Long Term Effects of Cattle Grazing on Age Distribution

In a Population of *Carnegiea gigantea* in Saguaro National Park

by

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ABSTRACT

Livestock-grazing, in particular cattle grazing, is a common use of public and private lands in western North America. As a result, the effects of grazing on both plants and animals are widely studied. Few studies, however, look directly at the long-term effects that cattle grazing may have on a particular species. The goal of this experiment was to continue research begun in 1988, to determine if the effects of cattle grazing are still seen in the age structure of two populations of saguaros (*Carnegiea gigantea* [Engelm.] Britton & Rose) at Saguaro National Park - Rincon Mountain District (SNP-RMD). The null hypothesis stated that enough time has elapsed since the cessation of grazing, and there is no difference in the age distribution of the saguaros of the two populations.

The study area was comprised of a former fence line where grazing ceased on the western side of the fence in 1958 and the eastern side in 1978. Belt transects were laid on each side of the fence line and height was measured for each saguaro encountered in a transect. Approximate age of the individual was then calculated using an age-height correlation for SNP-RMD. Individuals were then placed into age classes of 10 year increments and a Log-Likelihood test was performed. The resulting calculated P value of 0.12 meant the null hypothesis was not rejected and there was no statistical difference between the age structure of the two populations.

After 34 and 54 years rest from grazing, the negative effects of cattle grazing on the retention and recruitment of saguaro seedlings have ended, and replenishment of the populations is now dependent upon factors such as temperature and precipitation. Other factors such as climate change, increasing fire frequency, encroachment by invasive species, and poaching are sources of concern and increased mortality for these and other saguaros.

DEDICATION

This thesis is for my family.

Without their support, completion of this project would not have been possible.

And for my grandmother and grandfather,

who always believed in furthering one’s education and in me.

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INTRODUCTION

Biology of the Saguaro

The saguaro cactus (*Carnegiea gigantea* [Engelm.] Britton & Rose), is an iconic species of the American Southwest and often used as a symbol of the Sonoran desert (USDA-NRCS 2013). The Sonoran Desert covers most of southern Arizona, parts of southwestern California, and extends into northern Mexico. The mean winter and summer temperatures for the Sonoran Desert are 13 °C and 30 °C respectively (55 to 86 °F), and precipitation averages 7.6 to 30.5 cm (3 to 12 inches) annually (Shelton 1972; Brown 1994).

Saguaros are a long lived species, easily living to be 150 years old or more (Pierson and Turner 1998). Individuals have been documented to grow to be as tall as 15 meters (50 ft) or more (Shelton 1972). Saguaros are usually found below elevations of 1 500 meters (5 000 ft), predominately located on southern and western exposures (USDA-NRCS 2013). They are usually found on rolling bajada habitat at the base of mountains, or on steep rocky slopes. Saguaros are not commonly found on flat valley floors throughout the Sonoran Desert (Steenbergh and Lowe 1977).

Regeneration and growth of the saguaro is dependent upon wetter conditions in the summer monsoon season (Steenbergh and Lowe 1977; Pierson and Turner 1998; Drezner 2005). Germination tends to follow cyclical patterns related to climatically favorable years, with increased numbers of saguaros regenerating in years with warmer fall temperatures and higher soil moisture; conditions usually associated with El Niño years (Drezner and Balling 2002). Once germinated, a saguaro seedling begins life usually under the protection of a nurse plant or in the protection of rock outcrops. These trees and shrubs and geological structures act to protect the saguaro in its early growth from sources of mortality such as freezing, predation by rodents or insects by concealing the seedling, and drought (Steenbergh and Lowe 1969; Shelton 1972; Steenbergh and Lowe 1977). Nurse plants serve to protect a saguaro seedling from freezing by trapping day time heat and reducing night time heat loss during the colder months, and protect from drought by shading the seedling to prevent excess water loss (Turner et al. 1966). Nurse plants species commonly associated with the saguaro are mesquite (*Prosopis* L. spp.), paloverde (*Parkinsonia* L. spp.), and bursage (*Ambrosia* L. spp.) (Drezner 2006; USDA-NRCS 2013). Saguaros can be dependent upon the nurse plant or rock outcrop for protection for as long as the first 30 to 40 years of their life (Hutto et al. 1986).

For the following discussion on saguaro growth patterns, Saguaro National Park Rincon Mountain District (SNP-RMD) is used as the baseline. Growth patterns of saguaros vary widely over their expansive range, and generalizations cannot be assumed across all habitat types and geographical areas. The saguaro's growth rate is slow at first, only reaching a height of approximately 7 cm (2.8 inches) in the first 10 years of life (Steenbergh and Lowe 1983). At 30 to 40 years, or 2 m in height, the cactus reaches sexual maturity and begins to produce flowers and fruits at the top of the stem (Steenbergh and Lowe 1977). During this stage, the growth rate increases rapidly, and then is maximized from approximately 40 to 60 years. The saguaros growth rate then slows again at 60 to 70 years, and instead of concentrating on growth of the main stem, the individual now concentrates on producing arms for increased reproductive potential (Steenbergh and Lowe 1983; Pierson and Turner 1998). This allows the saguaro increased surface area for flowers since each arm the saguaro produces can hold flowers atop it (Steenbergh and Lowe 1977).

As a key component of the Arizona Upland Subdivision of the Sonoran Desert, the saguaro plays many roles in its surrounding ecosystem (Shreve and Wiggins

1964). The saguaro stem provides nesting habitat for several species of birds and with its flower and fruits, it provides a food source for birds, bats, rodents, insects, and even humans (Steenbergh and Lowe 1969; Hutto et al. 1986; Olin et al. 1989). In addition to utilizing the saguaro as a food source, in the past Native Americans have used the ribs of the saguaro for construction of dwellings and as tools (Eppinga 2012; USDA-NRCS 2013).

Grazing History of Saguaro National Park – Rincon Mountain District

In 1854, the Gadsden Purchase was completed and Tucson and the surrounding area, including present day SNP-RMD, became part of the United States of America. Prior to this, the lands had been the property of the Mexican government and grazing had not been documented (Clemensen 1987). For two decades or so after the purchase had been completed the population of Tucson still remained close to the town due to frequent attacks by the Apache tribes in the area (Clemensen 1987). Then in the 1870s after a truce with the Apaches, settlers in the area began to move further away from town, and the first ranch was established in 1872 in the area adjacent to the boundaries of present day SNP-RMD. Homestead applications were made throughout the late 19th century and through the early 20th century. Settlers in the area grazed cattle on the land and grew cultivated crops such as fruit trees and grain. Crop lands were irrigated by diverting water from Tanque Verde Creek and other runoff, and from summer monsoon rains (Clemensen 1987).

At the beginning of the 1870s, there were approximately 1 800 cattle in Pima County. At that point in time, Pima County consisted of all land in Arizona south of the Gila River, except for a part of Yuma County (Clemensen 1987). By the late 1880s, there were an estimated 1 200 cattle grazing on what would become the northern part of SNP-RMD. Pamphlets were circulated in the 1870s extolling the virtues of the grazing lands of southern Arizona, and cattle grazing expanded rapidly in the area. Numbers of cattle dramatically increased on Arizona lands and a succession of droughts in the 1880s and 1890s brought large numbers of cattle mortality. Ranchers subsequently reduced cattle numbers, but the area was still over-grazed. By the 1930s, Arizona's semi-desert grasses were some of the most depleted rangelands in all of the western USA (Clemensen 1987).

With the creation of the United States Forest Service (USFS) at the turn of the 20th century, grazing allotments were created and grazing permits were assigned. This new system resulted in reductions of the number of livestock on western rangelands. The study site is located in what was formerly the Twin Hills grazing allotment, which in the 1920s had an allowed 50 animal per year grazing limit. In 1928, the Twin Hills allotment was transferred from the original rancher to James Converse (Clemensen 1987). James Converse also held the grazing permit for the adjacent Tanque Verde allotment. Since the same rancher was in control of both areas, there was little motivation to build a fence between the two allotments, as the rotation of grazing was not a commonly used technique at that point in time (Robin Lothrop Pinto, personal communication, March 2013). The Tanque Verde allotment had a 269 animal per year grazing limit in the 1920s (Clemensen 1987).

In 1933, Saguaro National Monument was established and transferred from the USFS to the National Park Service (NPS) (Clemensen 1987). However, the USFS still continued managing the grazing permits for the NPS. Cattle grazing continued on the monument's land, despite the fact that it was noted that the condition of the range was poor, with the cause believed to be overgrazing by livestock. The USFS began an experiment with Converse to further limit cattle on his allotments in 1939 by limiting the number of cattle on the land during certain months of the year. Range conditions were so poor that Converse chose to graze only a total of 25 cattle on his allotments year-round. Shortly thereafter, the USFS returned to a regular year-round grazing system with Converse (Clemensen 1987).

Range conditions throughout the area were still poor, and in 1941 the USFS instituted changes in permit conditions. Now each time a ranch changed ownership, the number of cattle permitted to graze on the lands was reduced, usually by 10 percent (Clemensen 1987). The land was still overgrazed, with much of the degradation occurring near watering locales and on the land that was more easily accessible to the cattle (Clemensen 1987).

By the 1950s, arrangements had been made between the NPS, the State of Arizona and the University of Arizona to place all acreage within the boundaries of the monument that was held by the state and the university into the monument's control. In exchange for the state and university land on the monument, the federal government gave each organization acreage elsewhere in Arizona (Clemensen 1987). An agreement was also made with Converse prior to transferring the grazing permit to Kenneth Kaecker, and as a result, all cattle grazing in the cactus forest area ended. When Converse sold his ranch to Kaecker in 1956, the Twin Hills allotment was absorbed into the Tanque Verde allotment (Eppinga 2012). The land trade agreement included the study area, at which point a fence was built and completed in 1958, separating the two sides of the study site and removing cattle from the eastern half of the study area (Saguaro National Park Land Ownership Map 1948). Continuing into the 1960s, areas of the monument that were still undergoing grazing were considered to be overgrazed and reductions in the number of cattle on the land was recommended (Clemensen 1987).

Finally in the 1970s, the USFS and the NPS ended their cooperative agreement in which the USFS managed the grazing permits for the NPS. The Park Service used the opportunity to end all cattle grazing on park lands. Kaecker, whose cattle still grazed on the western half of the study site, challenged the rule change and did not remove his cattle until May of 1978 (Clemensen 1987; Robin Lothrop Pinto, personal communication, March 2013). The last remaining feral cattle were removed from monument lands in the mid-1980s. Most of these cattle were located in the area of the former Rincon allotment, and so it would be unlikely that the eastern portion of the study site was heavily grazed during that time period (Clemensen 1987).

Saguaro National Monument became Saguaro National Park in 1994 through congressional legislation. This expanded the park's boundaries, and also shifted the focus of the park to the use of the people of the United States to enjoy the park's unique attributes (Eppinga 2012). A main focus in the park today is the preservation and conservation of the saguaro, and many research projects in the park are saguaro centric as a result (Ahnmark and Swann 2009; Nature and Science 2013).

Establishing Long-Term Research

The purpose of this experiment was to continue a research project originally conducted by Fareed Abou-Haidar in 1988. Abou-Haidar (1989) found that cattle grazing negatively affected saguaro seedling establishment. A decade after removal of grazing, a notable increase in the number of younger was observed. Abou-Haidar collected data 10 years after grazing ceased on the eastern half of the study site, which in relation to a saguaro's expected life span, is relatively short. Since saguaros are considered a long lived species, it is important to establish long term research to determine if changes in the population are merely part of larger cyclical patterns, or perhaps due to other, more direct causes, such as cattle grazing (Parker 1993; Ahnmark and Swann 2009).

Previous possible causes for diminished saguaro numbers in the study area could have included grazing on nurse plants, and thereby diminishing favorable habitat for seedlings, trampling of saguaro seedlings as cattle sought shelter or shade in the nurse trees and shrubs, increased erosion due to trampling from the cattle, and even submergence of a saguaro seedling in cattle feces (Abou-Haidar 1989; Parker 1993; Ahnmark and Swann 2009). Factors such as season of grazing, stocking rates, and duration of cattle grazing can also affect plant establishment (Fleischner 1994).

Historically the desert lands of Arizona have been extensively used for cattle grazing. Some grazing still continues to this day, and it is important to know long term effects on the ecosystem (Fleischner 1994). This can be important to the casual observer from an aesthetics point of view, to native peoples who may utilize the area from a cultural perspective, and from an ecosystem health/services perception. Since the saguaro is a long-lived species, climatic effects and effects of land management policies are not often seen until several years in the future (Parker 1993). Therefore, it is useful to establish data from past land management, to apply to future land management decisions.

This research project will help to serve land management agencies in determining management guidelines for areas containing saguaros that may be sensitive to cattle grazing. The study will also help serve to illustrate the long term effects on saguaro seedling establishment and survival in the presence of cattle grazing. This can be helpful when determining management strategies, such as eliminating access to areas or limiting duration or intensity (number of cattle) of grazing in specific areas. It can also be useful in implementing restoration techniques to facilitate recovery in areas that have already been impacted by cattle grazing. An example of this could include management actions that would increase nurse plant presence to encourage seedling establishment. Other studies needed include gaining knowledge on the dynamics of the relationships between saguaros and their surrounding environments.

Hypothesis, Problem, or Question

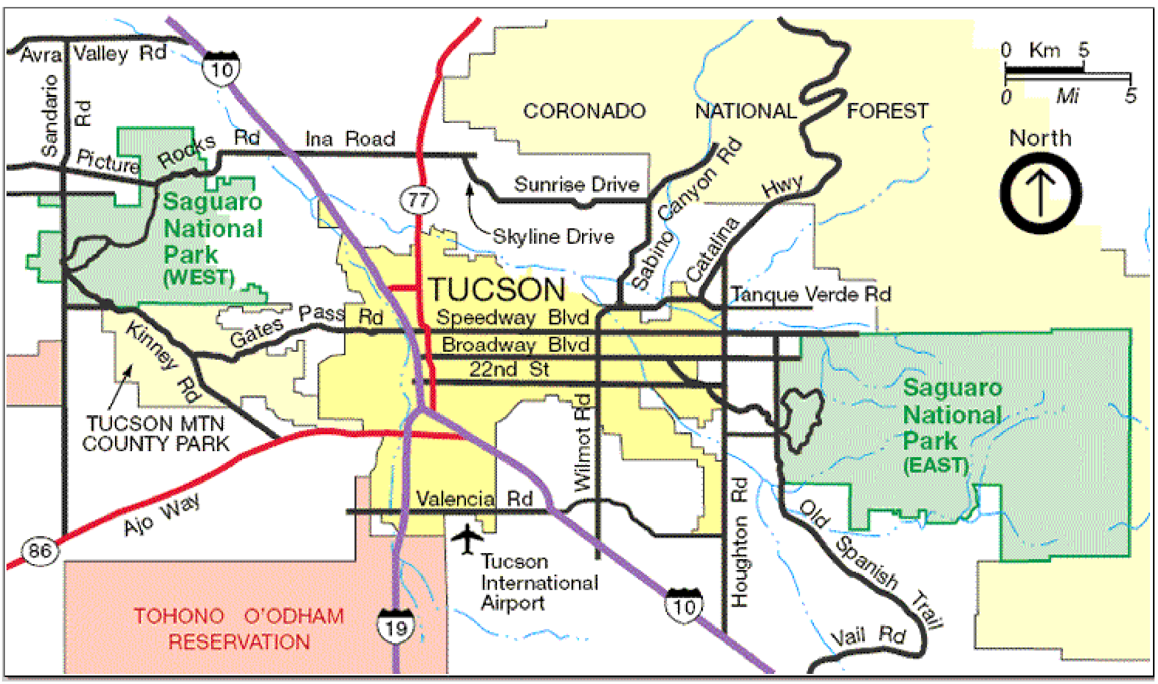
The goal of this research was to determine long term effects of cattle grazing on the age distribution of a population of saguaros in Saguaro National Park. In order to better understand long term effects of cattle grazing on saguaros, sampling of individuals and evaluation of their approximate ages was performed in the same manner as the previous investigator (Abou-Haidar 1989). Since Abou-Haidar did determine that there was a difference in the age composition between the two populations, the focus of this project was to determine if those differences found by Abou-Haidar were still apparent today. Thus, the null hypothesis states that no differences will be seen in the age structure of the two populations and cattle grazing is no longer affecting saguaro seedling recruitment and retention.

METHODS

Study Area

The study duplicated methods utilized by Abou-Haidar (1989) to determine age class distributions on the same population measured 24 years previously. The study site contained a total area of 0.88 ha located in Saguaro National Park Rincon Mountain District. Saguaro National Park Rincon Mountain District (also sometimes referred to as Saguaro National Park East) is located to the east of the Tucson metropolitan area in southern Arizona.

Figure 1. Map of greater Tucson area, with Saguaro National Park (SNP 2006).

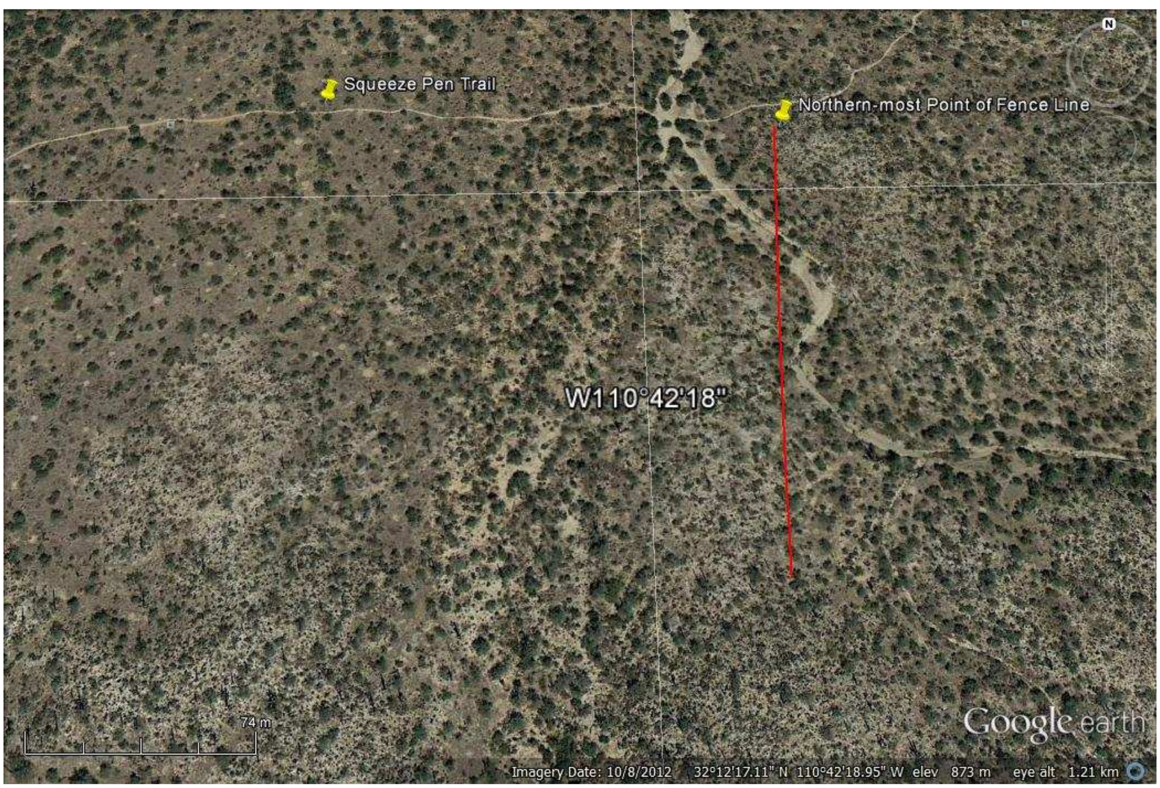


The study site was accessed by parking in the designated parking area at the Loma Verde Trailhead at the north-eastern corner of the Cactus Loop Drive. The site was accessed by hiking along the Loma Verde Trail for 0.32 km to the Squeeze Pen Trail. From there, the northern most portion of the study site is located just south of Squeeze Pen Trail, approximately 0.66 km from the junction with the Loma Verde

Trail. At this point, the trail begins to turn from an east/west orientation to a north/south path (see Appendix B for detailed hiking trail map of SNP-RMD).

At the time of Abou-Haidar's research, a fence ran in a north/south direction which marked the boundary of the western portion, in which grazing was halted in 1958, and the eastern portion, where grazing stopped in 1978 (Robin Lothrop Pinto, personal communication, March 2013). The fence has since been removed. The northern most portion of the original fence line site was located at lat 32°12'21.80"N, long 110°42'15.48"W, with the fence line running north/south at long 110°42'15.48"W. This site was specifically chosen because of the close proximity of the 1958 vs. 1978 sides, and a constant topography between the two sides which would indicate similar grazing utilization of the cattle (Abou-Haidar 1989).

Photograph 1. Aerial view of the study area. The red line depicts the fence line in the center of the study area.



The study area has vegetation typical of the Arizona Upland Subdivision of the Sonoran Desert (Brown 1994). Tree species located within the study area include foothills paloverde (*Parkinsonia microphylla* Torr.), mesquite (*Prosopis glandulosa* Torr. Var. *torreyana* [L.D. Benson] M.C. Johnst), and desert hackberry (*Celtis pallida* Torr.). Predominant shrub species of the study site include brittlebush (*Encelia farinosa* A. Gray ex Torr), catclaw (*Acacia greggii* A. Gray), species of *Lycium* L., and fairy duster (*Calliandra eriophylla* Benth.). Staghorn cholla (*Cylindropuntia versicolor* [Englem. ex J.M. Coult] F.M. Knuth) is the predominant cholla of the study area, with a small amount of teddybear cholla (*Cylindropuntia bigelovii* [Englem.] F.M. Knuth) present as well. Ocotillo (*Fouquieria splendens* Englem.) and barrel cacti (*Ferocactus cylindraceus* [Englem.] Orcutt) are also apparent throughout the site. There are a significant amount of grasses present on the study site as well. Arizona muhly (*Muhlenbergia arizonica* Scribn.), grama grasses (*Bouteloua* Lag.), buffelgrass (*Pennisetum ciliare* (L.) Link), and red brome (*Bromus rubens* L.) were the predominant species. Common Sonoran Desert species ironwood (*Olneya tesota* A. Gray), creosote (*Larrea tridentata* [DC.] Coville), jojoba (*Simmondsia chinensis* [Link] C.K. Schneid.) and blue paloverde (*Parkinsonia florida* [Benth. Ex A. Gray] S. Watson) were all conspicuously absent from the study site. All scientific nomenclature for plants found on the study site was sourced from the United States Department of Agriculture PLANTS Database (USDA-NRCS 2013).

The study area sits upon well drained soil, classified as a Cellar-Lehmans complex. In the Cellar soil, a Lithic Torriorthent, the first 25.4 cm (10 inches) are comprised of an extremely gravelly sandy clay loam, the remaining depths to 152.4 cm (60 inches) is comprised of bedrock. The Lehmans soil's, a Lithic Haplargid, first 12.7 cm (5 inches) is comprised of gravelly sandy clay loam and from 12.7-33 cm is clay. The remaining depth from 33 cm to 152.4 cm (60 inches) is comprised of bedrock (NRCS 2012). Elevation at the study site is approximately 870 meters (2879 ft). The topography of the site is gently rolling hills. To the west of the site, the landscape flattens out and to the east of the site the topography becomes much steeper as it leads into the Rincon Mountains. For these reasons, the study site was chosen to be narrow to ensure cattle usage across the site would have been comparatively uniform due to the consistent topography (Abou-Haidar 1989). Grazing utilization would have been heavier in the flat area and less intense in the more rocky terrain, and would not have provided two comparable data sets due to the different treatments of each area (Steenbergh and Lowe 1977; Clemensen 1987; Parker 1993). There is a wash running through the study area in a general east/west direction, but since it is distributed evenly between the two sides of the study area, it was determined the wash would not negatively impact the data set.

There is no 30 year climate data available for the park itself, but data is available from stations in the surrounding Tucson metropolitan area. The average annual temperature in Tucson is approximately 20.5 °C (68.7 °F), with summertime highs often exceeding 37.7 °C (100 °F) and winter lows usually averaging 4.4 °C (40 °F) (WRCC 2013). Freezing can and does occur with frequent occurrences in the area. There are 17 days with minimum temperatures below freezing for the Tucson area in a year on average (NOAA 2008). Annual precipitation averages 30 to 35.5 cm (12-14 inches) with two main rainy seasons (WRCC 2013). One rainy season is comprised of the summer Monsoons, which occurs July through September, in which 45% of the annual precipitation falls (ASU-SGS&UP 2013; WRCC 2013). The other rainy season occurs from December to March, with 37% of the yearly precipitation falling during this time (WRCC 2013). It is not uncommon for the months in between the rainy seasons to have very little or even no precipitation (WRCC 2013). Data for the 30 year averages ending in 2010 was sourced from WRCC's COOP stations

Tucson WBO #028820 (Fig. 1) and Tucson Magnetic Obsy #028800 (Fig. 2). The Tucson WBO station is located in the south-central Tucson metro area at an elevation of 780 m (2559 ft). The Tucson Magnetic Obsy is located on the north side of the Tucson metro area close to the Catalina Foothills and is at an elevation of 770 m (2526 ft). These two stations were chosen because of their proximity to the park, as well as the fact that they had complete 30 year climate data. Many of the stations located around Tucson did not have complete, or any, 30 year averages available.

Figure 2. Average annual temperatures and precipitation for Tucson WBO Station located near Davis Monthan Air Force Base, Arizona. (WRCC 2013)

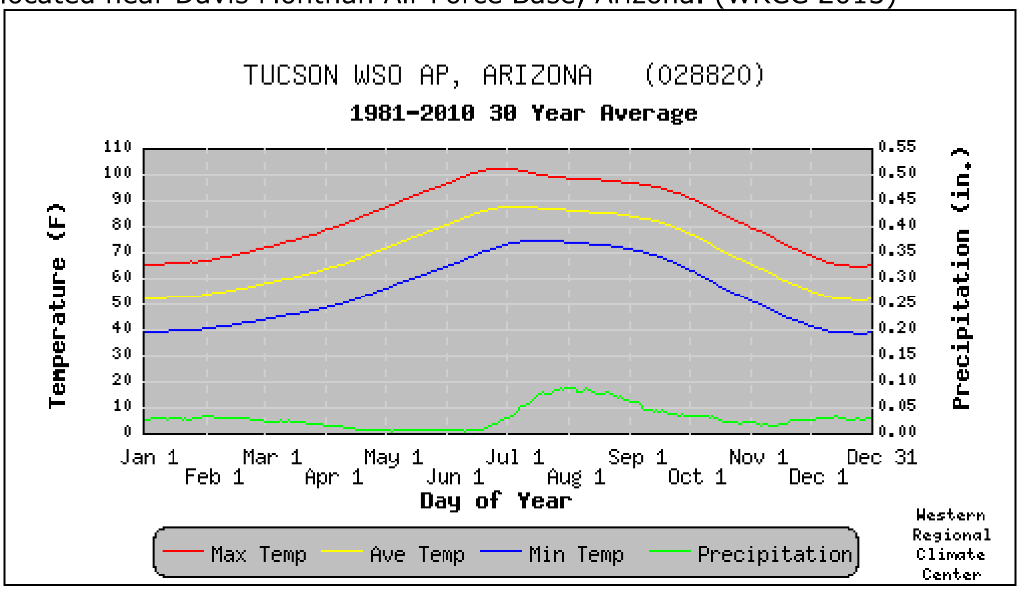
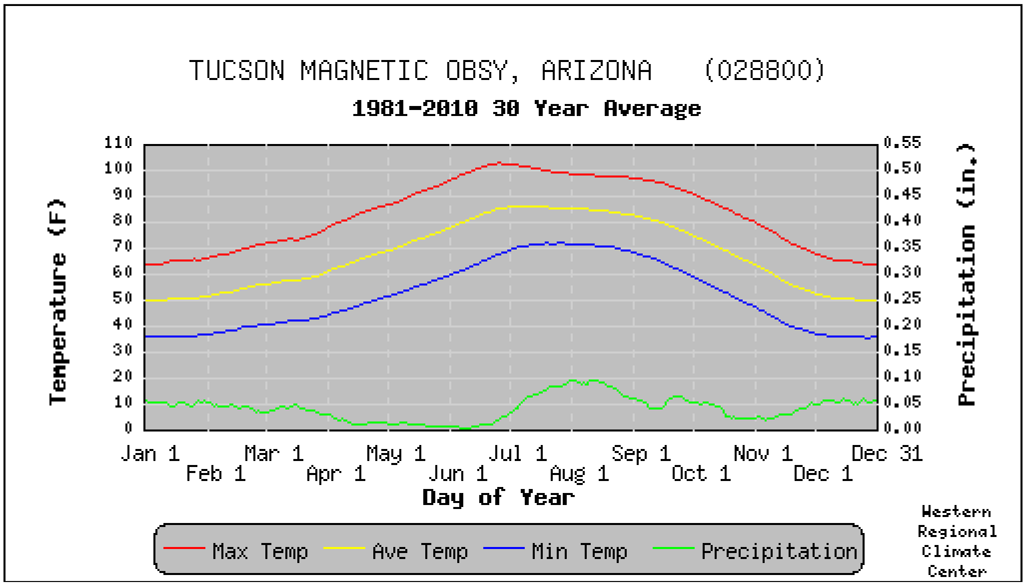


Figure 3. Average annual temperatures and precipitation for Tucson Magnetic Obsy station located in northern Tucson near the confluence of Tanque Verde and Sabino Creeks. (WRCC 2013)



Methods

As this was a continuation of research, the methods used in this study mimic those established by Abou-Haidar (1989). Abou-Haidar (1989) collected data during the summer of 1988, field work for this experiment was collected in March of 2012. Ten belt transects were laid parallel to the fence on both the eastern and western portions of the fence line for a total of 20 transects. The center line of the transect was laid in a straight line following the north/south orientation of the former fence. The lines were laid using a compass as well as visual sighting to ensure straightness and consisted of landscaping flags to mark the center of the belt transect. The center line of the transect was then walked to look for individual saguaros. Each of these transect belts was 220 meters in length, and 2 m wide, leaving 1 m in between the boundaries of each transect (Brower et al. 1998). To ensure adequate sample size, the length of the transect was determined by taking into account the natural spacing of saguaros over the landscape. The width was kept narrow to keep the sampling terrain homogenous so that the previous usage by cattle would not have varied over the study area (Brower et al. 1998).

An individual was classified as "in" the transect if it was more than half rooted within the transect belt. A measuring tape or stick was used to help determine rooting distance from the center line of the transect to center of the plant to determine if an individual was considered in the transect or not. While walking the transect in search of individuals, mature saguaros were obvious, as they were generally taller than the surrounding vegetation, and small seedlings and younger saguaros were sought in the cover of nurse plants by probing the canopies. The number of individuals was counted, and the height of each saguaro encountered was determined to calculate age. Height was measured by using a measuring tape, stick or rule for smaller individuals, or a clinometer for taller individuals (O'Brien et al. 2011). To keep the data collection methods in this study consistent and comparable to data in the Saguaro Census, when using the clinometers, the data collector stood 10 meters from the base of the saguaro. Heights taken with the clinometers were taken by two data collectors to help account for bias and errors (O'Brien et al. 2011). If there was a disagreement on the height of the saguaro, the collectors would re-measure until they obtained consistent measurements or if the difference was within 0.1 m, the two values were averaged and recorded. The height measurements included the spines of the plant rather than ending at the green fleshy part of the plant, and were taken at the main stem of the plant, not any of the arms. These steps helped to keep measurements consistent throughout the data collection, and also helped to keep the measurements taken in this study comparable to the Saguaro Census, which included the spines in the height measurement (O'Brien et al. 2011). There were no saguaros encountered in the study area with main stems that were shorter than the height of the arms.

Saguaros were flagged with a temporary piece of colored flagging, and numbered to prevent double sampling. Flags were placed on the north side of the cactus at about eye level (approximately 1.5 m or 5 ft), or if the cactus was significantly shorter than eye level, a flag was placed on the top of the cactus. All transects were walked twice to ensure all individuals had been counted and measured. Once a transect was completed and the transect directly parallel to it had been completely laid, flagging and the landscaping flags designating the transect were removed.

Once data collection was completed, approximate ages for the individuals needed to be determined. This was done using Steenbergh and Lowe's (1983) age/height correlation from table 2-10. Ages of the saguaros were divided into classes by 10 year increments. Data analysis was then performed to determine whether there was a significant difference between the age distributions of the two areas, and the results compared to those previously obtained by Abou-Haidar (1989). The Log Likelihood Ratio test (a form of Chi-Square analysis) was used to keep the data comparable as well (Abou-Haidar 1989; Zar 1999). All data analysis was performed in the computer program Microsoft Excel, 2007 edition.

RESULTS

In 2012, 26 saguaros were located in the transects on the western half of the study site, and 24 individuals were found on the eastern half. In 1988, 34 saguaros were located on the western half of the study site and 29 saguaros were located on the eastern half. All saguaros were measured from the height of the main stem, and no individuals that were measured had either broken stems or arms at a greater height than the main stem.

Table 2-10 from Steenbergh and Lowe's Ecology of the Saguaro (1983) was used to approximate the age of each individual (Appendix A). Since the study site was not located in rocky habitat, and was in the area of Steenbergh and Lowe's original measurements, it was determined that use of the original Steenbergh and Lowe table was acceptable, rather than having to use a formula with modified regression coefficients (Steenbergh and Lowe 1977; Drezner 2003).

Data collected from the two sides of the study site is depicted in Tables 1 and 2. The average age for the saguaros on the western portion was 42.13 years and the eastern portion had an average age of 41.23 years. Saguaros were placed into age classes of 10 years, as depicted in Table 3.

The results of the Log Likelihood analysis with all age classes included are located in Table 4. The age composition of the two populations was not considered statistically different, with the p value calculated at 0.12, much higher than the $p < 0.05$ value that would indicate that the populations came from two different age distributions.

Keeping in line with results from Abou-Haidar's study, to account for the 20 years difference in which one half of the study site was grazed while the other was not, all saguaros younger than 21 years of age were dropped from the sample size and the Likelihood Ratio analysis was ran a second time (Table 5). Again, results showed that the two populations are not considered statistically different in age composition with a *p* value of 0.30. The results of these analyses would suggest that the null hypothesis should not be rejected. Due to the limited sample size of older individuals, it was not possible to perform an analysis where all individuals younger than 54 years old were removed from the sample.

Table 1. Transects located on western portion (grazing stopped in 1958) of Saguaro National Park field site, with saguaro heights in meters (H) and ages in years (A).

Transect No.	Saguaro Individual No.				
	1	2	3	4	5
1W	H – 3.7 A – 50	H – 4.4 A – 50	H – 3.2 A – 46	H – 4.7 A – 57	H – 0.36 A – 18
2W	H – 0.98 A – 27	H – 6.7 A – 73	H – 0.9 A – 26	--	--
3W	H – 0.87 A – 26	--	--	--	--
4W	H – 4.7 A – 57	H – 4.7 A – 57	H – 1.2 A – 30	H – 0.41 A – 19	--
5W	H – 4.9 A – 52	--	--	--	--
6W	H – 0.34 A – 18	H – 3.1 A – 45	H – 1.17 A – 29	H – 6.1 A – 68	--
7W	H – 0.74 A – 24	H – 6.0 A – 67	--	--	--
8W	H – 4.7 A – 57	H – 0.7 A – 24	--	--	--
9W	H – 3.7 A – 50	H – 2.0 A – 36	--	--	--
10W	--	--	--	--	--

Table 2. Transects located on eastern portion (grazing stopped in 1978) of Saguaro National Park field site, with saguaro heights in meters (H) and ages in years (A).

Transect No.	Saguaro Individual No.				
	1	2	3	4	5
1E	H – 3.35 A – 47	H – 5.9 A – 66	H – 6.1 A – 68	H – 1.69 A – 34	--
2E	H – 4.45 A – 55	H – 2.2 A – 38	H – 5.5 A – 63	--	--
3E	H – 8.3 A – 88	H – 0.29 A – 17	H – 0.25 A – 16	H – 0.21 A – 15	H – 3.96 A – 51
4E	H – 4.48 A – 55	--	--	--	--
5E	H – 0.4 A – 19	--	--	--	--
6E	H – 0.46 A – 20	--	--	--	--
7E	H – 0.4 A – 19	H – 6.5 A – 71	--	--	--
8E	H – 0.87 A – 26	H – 3.47 A – 48	H – 0.43 A – 20	--	--
9E	H – 3.99 A – 52	H – 3.27 A – 46	H – 3.31 A – 47	--	--
10E	H – 2.9 A – 43	H – 1.0 A – 27	H – 0.49 A – 21	--	--

Table 3. No. of individuals per age class (10 year increments).

Age of Saguaro (Calendar Years Spanned)	No. Individuals Western Portion of Study Site	No. Individuals Eastern Portion of Study Site
0 – 10 (2012 – 2002)	0	0
11 – 20 (2001 – 1992)	3	7
21 – 30 (1991 – 1982)	7	3
31 – 40 (1981 – 1972)[1]	1	2
41 – 50 (1971 – 1962)	4	5
51 – 60 (1961 – 1952)[2]	6	4
61 – 70 (1951 – 1942)	2	3
71 – 80 (1941 – 1932)	1	1
81 – 90 (1931 – 1922)	0	1
91 – 100 (1921 – 1912)	0	0
100+ (prior to 1912)	0	0

[1]Period in which cattle grazing was discontinued on eastern portion of study site.
[2]Period in which cattle grazing was discontinued on western portion of study site.

Table 4. Chi Square test results for all age classes.

Age Class (in years)	East Actual	West Actual	West Expected	Chi Square Value
0 – 20[1]	7	3	3.2500	4.3269
21 – 30	3	7	7.5833	2.7701
31 – 40	2	1	1.0833	0.7756
41 – 50	5	4	4.3333	0.1026
51 – 60	4	6	6.5000	0.9615
61 – 70	3	2	2.1667	0.3205
71+[1]	2	1	1.0833	0.7756
Totals	26	24	26	10.0330
Chi Square Value ($P < 0.05$)				0.1233

[1]Age classes combined to prevent zeros in calculations.

Table 5. Chi Square test results with individuals < 21 years of age dropped from the sample.

Age Class (in years)	East Actual	West Actual	West Expected	Chi Square Value
21 – 30	3	7	6.3333	1.7544
31 – 40	2	1	0.9048	1.3258
41 – 50	5	4	3.6190	0.5269
51 – 60	4	6	5.4286	0.3759
61 – 70	3	2	1.8095	0.7832
71+[1]	2	1	0.9048	1.3258
Totals	19	21	19	6.0921
Chi Square Value ($P < 0.05$)				0.2974

[1]Age classes combined to prevent zeros in calculations.

DISCUSSION

Implications of Data Analysis

The results of data analysis suggest that the null hypothesis should not be rejected; now 34 and 54 years after the cessation of grazing on the two sides of the fence, the age structures of the populations are considered statistically the same. When the expected numbers of individuals in each age category for the western half of the study site (Tables 4 and 5) were examined, it showed that the expected and actual values were incredibly close in each of the age categories.

Average age for the eastern population was 41 years, and on the western portion, the average age was 42 years. At this point, the two populations are a year difference in their average ages. This becomes interesting when compared to the average ages of Abou-Haidar's data set. In 1988, the average age of the population on the eastern side of the fence was 53 years, and on the western half it was 35 years; a difference of 18 years in the average ages (Abou-Haidar 1989). A difference in average ages of one year, and of 18 years definitely indicates that something that happened to affect the population dynamics is no longer occurring.

At this point, the two populations structures have equaled out, but whether or not land managers would consider these populations to be healthy would be a matter of potential future research. Evaluation of the population's health may even perhaps simply be determined by the land manager's desired use for the land. It is interesting to note that the average ages of the current day populations is in the low 40s, where as in 1988 the eastern population which had only 10 years before been grazed had an average age of 53 years. A population with an average age of 41 or 42 would appear to be rather young, since the saguaro is known for its long life span. This could be due to a large influx of younger individuals into the area, something Abou-Haidar (1989) believed occurs after the removal of cattle, or could potentially lie in increased mortalities in older individuals. Abou-Haidar (1989) also encountered more older saguaros during his investigation. Eight saguaros over 60 years of age were counted in this study, but double that number were counted in 1988 by Abou-Haidar (1989). What the cause may be of this decrease in average age lies outside of the scope of this study, but may be a topic of further research interest to land managers. Possible causes of mortalities in older individuals could include normal cyclical patterns in the population, climate change, influences of invasive species, drought, poaching or other unknown influences (Shelton 1972; Pierson and Turner 1998; Hylton 2008; Ahnmark and Swann 2009). While other areas of the lower elevations of SNP-RMD have experienced fire in recent decades, the study site has not burned, and thus direct fire damage and mortalities can be ruled out as a cause for the decline in average age (Ahnmark and Swann 2009; Don Swann, personal communication, November 2011).

Effects of Cattle Grazing on Other Flora and Fauna

Today livestock grazing, primarily cattle, is one of the most widespread land use practices in the western U.S. and occurs in almost all ecosystem types (Fleischner 1994; Jones 2000). An ever present problem facing researchers today is the conflicting results obtained from grazing studies. Studies done at different sites in the same plant community can give conflicting results (Jones 2000; Drezner 2006). A possible reason why is due to the fact that it is difficult to find land that has truly never been grazed. Often times when grazing exclosures are created, they are done so on an area that had been previously grazed by cattle and are usually relatively small in comparison to the surrounding landscape (Fleischner 1994). This creates the challenge of being able to compare a truly non-grazed area to a grazed area. As a result, most livestock grazing studies examine the effects that the removal of cattle has on the landscape.

In Arizona, poor grazing practices have been shown to negatively impact many vegetation types. Grazing was shown to be a partial cause of transforming the ponderosa pine (*Pinus ponderosa* Lawson & C. Lawson) forest in Arizona from an open park-like canopy comprised of large ponderosa trees with a dense grass understory to one of little grass and many small trees (Fleischner 1994; USDA-NRCS 2013). Another example can be seen in microbiotic soil crusts are found in the deserts of Arizona. These crusts play essential roles in nutrient cycling in the ecosystem. Human activity has been shown to damage these crusts to the point where nutrient cycling is reduced by as much as 80 to 100%; it can easily be imagined that cattle would be no less destructive on the landscape (Fleischner 1994). Elsewhere in the western U.S., grazing has been shown to reduce native plants and encourage reproduction of alien invasive species (Kimball and Schiffman 2003).

Cattle grazing has affected not only plant but animal communities in western North America as well. Certain species of rodents have been found to be less tolerant of grazing than others (Jones and Longland 1999; Jones 2000). Lizard populations in central Arizona that have been exposed to heavy grazing had lower relative abundance and diversity when compared to the same habitat in a lightly grazed area (Jones 1981). Breeding birds can also be negatively impacted by cattle grazing, with the removal of cattle triggering an increase in the number of individuals in a species as well as the number of species overall (Taylor 1986; Krueper et al. 2003). All of these studies attributed the changes of the fauna in the area directly to changes in the flora caused by grazing practices.

The effects of grazing in arid regions can be controversial. Both negative and positive effects of grazing have been reported. Grazing can create habitat areas preferred by certain species, such as the creation of a more open habitat as preferred by kangaroo rats (*Dipodomys* spp.) (Jones and Longland 1999). Grazing by cattle also appeared to have minimal effect on annual plant species near watering locales in the Chihuahuan desert. Nash et al. (1999) expected to find a similar relationship to perennials; the most severe impact on perennials is close to water sources, and decreases with increasing distance from the watering site. Contrary to what was expected, grazing appeared to have minimal impact on annual plants near the watering sites. Removal of livestock caused a dramatic decline in the population of a rare native orchid (*Spiranthes delitescens* Sheviak) in Arizona (McClaran and Sundt 1992). It was even found that light grazing (defined as 25-35% use of key forage species) in the Chihuahuan Desert could be used to help improve the condition of the rangeland (Holechek et al. 2003).

The conflicting results from grazing studies It would likely be advisable to land managers to take into account their biotic system and its particularities, rather than simply importing management techniques from other ecological systems (Jones 2000).

Challenges in Continuing Long-Term Research

Long-term research can provide insights to trends that occur in populations which may not be captured in the breadth of a regular study (Pierson and Turner 1998). This is why long-term studies can be very useful to management agencies such as the National Park Service, who are managing the land to an indefinite end date. However, there are some inherent challenges that come with creating and maintaining long-term studies.

If an experiment was performed, and was not originally intended to become a long-term project, the original researcher may not document study site descriptions and locations in depth. The original researcher may not have quantified values such as canopy cover or ground cover, or descriptions of such attributes may be vague or even non-existent (Robin Lothrop Pinto, personal communication, March 2013). Parameters of the investigation may have not been made as clear as they should have been, and reasons for using specific sampling techniques may not have been identified either. All of these examples provide unique challenges to a new researcher who carries on the project when the original investigator is not available to clarify or provide input. Some of those challenges were encountered throughout this project.

When Abou-Haidar (1989) performed his data collection in 1988, the fence delineating the two sides of the study area was still intact, with no immediate plans for its removal. Therefore, there was probably no foreseen need to thoroughly document the exact position of the entire fence line. The fence was removed in the 1990s (exact date undocumented by the NPS), the result of which is aesthetically pleasing, but a difficulty for this study (Don Swann, personal communication, March 2013; Robin Lothrop Pinto, personal communication, March 2013). Since hand held Global Positioning System (GPS) devices were not widely in use at the time of Abou-Haidar's research, GPS locations of the exact fence location were not included in the manuscript. The fence location was not marked with GPS when the NPS removed the fence either. While topographic maps existed showing the fence's approximate location, it was simply that, approximate. The most concrete evidence of the fence's exact original location was from the photo accompanying Abou-Haidar's study, as seen in Photograph 2.

Photograph 2. Fence line through the study site in 1988, looking northward. The left-hand side of the fence is the western portion where cattle grazing was halted in 1958. The right side is the eastern portion where cattle grazing ceased in 1978. (Abou-Haidar 1989).

Using the silhouette of the Santa Catalina Mountains in the background, the topography of the ridge in the foreground, and by matching the placement of saguaros on the ridge, it was possible to match Photograph 2, to the modern day landscape, as shown in Photograph 3. The arrows in each of the photographs points to a now deceased saguaro on the ridge which was key to identifying the site due to its unique one arm anatomy. In the attempt to mimic the original photograph as closely as possible, Photograph 3 was taken behind the mature vegetation which was not present at the time of Abou-Haidar’s photo. Photos taken in front of the vegetation did not capture enough of the background landscape features or the two small arms of the saguaro in the left foreground, which I wished to capture in the photo as identifying features for any investigators who may wish to continue the project in the future.

Photograph 3. The 2012 view of the fence line location, looking northward. The arrow points to the dead and standing saguaro on the ridge, seen through the branches of the ocotillo in the foreground.

Once the original fence line was located, a few assumptions had to be made. One assumption was that the fence ran in a true north/south trajectory from that point. While the landscape is comprised of gently rolling hills, if an obstacle was encountered during construction of the fence, the fence builders may have deviated a small amount from that north/south trajectory for ease of fence completion. A second assumption was that I was in the same area where Abou-Haidar had completed his work. By referencing all his notes and other documentation, it would appear that the same general area was sampled both times. Since this area is close to the northern end of the fence line where the fence turned from north/south to east/west, going too far north would have put the sampling area back into lands where grazing ceased in 1958 (Saguaro National Park Land Ownership Map 1948). There was evidence found along what would have been the northern boundary of the fence running east/west that separated Sections 15 and 22. Barbed wire remnants were also located along the fence line that was determined by matching Photographs 2 and 3.

Photograph 4. Barbed wire remnants located along the assumed fence line, which would have separated Sections 21 and 22.

Not knowing the original fence line was a detriment because it introduced the possibility introducing a source of error by mixing the population samples. For example, if the original fence line had deviated further to the east to accommodate some building obstacle in a location, Abou-Haidar would have been able to still lay his transects so that they were completely parallel for the length of the fence. I, however, had to assume a straight north/south orientation, regardless of possible deviation, which could have placed some individuals that were originally on the eastern portion of the fence line into those counted on the western side, and vice versa.

Abou-Haidar only sampled a small portion of the land along the fence line constructed in 1958 that restricted cattle access from the western side of the park (USGS 1966; Abou-Haidar 1989). It is not stated why the study was not replicated at other locales along the fence line. By looking at topographic maps and visual inspection of the area, one can assume that the study area was not moved further south since the terrain becomes significantly rockier and with much steeper hillsides. Use of this terrain as sampling area would negate the use of Steenbergh and Lowe’s age-height table to approximate the age of the saguaros, and would have also likely been less heavily used by cattle (Steenbergh and Lowe 1977; Steenbergh and Lowe 1983; Clemensen 1987). The same does not appear to hold true for further north from the study area, but Abou-Haidar may have had unstated reasons for not selecting a study site further north as well. If future researchers encounter areas outside of SNP-RMD where they could repeat the investigation to see if cattle grazing negatively affects saguaro seedling recruitment, it would be recommended to establish more than one sampling area to ensure that the effects are seen across the region, rather than potentially being isolated to one small area.

Another area of ambiguity with the inquiry came in the discussion of canopy cover and density of nurse plant species. Abou-Haidar discusses very briefly the methods used to evaluate those variables, and states that there were no differences in density or average canopy cover of nurse plants between the two sides of the fence, but does not give any numerical values for any of his data (Abou-Haidar 1989). Without having any data to reference, that portion of his inquiry was unable to be replicated. Since saguaro regeneration and replacement is dependent upon nurse plants, having that information would have been beneficial to compare to today's values.

Historical range evaluations referred to bare ground, pedestaling of plants, and other signs of serious overgrazing, but the data was not often quantified (Clemensen 1987). Even though Abou-Haidar did not quantify his data, from the photographs of the study area, it is possible to draw some inferences. In Photograph 5, the spacing between the plants and the amount of bare-ground visible appears to be quite high. Especially notable was the lack of grasses present. Although Abou-Haidar collected his data during the hot summer months, annual grasses that germinated in previous seasons as well as perennial grasses would have still been present on the landscape (D'Antonio and Vitousek 1992). In comparison, the 2012 photograph of the same general area, as seen in Photograph 6, shows both a higher plant density, but also an abundance of grass cover, many of these grasses being native species. It is not known if the increase in grasses is due to the removal of cattle, or the difference is the result of differing precipitation amounts and temperatures in 1988 and 2012. This could be an area of future inquiry.

Photograph 5. A view looking northward on the western portion of the study area in 1988. Note the bare ground in the foreground of the photograph (Abou-Haidar 1989).

Photograph 6. Grass cover in March 2012 on western portion of study area, looking northward. Note the abundance of grass ground cover in the foreground of photograph in comparison to Photograph 5.

IMPLICATIONS

As an iconic species of Arizona, the saguaro cactus is protected by the Arizona Native Plants Law (SCDP 2006). However, the application of the Native Plants Law does not extend to protecting the saguaro or other native plants from destruction by ongoing activities such as livestock raising (Arizona State Legislature 2007). Many individuals and organizations throughout the state have an interest in the species stemming from activities such as tourism, wildlife management, cultivation and landscaping, or conservation and preservation. Some entities, such as SNP-RMD, may even have a combination of these factors to address in their management practices. Thus it is important to know the effect that anthropological activities have on the saguaro, including the effect of livestock grazing.

In these particular populations at 34 and 54 years after the cessation of cattle grazing, it appears that the negative effects of cattle grazing on the recruitment and retention of saguaro seedlings into the population are no longer present. There appears to be enough recovery in the vegetation that recruitment and retention are likely based on other factors such as temperatures, precipitation, and predation by rodents or insects. There is no difference in the age structures of the population, and thus the two populations can be treated and managed as one.

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APPENDIX A

AGE, HEIGHT AND GROWTH RATE OF SAGUAROS IN SAGUARO NATIONAL PARK EAST

Table 6. Age, aboveground stem height (cm), and subsequent 1-year apical growth rate (cm/yr) of saguaros in non-rocky habitats at Saguaro National Park – Rincon Mountain District. From Steenbergh and Lowe's Ecology of the Saguaro III (1983).

Age (yrs)	Height (cm)	Apical growth (cm/yr)
1	0.35	0.15
2	0.51	0.22
3	0.73	0.32
4	1.04	0.44
5	1.49	0.61
6	2.10	0.82
7	2.92	1.06
8	3.98	1.35
9	5.33	1.67
10	7.00	2.02
11	9.03	2.39
12	11.42	2.79
13	14.21	3.20
14	17.40	3.62
15	21.02	4.04
16	25.06	4.48
17	29.55	4.92
18	34.47	5.37
19	39.83	5.81
20	45.65	6.26
21	51.90	6.70
22	58.61	7.14
23	65.75	7.58
24	73.33	8.01
25	81.35	8.44
26	89.78	8.85
27	98.63	9.25

Table 6. Continued.

Age (yrs)	Height (cm)	Apical growth (cm/yr)
28	107.88	9.64
29	117.52	10.01
30	127.53	10.37
31	137.90	10.71
32	148.62	11.04
33	159.66	11.34
34	171.00	11.63
35	182.63	11.89
36	194.52	12.14
37	206.66	12.36
38	219.03	12.57
39	231.59	12.75
40	244.34	12.91
41	257.25	13.05
42	270.30	13.17
43	283.47	13.27
44	296.74	13.36
45	310.10	13.43
46	323.53	13.48
47	337.00	13.51
48	350.51	13.53
49	364.04	13.53
50	377.57	13.53
51	391.10	13.51
52	404.61	13.48
53	418.08	13.43
54	431.52	13.38
55	444.90	13.32

Table 6. Continued.

Age (yrs)	Height (cm)	Apical growth (cm/yr)
56	458.22	13.26
57	471.48	13.18
58	484.66	13.10
59	497.76	13.01
60	510.77	12.92
61	523.69	12.82
62	536.51	12.72
63	549.23	12.62
64	561.85	12.51
65	574.36	12.40
66	586.76	12.29
67	599.05	12.17
68	611.23	12.06
69	623.28	11.94
70	635.23	11.83
71	647.05	11.71
72	658.76	11.59
73	670.35	11.47
74	681.82	11.35
75	693.17	11.23
76	704.41	11.12
77	715.52	11.00
78	726.52	10.88
79	737.40	10.77
80	748.17	10.65
81	758.82	10.54
82	769.36	10.42
83	779.78	10.31

Table 6. Continued.

Age (yrs)	Height (cm)	Apical growth (cm/yr)
84	790.09	10.20
85	800.30	10.09
86	810.39	9.98
87	820.37	9.88
88	830.25	9.77
89	840.02	9.67
90	849.68	9.56
91	859.25	9.46
92	868.71	9.36
93	878.07	9.26
94	887.33	9.16
95	896.50	9.07
96	905.56	8.97
97	914.54	8.88
98	923.42	8.79
99	932.20	8.70
100	940.90	8.61
101	949.51	8.52
102	958.03	8.43
103	966.46	8.35
104	974.81	8.26
105	983.07	8.18
106	991.25	8.10
107	999.35	8.02
108	1,007.37	7.94
109	1,015.31	7.86
110	1,023.17	7.79
111	1,030.96	7.71

Table 6. Continued.

Age (yrs)	Height (cm)	Apical growth (cm/yr)
112	1,038.67	7.64
113	1,046.31	7.56
114	1,053.87	7.49
115	1,061.36	7.42
116	1,068.78	7.35
117	1,076.13	7.28
118	1,083.42	7.21
119	1,090.63	7.15
120	1,097.78	7.08
121	1,104.86	7.02
122	1,111.88	6.96
123	1,118.84	6.89
124	1,125.73	6.83
125	1,132.56	6.77
126	1,139.33	6.71
127	1,146.04	6.65
128	1,152.69	6.59
129	1,159.29	6.54
130	1,165.82	6.48
131	1,172.31	6.43
132	1,178.73	6.37
133	1,185.10	6.32
134	1,191.42	6.26
135	1,197.69	6.21
136	1,203.90	6.16
137	1,210.06	6.11
138	1,216.17	6.06
139	1,222.23	6.01

Table 6. Continued.

Age (yrs)	Height (cm)	Apical growth (cm/yr)
140	1,228.24	6.96
141	1,234.21	5.92
142	1,240.12	5.87
143	1,245.99	5.82
144	1,251.81	5.78
145	1,257.59	5.73
146	1,263.32	5.69
147	1,269.00	5.64
148	1,274.65	5.60
149	1,280.25	5.56
150	1,285.80	5.51
151	1,291.32 [1]	5.47
152	1,296.79	5.43
153	1,302.22	5.39
154	1,307.62	5.35
155	1,312.97	5.31
156	1,318.28	5.27
157	1,323.56	5.24
158	1,328.79	5.20
159	1,333.99	5.16
160	1,339.15	5.12
161	1,344.28	5.09
162	1,349.36	5.05
163	1,354.42	5.02
164	1,359.43	4.98
165	1,364.41	4.95
166	1,369.36	4.91
167	1,374.27	4.88

Table 6. Continued

Age (yrs)	Height (cm)	Apical growth (cm/yr)
168	1,379.15	4.85
169	1,384.00	4.81
170	1,388.81	4.78
171	1,393.60	4.75
172	1,398.35	4.72
173	1,403.06	4.69

[1] Growth data limit (ht 1,292.7 cm). Subsequent values by regression.

APPENDIX B

DETAILED HIKING TRAIL MAP OF SAGUARO NATIONAL PARK RINCON MOUNTAIN DISTRICT

Figure 4. Detailed hiking trail map of Saguaro National Park Rincon Mountain District (NPS 2013).