes in winter snow and rain events. Winter minimum temperatures during the early 1900's were often in the low-mid 10's (F) at Tucson International Airport, but in recent years minimum low temperatures below freezing have become rare (NOAA, 2020). Tucson International Airport is warmer and drier than our study area, so historical lows in the 3200-4300 ft elevation range were likely to have ranged into the single digits during many winters prior to the 1980s.

Methods

***Vegetation**.* Each of Steenbergh's original ten plots were 0.1 hectare (20x50 meters). Starting with the upslope (highest) corner of the plot, 21 transects, each 20 meters, were used to document cover (Figure 2). 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 .05 meters (such as is common with *Opuntia spp.*). Height was documented for all species that intersected the line and no measurements past the 20-meter transect or before the "0" on the tape measure were recorded. Density was calculated within ten 20x5 meter subplots where species were tallied above 0.25 meters in height and totaled by plot. These density sub-plots were labeled A-J. Frequency was taken from these sub-plots (A-J) in micro-plots of 5 meters x 2 meters. Every individual species was counted, regardless of height, as long as it was present in the micro-plot. These plots (1-8) were paired into intense grazing plots, immediately adjacent to water (plots 1,3,5,7), and less intense grazing plots that were 0.25-0.50 miles away from water sources and thus saw much reduced grazing (Steenbergh, 1976). Because we could not compare greater grazing v. lesser grazing without knowing more details of grazing intensity, paired plots were not considered during our analysis with a traditional "control" v. "treatment" method. Plots 9 & 10 were not originally paired but added to give further insight into middle elevation succession and associated compositional change.

Analysis. We compared species guild composition changes, individual indicator species, and percentage shifts through the three surveys of all plots. R statistical software was used to analyze these variables and fire variables as well as plots 3 & 7 were not burned as all eight other plots were. However, we must again stress that fire intensity is not known so simple differences in vegetation type and class were the desired analysis here.

Hypotheses. Our hypotheses coming into this project were as follows: Between 1976 and 2019:

(1) Cover, density, and diversity would increase as recovery and succession continue; (2) Woody species would increase compared to graminoids due to climate change and associated increased drought that we expected would aid deep rooted species that require less frequent precipitation; (3) Unpalatable species would decline without the influence of grazing, with more palatable species increasing as typical succession dictates; (4) Plots burned during the 1980's and 1990's would show significant difference from unburned plots as a result of these fire; and (5) cold sensitive species would move up in elevation due to increasing winter low temperature and, reduced hard freeze events.

Results

Cover and density: In general, vegetative canopy cover and density increased extensively from 1976 through 2019 (Figure 4). Overall, plant density increased 267.27% from 1976-2007 and a further 189.51% from 2007-2019 (Figure 5). Canopy cover decreased slightly from 1976-2007 (-15.65%) but increased 65.31% during 2007-2019.

The greatest increases were with grasses. Grass canopy cover rose 255.35% during 1976-2007 and a further 65.31% during 2007-2019 (p=0.0293). The largest individual plot increase was plot 8, which increased graminoid canopy cover by 2,416.7% during 2007-2019. Density of grasses also increased 77.89% from 2007-2019 (p=0.0003). Certain species of perennial grasses, such as gramma grasses (*Bouteloua* sp.) went from being nearly absent from the plots in 1976 to very abundant in 2019 (Table 1). The non-native Lehmann's lovegrass (*Eragrostis lehmannaina*) also increased dramatically.

Within this general increase in cover and density we found subtle differences among guilds, and an overall decrease in tree cover. Trees were the only guild of plants that decreased in canopy cover from 2007-2019 overall (-4.9%), although at an insignificant level (p=0.885). Density of trees dropped 49% from 1976-2007 and 31% further by 2019, and overall tree species composition fell 4.9% during the entire period.

Sub-shrub cover increased 824% from 1976-2007 and 46.49% from 2007-2019. Shrub cover decreased 32.9% during 1976-2007 but increased 74.23% by 2019. Canopy of succulents dropped from 1976-2007 (-40.1%) but increased 4.76% during 2007-2019.

Diversity and composition*.* Diversity on the plots also increased since the original survey, with the greatest increase occurring between the 1976 and 2007 surveys, when biodiversity increased by 25.8%. From 2007 to 2019, diversity increased 2.9%. The two unburned plots (3 and 7) were not dramatically different in species composition than the burned plots. However, one species (*Carlowrightia arizonica)* was extensively present on the unburned plots compared to only slight increases on burned plots.

Changes in individual species*.* An important tree species in the area, velvet mesquite *(Prosopis velutina)* decreased in cover 18.4% during 1976-2007 and was stable (0.3% increase) during 2007-2019; it also decreased in density by 53.9% during 1976-2007 but increased 66.67% during 2007-2019 (Table 1).

Turpentine bush (*Ericameria laricifolia)*, an unpalatable subshrub, declined drastically (93%) in cover in during 1976-2007, with a slight increase (13.11%) during 2007-2019; it also declined in density (-72.5%) during 1976-2007 and 2007-2019 (-18.2%). Another unpalatable species, *Fourqueria splendens* (ocotillo) increased 24.23% in cover and 30.59% in density during 2007-2019.

In contrast, palatable plants increased greatly. In addition to nearly all grass species, desert vine (*Cottsia gracilis)* increased in cover by 64.68% by 2007 and by more than 269.19% by 2019; density increased 226.45% by 2007 and an additional 198.79% by 2019. The very nutritious faerie duster subshrub (*Calliandra eriophylla)* increased 173.13% in density by 2007 and 537.27% by 2019, with cover increasing 976.59% by 2007 and 173.13% by 2019*.*

Among species considered cold-intolerant, limberbush (*Jatropha cardiophylla,* known for its tendency to grow taller and more numerous in warmer locations) only increased slightly at lower elevations. However, the cold-intolderant subshrub brittlebush (*Encelia farinose)*, (which has pushed far beyond historic boundaries and in the past 50-60 years has become a dominant species up to 3600 feet; McAuliffe & Van Devender, 1998) increased greatly across nearly all plots. Brittlebush increased in cover from the 1976 to 2007 by 82.31% by 2007 and 258.58% between 2007-2019. Brittlebush density increased 34.1% during 1976-2007 and 281.3% during 2007-2019.

Discussion

In general, we observed several consistent patterns during this study: 1) a dramatic increase in cover and density of most plant guilds (supporting Hypothesis #1), 2) with the one exception being tree species, which decreased (not supporting Hypothesis #2); 3) a huge increase in palatable species, especially grasses and nutritious plants such as desert vine (supporting Hypothesis #3); and 4) an increase in cold-tolerant species (supporting Hypothesis #5). Although we did not find direct support for Hypothesis #4, that the two unburned plots would have different responses in time as a result of fires, these broad patterns suggest that the vegetation community in desert areas of Saguaro National Park has not only dramatically responded from the cessation of cattle grazing in the past 40-50 years, but has also responded to changes in fire regimes and climate.

Trees. The loss in both cover and density of trees is most likely to be related to fires in the 1980s and 1990s that burned through nearly all the plots. Density of trees dropped nearly 50% from 1976-2007 following the large Chiva (1989) and Box Canyon (1999) fires. Interestingly, however, tree density also decreased by 31% between 2007-2019, suggesting other factors may be involved. These factors could include competition from grasses, interactions with grassland mammals, and climate.

Among specific species, both cover and density of mesquite decreased from 1976-2007. Although cover did not increase during 2007-2019, density did increase significantly (66.67%). This is in contrast to similar sites in southern Arizona, such as the Santa Rita Experimental Range (McClaran, 2003), where mesquite has greatly increased. Our results suggest that mesquite population dynamics may be related to local conditions, especially the fires the park has experienced, possibly in combination with long-term drought. In our study, the average number of mesquites/ha is 78, in contrast to 200-450/ha in the foothills of the Santa Ritas. However, fires are generally suppressed in the Santa Ritas, supporting the idea that mesquite may be a climax species that is controlled where natural fire regimes are present.

Mesquite is considered a biodiversity increaser (Golubov et. al., 2001). The "life island" concept of the nitrogen-fixation *Rhizobium* spp. enables hundreds of species to grow beneath mesquites, and they are the primary nurse plants for saguaros in Saguaro National Park. It does seem possible that long-term decreases in this species could impact establishment of saguaros, but saguaros are also directly affected by fire and drought.

Shrubs, subshrubs, and vines. Similar to trees, cover of shrubs decreased (32.9%) during 1976-2007; however, unlike trees, shrub cover increased greatly (74.23%) by 2019. We speculate that shrubs were similarly impacted by the large wildlife fires between 1976-2007 but were able to recover more quickly.

Sub-shrub cover increased dramatically through the entire period, but especially during the wetter period from 1976-2007. However, there were some exceptions that would be expected from the release of grazing pressure, such as the decline in the unpalatable subshrub turpentine bush and the dramatic increase in species strongly preferred by cattle such as fairy duster, which is highly nutritious in both its green growth and seed pods *(*Golubov et al., 2001*).* Although vines make up only a small percentage of overall cover in our study, the dramatic increase in desert vine – a high protein, low salt perennial that is also a favorite food of desert tortoise – is certainly related to the release from cattle grazing.

Among sub-shrubs, the most dramatic increase was in brittlebush (*Encelia farinosa*), which is becoming a visually dominant species in many areas of Saguaro National Park. Brittlebush increased in cover by 82.31% during 1976-2007 and 258.58% by 2019. This cold-intolerant species, which limits the growth of other species through inhibitory toxins, is believed to have arrived in the Rincon Mountains in at some point in the early-20th century, not having occurred during earlier periods when winter minimum temperatures were colder (McAuliffe & Van Devender, 1998). Its dramatic increase is certainly related to much warmer winters. However, within its historic range brittlebush is an early-mid seral dominator in post-disturbance areas (such as intense cattle grazing and fire), which suggests that it could decline in the future as the vegetation community matures. Other sub-shrubs influenced by climate include limberbush, which increased, but not dramatically, over the study period.

Succulents and cacti. Canopy of succulents and cacti such as prickly pear dropped from 1976-2007 (-40.1%) but increased 4.76% during 2007-2019. As with the decrease in trees and shrubs, the decrease during 1976-2007 is most likely due to fire, as many subshrubs are not fire-adapted. The more recent increase suggests that post-fire recovery is continuing.

Grasses. Of all the plant guilds we surveyed, the most dramatic increases were in perennial grasses. Grass canopy cover rose 255.35% during 1976-2007 and 65.31% during 2007-2019, with perennial bunchgrass canopy rising more than six-fold during 2007-2019 alone.

This tremendous increase in grasses can certainly be attributed, at least in part, to the cessation of grazing. Grasses are highly desired by cattle, and many other studies have shown an increase in perennial grasses when cows are removed from an area. Density of all grasses was extremely low when the plots were first sampled in 1976, when there were literally no individual gramma grasses recorded (Appendix A). That said, diversity of grasses in 1976 was higher than we expected, indicating that many species were able to persist and respond rapidly following decades of intense grazing.

It also seems likely that the recent tropical storms during September-November have provided a more optimal environmental for survival of perennial grasses. Perennial grasses require more consistent (frequency) precipitation events first during the monsoon season (July & August), and then "survivability" events in the following fall months (September-November) (Roundy & Biedenbender, 1996). Despite an overall trend towards drier winters and warmer temperatures that increase drought, increases in tropical precipitation events, particularly since 2007, are likely improving conditions for perennial grasses both regionally and within Saguaro National Park. It will be important to track this trend to see if it continues.

Conclusion

The overall trajectory of increasing perennial grass cover, clearly due in part to cessation of cattle grazing, is good news that highlights the long-term ecological benefits of National Park Service management practices. Not only do grasses enhance infiltration and soil moisture retainment, but extensive grass cover is also likely to reduce sediment loading in streams and potentially refill springs in the Rincon Mountains. Increases in highly palatable species such as grasses and desert vine increase biological diversity and provide nutritious food for important species such as deer and desert tortoises.

Our study has other important implications for current and future Saguaro National Park management. In conjunction with other WNPA-supported studies of Saguaro (e.g., Winkler et al. 2019), our results provide support that long-term climate changes, including warming temperatures and shifting tropical storm patterns, are impacting the park's vegetation. The major increase in brittlebush is a sign of this change, but in the future we can also expect that other opportunistic species, including invasive grasses, will begin outcompeting the park's traditional Sonoran Desert plants. In addition, changes in vegetation appear to be influencing wildlife, with decreases in mule deer and kangaroo rats, and increases in white-tail deer and murid rodents, occurring or expected to occur. Because increasing native and non-native grasses can drastically increase fine fuels for wildfire, it seems likely that the park may face more wildfire during periods of plentiful moisture. It is important that park managers support continued monitoring and research on these changes going forward as these ecosystems move back towards a climax state, or forward into unknown territory.

In completing this study, we have fulfilled nearly all the requirements of our WNPA research grant, which supported the graduate work of Ryan Summers, who is defending his thesis on this topic at Oregon State University in May 2020 and finishing a peer-reviewed paper. The only research aspect we did not complete was analysis of soils crusts, which was a minor component that we came to realize could not be replicated meaningfully without significant additional training and commitment of resources. Our many interpretive products include grass identification guides created for visitors and Visitor Center staff; interpretive hiking tours conducted by Ryan while he worked as an intern and student employee in the Visitor Center; and an interpretive video on this project shown in the Visitor Center Science Corner (Figure 7). We are grateful for WNPA's support of this project, which we believe presents important quantitative data for Saguaro National Park's future management knowledge and decision-making.

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Figures and Tables

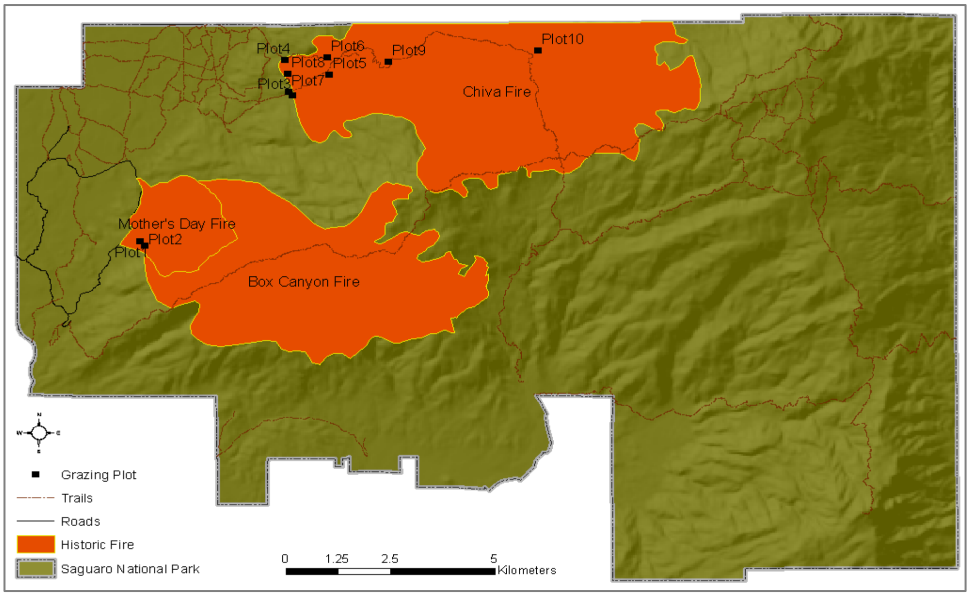

Figure 1. Location of grazing plots surveyed in 1976, 2007 and 2019 their exposure to the Chiva (1989), Mother's Day (1994), and Box Canyon (1999) fires at the Rincon Mountain District of Saguaro National Bottom (bottom). Most plots burned once between 1976 and the present (2018) with the exception of plots 3 and 7.

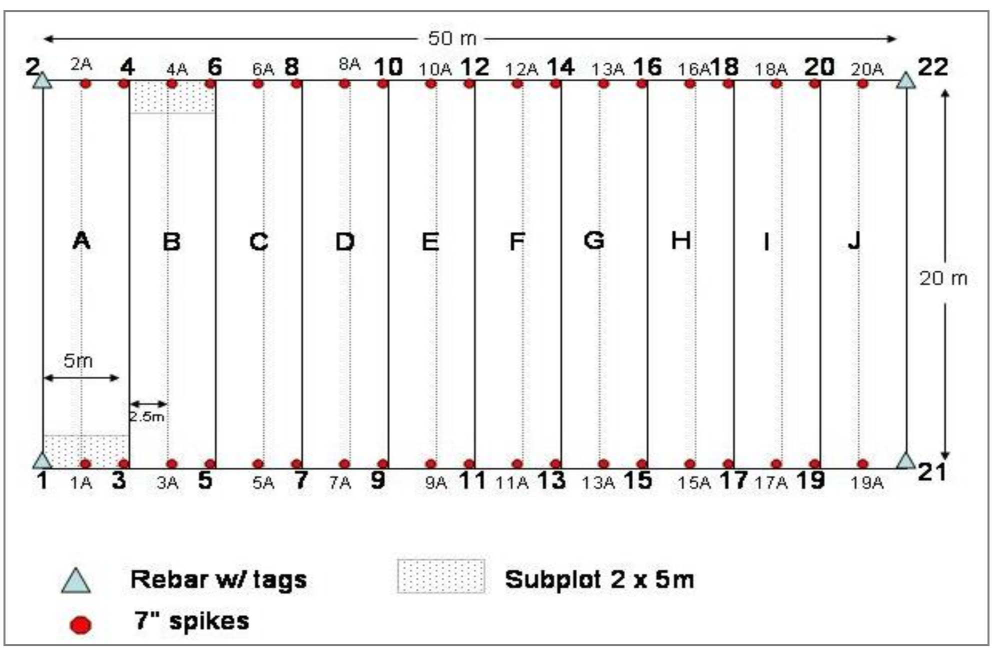

Figure 2. General plot layout

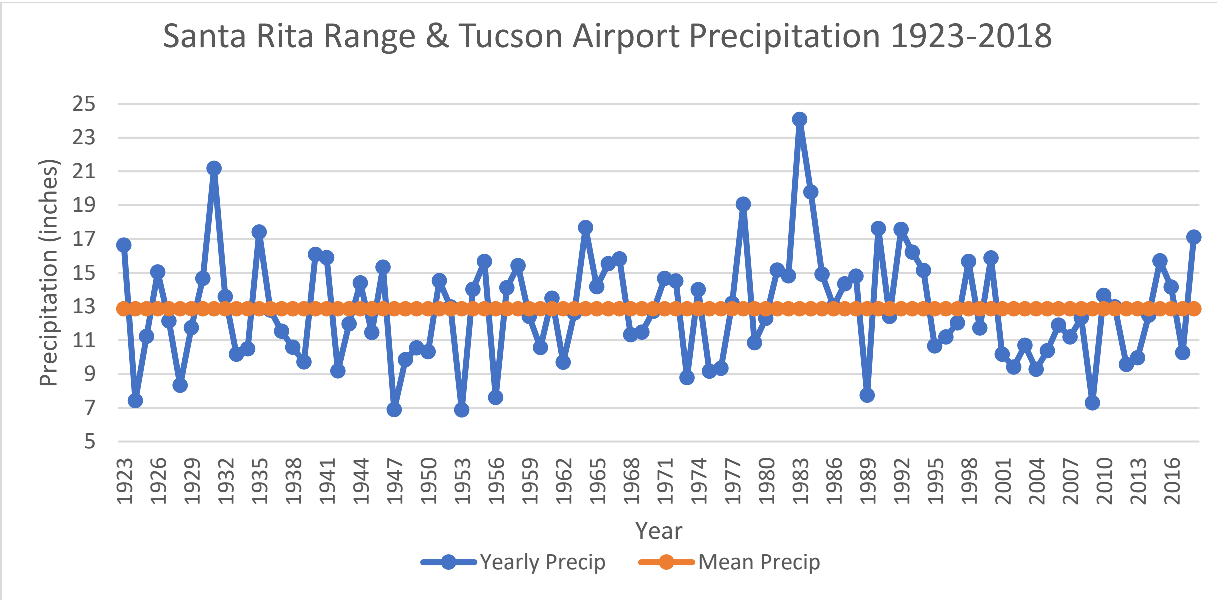

Figure 3. Combined yearly precipitation, Santa Rita Range and Tucson International Airport.

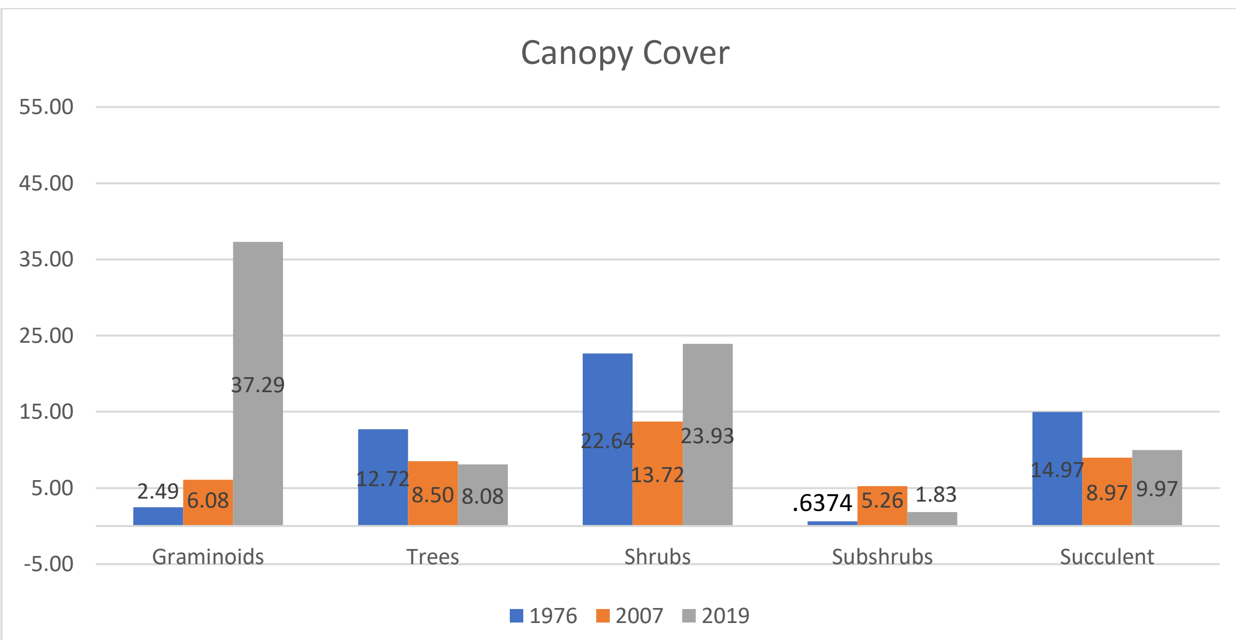

Figure 4. Canopy Cover for the five dominant vegetation guilds between treatment years.

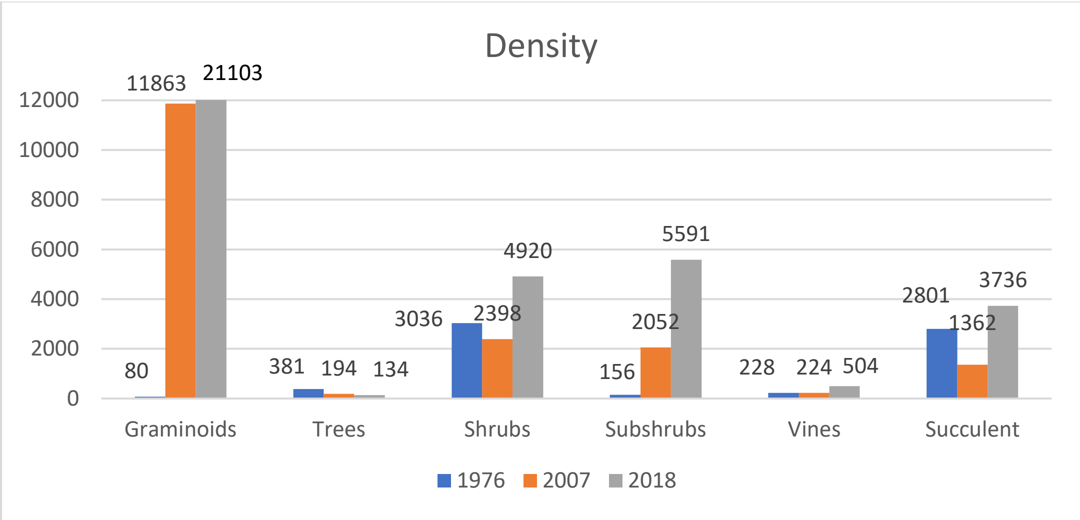

Figure 5. Comparison of density between guilds and treatment years.

Table 1. Individual Indicator Species Cover and Density

Species	1976 Cover (%) Meters	1976 Density (Total#)	2007 Cover (%) Meters	2007 Density (Total#)	2019 Cover (%) Meters	2019 Density (Total#)
Overall (Total)	54.09	2801	44.07	1362	89.16	3736
Ericameria laricifolia (turpentine)	11.16	1577	.79	127	.89	104
Encelia farinosa (brittlebush)	1.1	367	2.01	492	5.19	1384
Opuntia spp. (prickly pear)	2.83	600	4.49	625	4.84	1271
Cottsia gracilis (janusia)	.42	76	.95	185	1.88	498
Calliandra eriophylla (fairy duster)	.32	65	3.15	864	5.45	4642
Prosopis velutina (mesquite)	6.15	91	5.02	42	5.04	70
Bouteloua repens (slender grama)	.99	0	1.3	4562	7.09	5738
Eragrostis lehmanniana (Lehmann's lovegrass)	0	0	.32	1674	8.56	4579

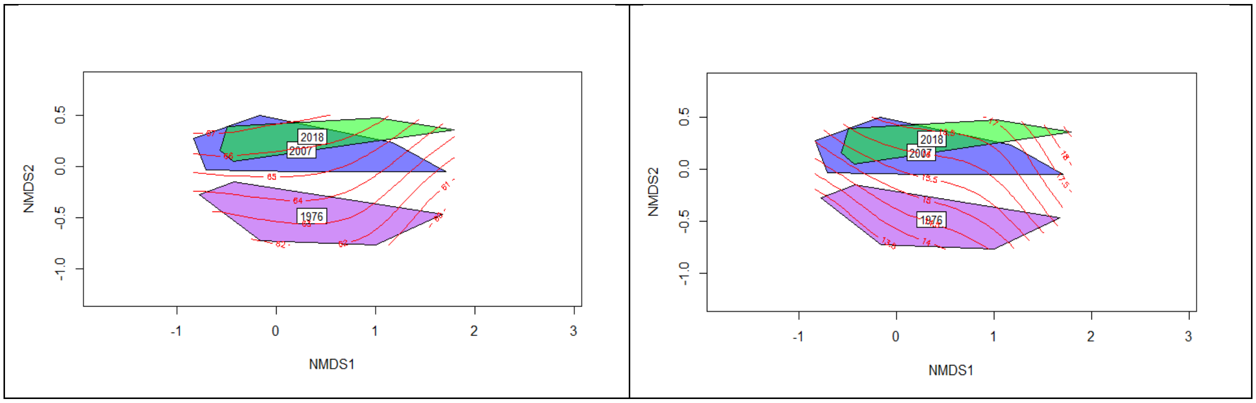

Figure 6. Temperature (left) and precipitation (right) during the three previous years to each survey in 1976, 2007, and 2018.

Figure 7. Graduate student (and now student employee) Ryan Summers appearing in educational video on this project created by film intern Marcos Vidal and shown in the park's Visitor Center Science Corner.