Preliminary Results of a Re-survey of Historic Plots Established in 1941 in Organ Pipe Cactus National Monument

Technical Report
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INTRODUCTION

The giant saguaro (*Carnegiea gigantea*) cactus is an iconic species of the Sonoran Desert that has interested researchers for more than 100 years. Permanent plots have been established throughout southern Arizona and northern Sonora, Mexico, in order to investigate the long-term growth and population dynamics of the species relative to its environment (Gill and Lightle 1942; Hastings and Alcorn 1961; Steenbergh and Lowe 1977; Duriscoe and Graban 1991; Orum et al. 1999; Pierson et al. 2013). In this report, we compare current growth rates and age-height structures with findings from a resurvey of five plots established in 1941 in Organ Pipe National Monument (ORPI). These plots were founded with the purpose of keeping detailed observations about saguaro and organ pipe cacti (Lightle 1942). The results of our work will provide insight into saguaro population dynamics.

In the 1940s, plant pathologists Lake S. Gill and Paul C. Lightle studied the cause of a black fluid, hypothesized to be bacterial necrosis, oozing from saguaros in Saguaro National Monument (now Saguaro National Park; SNP) and Organ Pipe National Monument. While the hypothesis was incorrect, the data from the Gill and Lightle plots showed an unbalanced, unsustainable population structure at SNP (Gill and Lightle 1942) whereas plots at ORPI showed "an abundance of young healthy plants" (Steenbergh and Lowe 1983). The ORPI plots were revisited annually from 1967 to 1977 by Warren Steenbergh and Charles Lowe in order to construct site-specific growth rate curves as part of the third volume of the Ecology of the Saguaro series (1983). ORPI Resource Management staff visited four of the five plots between 2005 and 2007 with the purpose of modernizing the dataset by collecting GPS coordinates for saguaros and plot markings. In February 2016, staff from SNP repeated the census of all five plots as part of the Centennial Saguaro Census with assistance from ORPI staff.

METHODS

Study Area

ORPI is located near the geographic center of the Sonoran Desert on the US-Mexican border. The area within the monument boundary encompasses a series of low-lying mountains that separate alluvial basins. Precipitation averages 9.6 inches (245 mm) and occurs in a bi-modal pattern dominated by winter storms and late summer monsoons. Temperatures average a high of 102 degrees (40 C) during the summer and drop to the high 60s during winter.

Four of the five plots are located in bajada habitats with flat topography and are split evenly between rocky and non-rocky sites. Two rocky plots are located on the southwestern side of the Ajo Mountains, and there are non-rocky plots in Alamo Canyon and along the old Sonoyta road (Fig. 1). The fifth plot, located near Monument Hill close to the international border, is situated low on the mountain slopes and contains numerous rock outcrops. All plots measure 3x3 chains, or 0.9 acres, in size and are marked with rebar benchmarks.

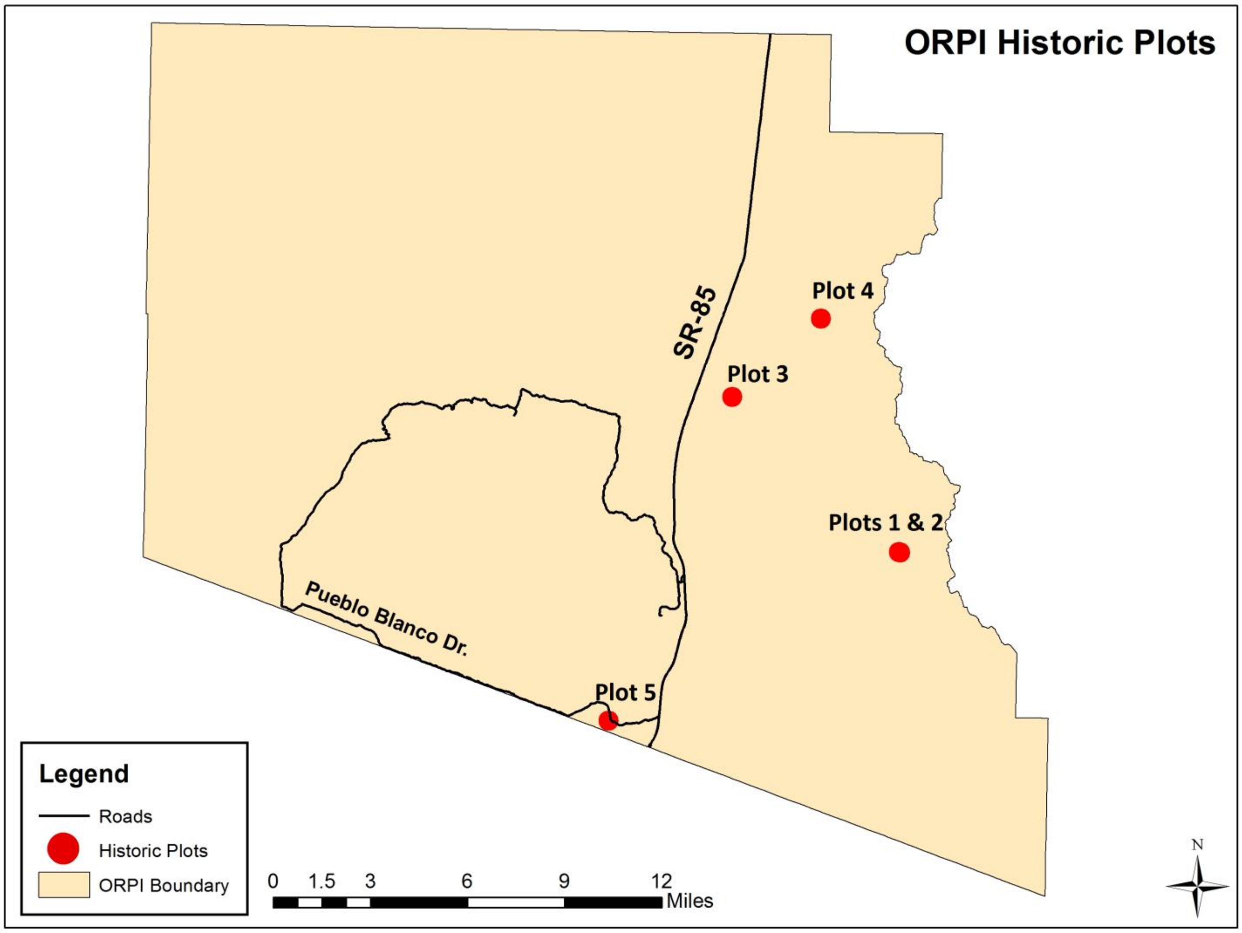

Figure 1 – Location of surveyed plots in Organ Pipe National Monument.

Field Methods

We followed a field protocol established Turner and Funicelli (2000) and modified by O'Brien et al. (2011) and Conver et al. (2013). This protocol is based on systematic surveying with GPS units. The crew separated into groups of three to four employees, lined up along the plot boundary, and walked three transects across the plot (Fig. 2). Data were collected during the first transect and measured cacti were marked with a pin flag. When groups completed the first transect, they turned around and walked the transect backwards to check that all cacti were surveyed. On the third pass, crews picked up the pin flags. Two designated employees floated among groups and were responsible for monitoring group progress and safety and facilitating efficient communication among groups.

All groups were equipped with Trimble GPS units, stadia rods, and folding rules to map and measure height of saguaros and organ pipes. We measured height below two meters to the nearest 0.01 m and height above two meters to the nearest 0.1 m. Crews recorded the GPS coordinates of all saguaros, organ pipes, rebar and benchmarks. We counted the number of arms and bird holes for saguaros, and the number of arms at four feet and total number of arms for organ pipes. In an addition, crews noted the species of nurse plant and assessed all cacti for frost, animal, insect, or physical damage.

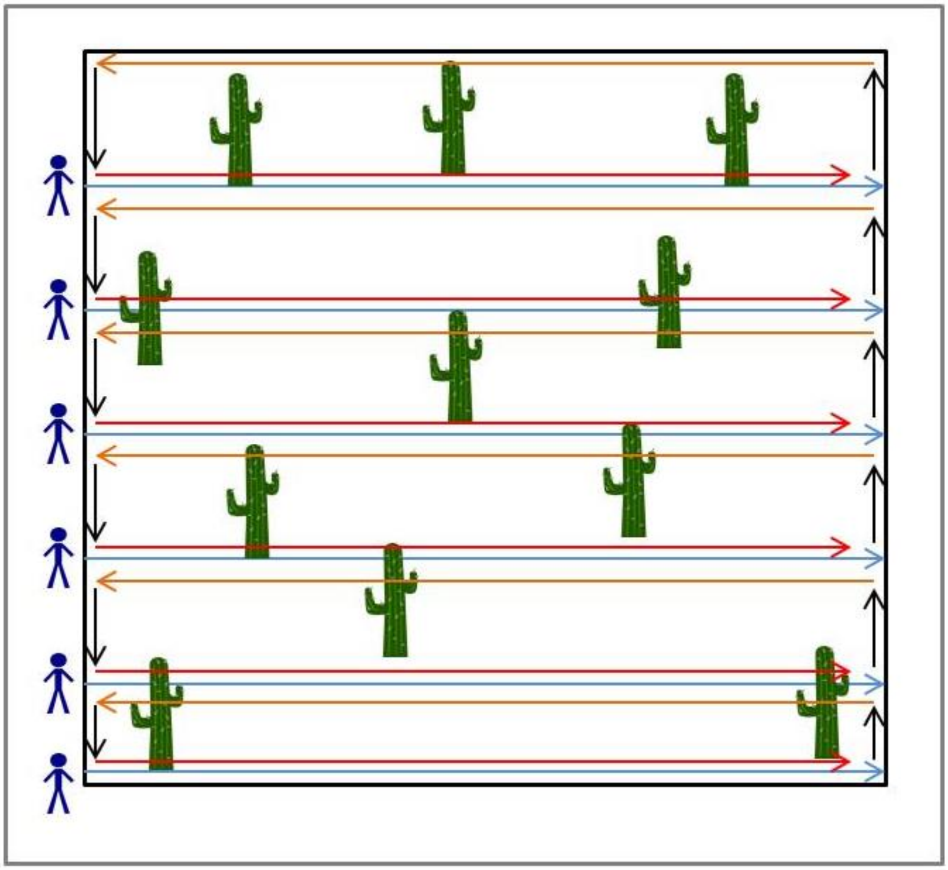

Figure 2 – Survey protocol schematic showing three passes through the plot. The blue arrow represents the first survey pass, the orange arrow marks the second pass to ensure all cacti were found and measured, and the red arrow indicates the third pass to collect pin flags.

Data Analysis Methods

We examined past saguaro regeneration in two ways. First, we used the ORPI-specific age-height curve from Steenbergh and Lowe (1983) to calculate the year of germination for all 195 surveyed saguaros. The earliest recorded height measurement was used to determine age. We summed the number of saguaros that germinated per year and divided by 4.5, resulting in established saguaros per acre per year. Second, we analyzed the change in the population height class structure over time on three plots. Saguaros were sorted into five bins based on height and age (Table 1). We found saguaros on all plots in 2016, but no saguaros were found on plots 1 and 2 in the 1941 and 1967 surveys, so we performed the age-height analysis on data from plots 3, 4, and 5. Our results for the 1941 survey differ slightly from those presented in Steenbergh and Lowe (1983) because the data from plot three are missing from the data record provided by ORPI staff.

Repeated measurements of height over time are useful to examine the rate of growth. We used the estimated age in 1941 for 57 saguaros that were measured in all three surveys as a baseline and compared measured height in 1967 and 2016 to predicted height using the Steenbergh and Lowe (1983) growth curve.

Height Class	Height (m)	Age Range
1	0-2.13	0-70
2	2.14-3.8	71-88
3	3.9-5.7	89-109
4	5.8 – 7.6	110-132
5	>7.6	>133

Table 1 – Height class definitions from Steenbergh and Lowe (1983) for the saguaro population structure. Saguaros reach reproductive maturity by the second height class and grow arms in the third height class.

RESULTS

Annual saguaro establishment rates ranged from zero to 4.44 plants per acre with a mean of 0.21. The rate exceeded one saguaro per acre during six years in the 19th century (1804, 1848, 1854, 1871, 1875, 1899; Fig. 3) and three years in the 20th century (1904, 1910, 1919). The establishment trends show two temporal windows where conditions favored the survival of seedlings; 1828 to 1855 and 1885 to 1921. Establishment rates have remained under one saguaro per acre for the past 100 years, but new saguaros consistently established throughout the 20th century.

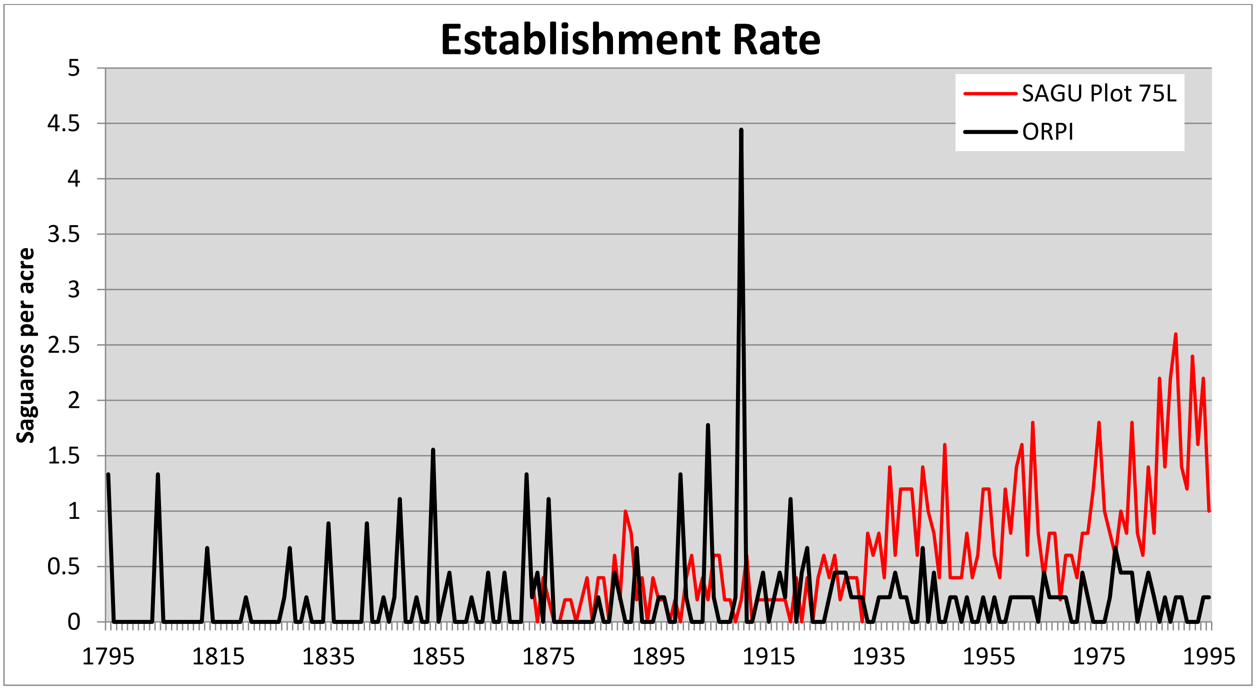

Figure 3 – Annual establishment rates per hectare for saguaro cacti on all ORPI plots and cacti surveyed in 2014 on SAGU plot 75L in the Tucson Mountain District. SAGU data were included for comparison and ranges from 1872 to 1995. The youngest saguaro measured at ORPI in 2016 dated to 1995 according to the age-height curve, while the oldest saguaro dated to 1714. We set our lower boundary for analysis at 1795 because we did not have adequate sample depth prior to that date.

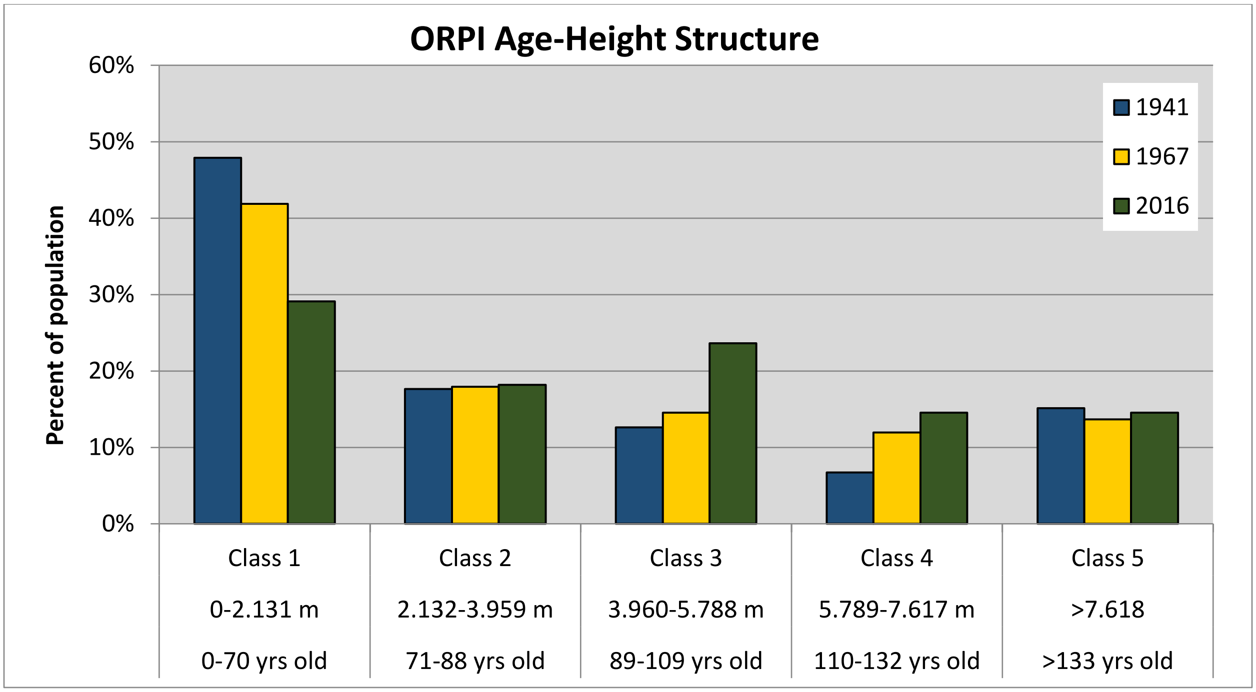

Figure 4- Age-height class structure for ORPI plots 3, 4, and 5 for the three survey years.

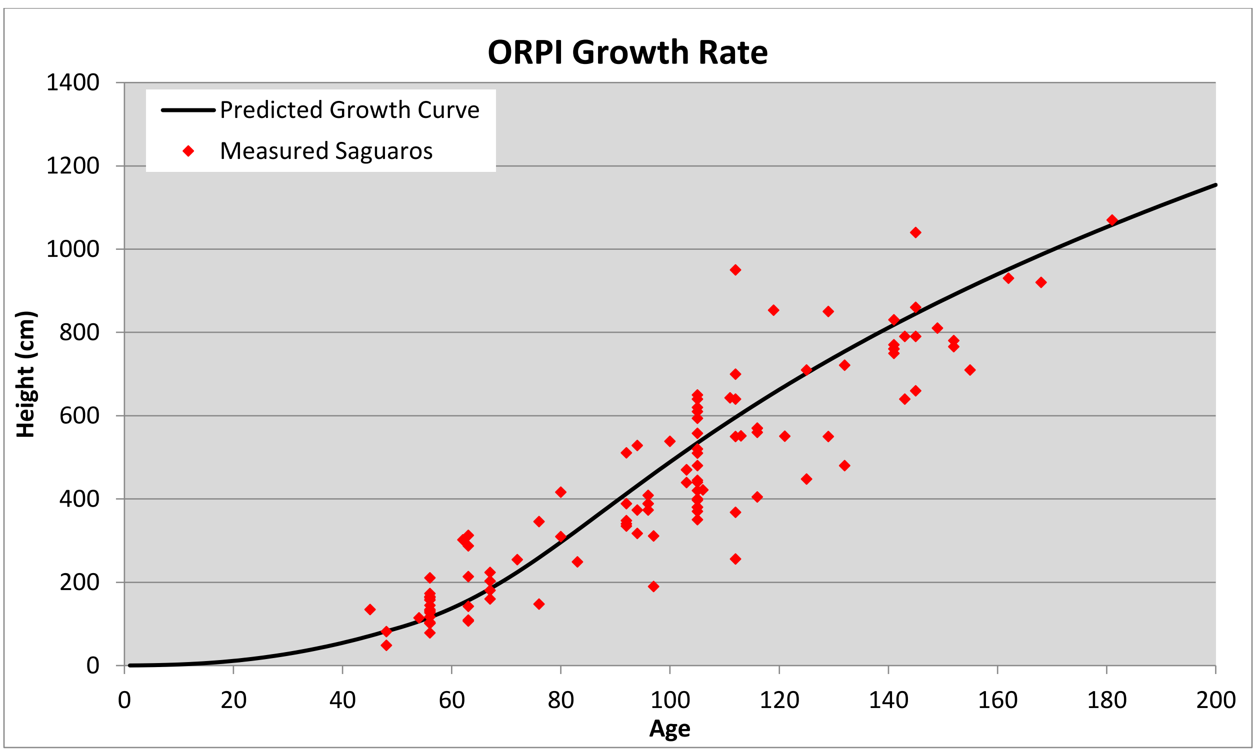

Figure 5 – Measured growth for 56 saguaros that were present on the plots in 1941, 1967, and 2016 with the age-height curve from Steenbergh and Lowe (1983). Points under the curve grew slower than expected and points above the curve grew faster than expected.

The distribution of the saguaro height class data (Fig. 4) showed a stable, mature population in 2016. 52.74% of the saguaros on the plots in 2016 were taller than 3.96 m. The percent of saguaros in the largest height class has remained stable over time, but the percent of saguaros in the third and fourth height classes have nearly doubled since 1941. This result is a change from the juvenile-dominated populations surveyed in 1941 and 1967, when 66% and 60% of the population was shorter than 3.96 m respectively. The shortest height class contained the highest percentage of the saguaro population in all three surveys.

The growth rate analysis (Fig. 5) showed that the majority of saguaro cacti grew slower than the growth rate curve predicted. The curve performed better for younger and shorter saguaros than for older and taller cacti. Saguaro heights ranged widely for age estimates, and the range increased with age. For example, we found a 7 meter difference between the min and max height for saguaros estimated to be 112 years old but a 1 meter difference at 56 years old.

DISCUSSION

The establishment rate results show that the saguaro population at ORPI experienced its last substantial recruitment episode in the 1910s. The recruitment windows of 1828 to 1855 and 1885 to 1910 are consistent with cool and wet periods of recruitment associated with ENSO variance as determined by regional climate reconstructions (Pierson et at. 2013). However, the regional episodic recruitment events in the late 1960s and the 1980s (Danzer and Drezner 2010; Pierson et al. 2013) apparently did not occur at ORPI. Despite this, the ORPI saguaro population seems able to maintain itself outside of favorable germination conditions for decades because the recruitment rate has been fairly constant, if low, since the 1910s. The age height class structure of cacti on plots 3, 4, and 5 indicates that nearly 30% of population is shorter than 2.13 m and younger than 70 years old, the largest percentage of any age height class.

The population is also well-situated for a recruitment event in the future; nearly 70% of cacti had reached the age of flowering and branching in 2016, the largest percentage of any survey year. Consequently, reproductive potential may be higher now than at any time in the last 100 years. A higher volume of seed is produced if more saguaros are capable of producing arms and fruit. While the current population structure is mature and developed, a future recruitment episode would result in an age height structure that resembles the 1941 result because of the germination of new individuals. Thus, natural climate cycles and the age height structure of the saguaro population have a positive feedback in the perpetuation of the species on the landscape.

The legacy of recruitment events can linger for decades as new recruits grow and graduate into the subsequent height classes. Not all of the saguaros that germinated in the 1910 recruitment pulse may have graduated into height class 2 when the 1967 survey was performed, essentially inflating the results for the 0-2.13 m height class in that year. The 2016 survey detected the 1910 event primarily in height class 3.

It is important to acknowledge that the saguaro population is always in flux due to the episodic nature and longevity of the species. The ORPI surveys represent snapshots in time. We detected recruitment windows at the decadal to multi-decadal temporal scale due to the time between surveys. Surveying the plots more often, once or twice a decade, would provide a valuable dataset for the analysis of the controls on population dynamics and growth.

The Steenbergh and Lowe (1983) curve fit the growth rate data well but overestimated growth after 90 years old. This is possibly due to the favorable cool and wet conditions that existed at the time the data were collected to create the growth curve (Munson et al. 2012). The variance of growth around the curve, while significant, is not unexpected and can be attributed to differences in aspect, slope, exposure, soil, and other factors occurring at the individual to cluster or sub-stand scale. The data also show two clusters of measurement points at 50 years of age (200 cm height) and 110 years old (400 cm height) that correspond with changes in the way that saguaros allocate energy between growth and reproduction during different growth forms and life stages. Saguaros reach the age at which they flower at the first cluster and develop arms at the second cluster (Steenbergh and Lowe 1977).

ORPI's climate is generally hotter and drier than other sites within the range of the saguaro, which results in a local climate regime that suppresses juvenile growth rate but promotes faster growth in mature plants (Steenbergh and Lowe 1977). Temperature is a primary limiting factor for the saguaro, and ORPI is virtually free from catastrophic freeze events that disproportionally affect juveniles. Freezing nights at ORPI have become less frequent over the last 50 years and have decreased from 20 to fewer than 10 freezing nights annually (Munson et al. 2012).

LITERATURE CITED

Conver, J., Weber, I.,Foley, T., Swann, D., MacEwen, B., Farjardo, E., Gamez, Y. 2013. The Saguaros of "Section 17" in Saguaro National Park: Re-survey of a One-Square-Mile Section First Surveyed in 1941. Unpublished report to Friends of Saguaro National Park.

Danzer, S. and T.D. Drezner. 2010. Demographics of More than 12,000 Individuals of a Keystone Species in the Northern Sonoran Desert since the Mid-1800s. International Journal of Plant Sciences, 171(5), pp.538-546.

Duriscoe, D. M., and S.L. Graban. 1991. Epidermal browning and population structure of giant saguaro cactus (*Carnegiea gigantea*) in Saguaro National Monument, Arizona. Eridanus Research Associates, California. Unpublished report to Saguaro National Park.

Gill, L.S., and P.C. Lightle. 1942. Cactus disease investigations: An outline of objectives, plans, and accomplishments on project j-2-8, Saguaro National Monument, Tucson, Arizona. In: W.F. Steenbergh and C.H. Lowe. 1983. Ecology of the saguaro: III. Scientific Monograph Series No. 17. US DOI, NPS, Washington.

Lightle, P.C. 1942. Progress report, Organ Pipe Cactus National Monument 1942. Official Report. In: In: W.F. Steenbergh and C.H. Lowe. 1983. Ecology of the saguaro: III. Scientific Monograph Series No. 17. US DOI, NPS, Washington.

Munson, S.M., R.H. Webb, J. Belnap, A.J. Hubbard, D.E. Swann, and S. Rutman. 2012. Forecasting climate change impacts to plant community composition in the Sonoran Desert region. *Global Change Biology*, *18*(3), pp.1083-1095.

O'Brien, K., D. E. Swann, and A. C. Springer. 2011. Results of the 2010 Saguaro Census, Saguaro National Park. Unpublished report to Friends of Saguaro National Park.

Orum, T. V., S. M. Alcorn, and N. Ferguson. 1999. Changes in the population of saguaros in the cactus forest of the Rincon Mountain District of Saguaro National Park since 1942. Second Conference on Research and Management in Southern Arizona National Park Areas: Extended abstracts. Eds. L. Benson and B. Gebow. NPS and USGS Sonoran Desert Field Station, University of Arizona, Tucson. 2 pp.

Pierson, E. A., R.M. Turner, and J.L. Betancourt. 2013. Regional demographic trends from long-term studies of saguaro (*Carnegiea gigantea*) across the northern Sonoran Desert. Journal of Arid Environments. 88: 57-69.

Steenbergh, W. F. and C. H. Lowe. 1977. Ecology of the saguaro: II. Reproduction, germination, establishment, growth, and survival of the young plant. National Park Service Scientific Monograph Series Number 8. US DOI, NPS, Washington.

Steenbergh, W. F., and C. H. Lowe. 1983. Ecology of the saguaro III: growth and demography. USDS, National Park Service Scientific Monograph Series No. 17. US DOI, NPS, Washington.

Turner, D. and C. Funicelli. 2000. Ten-year resurvey of epidermal browning and population structure of saguaro cactus (Carnegiea gigantea) in Saguaro National Park. United States Geological Survey Technical Report No. 69, Tucson, AZ. 30 p.