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Natural Resource Stewardship and Science

Climate Change and the Saguaro Cactus

Saguaro National Park

Natural Resource Report NPS/SAGU/NRR—2018/1583

ON THE COVER
Landscape view of saguaros in Saguaro National Park West (Tucson Mountain District).
Photography by NPS.

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Executive Summary

The iconic saguaro cactus in the desert Southwest is frequently evoked as a symbol of climate change, and Saguaro National Park (NP) has been rated as one of America's national parks most imperiled by climate change. Establishment of new saguaros at the park has been relatively low since the early 1990s, a period when temperatures in the Sonoran Desert began rising dramatically and the area entered a long-term drought. We explored the relationship between climate and saguaros through a large citizen science effort, the Centennial Saguaro Survey (CSS), and by resampling long-term saguaro monitoring plots, some of which date back to the 1940s. An important secondary goal was to communicate climate change and the status of the saguaro in the Sonoran Desert through social media, video, and outreach to a diversity of audiences ranging from underserved high school students to the scientific community and the general public.

During 2015 and 2016, more than 475 citizen scientists donated 3,000 hours working with student interns to collect data on 38 historic study plots established across a range of elevations in Saguaro NP. Citizen scientists measured approximately 10,000 individual saguaros during this study. We also initiated a long-term study on climate and saguaro growth rates at Saguaro NP and re-sampled historic saguaro plots at two other national parks, Organ Pipe Cactus National Monument (NM) and Tonto NM. In addition, we worked with academic partners to analyze data from the more than 75 years of saguaro monitoring to provide insight into how saguaros have responded to climate and other factors in the past. Additionally, we supported studies on climate and saguaro nurse trees and climate and saguaro flowering phenology.

The results confirm that although the population of saguaros in Saguaro NP is quite healthy, establishment of young saguaros has nearly ceased since the early 1990s in nearly all habitats. Of the nearly 10,000 saguaros surveyed, only 70 were less than 0.1 meters in height, or less than 11–15 years old. We found young saguaros almost exclusively in rocky foothill habitats, consistent with the relatively even-aged stand structure observed in these areas.

Establishment of saguaros in Saguaro NP in the past appears to be strongly influenced not only by human activities such as woodcutting and cattle grazing, but also by climatic factors. The effects of the current extended drought (>20 years) appears to be exacerbated by higher temperatures, which dry out soils and increase mortality of saguaros that are too small to store sufficient water. In rocky foothills, local microhabitat features such as slope, aspect, soil type, and features that affect the accumulation of water may slightly mitigate these factors. Results from Organ Pipe Cactus and Tonto national monuments suggest variation across the region, as Tonto NM has experienced regular establishment for the past few decades, while establishment at Organ Pipe Cactus NM has been more episodic. Evidence also suggests that saguaros survive for longer periods at Organ Pipe Cactus NM because of the relative absence of extended, extreme freezing events, whereas, a major freeze in 2011 killed saguaros at Tonto NM and Saguaro NP.

Our results will be broadly applicable to other desert areas for predicting how the saguaro and other long-lived desert species may respond to anticipated climate change. Contrary to some models, saguaro survival in a changing climate may not be influenced as strongly by elevation as by microhabitat features not necessarily associated with elevation, such as distribution and type of bedrock, which in turn influences local hydrology and vegetation. We suggest that future conservation and management strategies be based on evaluation of the relative value of different habitats for saguaro recruitment and survival.

We coupled this project with the 2016 National Park Service (NPS) Centennial and developed a large educational component related to saguaros and ecological change. From 2015–2016 we gave more than 15 interpretive talks to very diverse audiences, ranging from Junior Ranger Camps and University of Arizona classes to the NPS Centennial exhibition at the Philadelphia Flower Show. We produced more than 120 social media posts about this project on Facebook, Twitter, Snapchat, and Instagram. We received significant press coverage, with multiple stories about the project in the local Tucson newspaper, television and radio stations; major magazines including Arizona Highways and Edible Baja Arizona; and literally dozens of articles that appeared on news websites and

syndicated press. We produced or were involved in several high quality outreach videos related to saguaros, citizen science, and climate change that were displayed in the newly renovated visitor center. Finally, we sponsored the Tucson regional science fair awards for STEM projects related to saguaros, climate change, and the Sonoran Desert in 2015, 2016, and 2017.

To communicate science results, we wrote two scientific papers, one published in January 2017 and a second one that is currently in review. We gave several talks at science conferences and supported publication of 75 years of saguaro monitoring data at Saguaro NP through the NPS Data Store. In partnership with the College of Science at the University of Arizona, we created a major event in downtown Tucson that celebrated science and the saguaro, and we gave a Lifetime Science Achievement Award to long-time saguaro researcher Raymond Turner.

This high profile project played an important role in highlighting how climate change may be affecting Saguaro NP and other national parks, and also served to communicate the importance of science and long-term studies to help understand these changes. The project provided hands-on learning about saguaros and climate change to our many dedicated citizen scientist volunteers.

Acknowledgments

This project was funded by the NPS Climate Change Response Program and the Friends of Saguaro National Park. We greatly appreciate the support of Larry Perez and Melanie Wood from CCRP and Bob Newtson from the Friends. We received addition support from the Western National Parks Association.

We thank Saguaro NP past and current superintendents, Darla Sidles and Leah McGinnis, and many staff at the park, especially Scott Stonum, Dana Backer, Bella Furr, Andy Fisher, Nic Perkins, Kara O'Brien, Drew Jackson, Lauren Kramer, and Lauren Nichols. We appreciate scientific counsel from Tom Orum, Nancy Ferguson, Ray Turner, Mike Crimmins, Andy Hubbard, Sarah Studd, Dale Turner, Carianne Funicelli Murphy, Travis Huxman, Theresa Foley, Adam Springer, and many others.

We are grateful for the inspiration provided by Tom Orum, Nancy Ferguson, Ray Turner, Kimi Eiesle, Dan Bell, and Ron Bend, among others. And above all we thank the more than 475 volunteers who assisted with this project, especially the dozen or so "Centennial Saguaro Interns," especially Lorna Battista, Ami Beisley, Jordan Fowler, Violeta Keifer, Jessica Ladesma, Lia Ossanna, Jordan Patron, Sara Swiokla, and Casey White.

Introduction

Saguaro National Park (NP) was established (1933) and expanded (1995) to "preserve the exceptional growth thereon of various species of cacti and the prime Sonoran Desert habitat that the saguaro lives in" (US Presidential Proclamation #2032, 1933). The park foundation document (Saguaro NP 2014) states that the "purpose of Saguaro National Park is to preserve and protect saguaro cacti" and the park's diverse biotic community.

The saguaro cactus (*Carnegiea gigantea*; Figure 1) is a symbol of Arizona and the desert Southwest and an important component of both the local economy and the Sonoran Desert ecosystem. Saguaros are unique to southern Arizona, extreme eastern California, and Sonora, Mexico (Steenbergh and Lowe 1983). They provide nesting, roosting, or foraging habitat for more than 100 animals including the sensitive cactus ferruginous pygmy-owl and the endangered lesser long-nosed bat. (Drezner 2014). In addition to being the primary focus of Saguaro NP, the plant is also an important species in Organ Pipe Cactus and Tonto national monuments.

Figure 1. Saguaro cactus in bloom.

Climate change appears to threaten the saguaro directly through increased drought and increasing summer temperatures, and indirectly because warmer winter temperatures may promote the invasive buffelgrass. This invasive grass represents an extreme threat to the saguaro through potential competition and the ability to change fire regimes. Due to the integrated threat of climate change and invasive species, Saguaro NP was named one of the country's 25 most imperiled national parks in 2009 (Saunders et al. 2009). Results from monitoring indicate that saguaro establishment in the park's famous "Cactus Forest" area essentially stopped about 20 years ago (Orum et al. 2016; Conver et al. 2017), coinciding with increasing temperatures and aridity in the park and throughout the desert Southwest (Weiss and Overpeck 2005; Munson et al. 2012).

The relationship between the iconic and relatively long-lived saguaro cactus and climate has been the subject of intense study for more than a century. The pioneering Sonoran Desert ecologist, Forrest Shreve observed that saguaros disappeared along a gradient of increasing below-freezing hours during winter (Shreve 1911), and that winter low temperatures established the northern and upper elevational boundary of the cactus.

The main feature of the park in its early years was the Cactus Forest, a magnificent stand of giant saguaros that stands at the foothills of the Rincon Mountains (Figure 2). The death of many of these large saguaros in the 1930s and 1940s greatly alarmed park visitors and the NPS. In 1941, Saguaro NP (a national monument at the time) and Organ Pipe Cactus National Monument (NM) began an intensive research program to determine the cause. As the saguaro continued to decline, determining the ultimate caused proved to be difficult, and research continued for several decades (Gill and Lightle 1942; McAuliffe 1996; Ahnmark and Swann 2009). Although disease was originally implicated in the death of many saguaros, by the 1970s detailed and long-term ecological

Figure 2. The "Cactus Forest" at Saguaro National Park as it appeared in 1935. NPS, photographer unknown.

research by Warren Steenbergh and Charles Lowe at the two parks (Steenbergh and Lowe 1976, 1977, 1983) provided strong evidence that climate, and specifically winter freeze events, was the driving factor in the loss of saguaros in the Cactus Forest.

Beginning in the 1970s, establishment of young saguaros finally began to occur in large numbers in Saguaro NP, and establishment surged during a warm, wet period in the 1980s and 1990s (Pierson and Turner 1998; Turner and Funicelli 2001; O'Brien et al. 2011; Conver et al. 2013). Most scientists now believe that the long decline of the saguaro in the park was the result of climate in combination with other factors such as cattle grazing and wood-cutting that nearly eliminated nurse plants from the Cactus Forest area prior to the park's establishment (McAuliffe 1996). The new generation of saguaros grew up following the protection afforded by the NPS, which led to the recovery of nurse trees that protect saguaros from extreme and cold.

However, the period of high establishment that peaked in the early 1990s slowed later in the decade as southern Arizona entered a prolonged drought with exceptionally high temperatures (Weiss and Overpeck 2005). Saguaros require extended wetter, cooler periods for the seedlings to survive the critical first two years (Drezner 2006), and these conditions have not occurred in more than 22 years. It seems possible that warmer winter temperatures may have encouraged the growth of buffelgrass, which has moved rapidly into saguaro habitat in the past 20 years. Saguaros and most other Sonoran Desert plants are not fire-adapted, and large numbers have been killed in recent desert fires in the park that have been fueled by invasive plants (Esque et al. 2004).

We began this project in hopes of exploring the complex and evolving relationship between climate and the saguaro in the northern Sonoran Desert. Our approach was to leverage data from more than 70 years of saguaro research at Saguaro NP, Organ

Pipe Cactus NM, and Tonto NM. Historic records included data from the 1970s that explicitly relate saguaros and climate data on temperature and precipitation (Steenbergh and Lowe 1977, 1983), as well as the peer-reviewed study design for the park's Saguaro Census (previously conducted in 1990, 2000 and 2010) and re-surveys of historic (non-random) study plots that were established in 1941 at Saguaro NP and Organ Pipe Cactus NM.

Our major goal was to develop a deeper understanding of the role of climate in recruitment, growth, and survival of saguaros in different areas of the park and other areas of the Sonoran Desert. A secondary goal, though no less important, was to raise awareness of saguaros, climate, and ecological change through Citizen Science, environmental engagement, and social media. This project (PEPC #58495) was approved by the Saguaro National Park Interdisciplinary Team in May 2015.

Saguaros and Climate Study

Study Sites

Most of the activities described in this report occurred in Saguaro NP located near Tucson, Arizona (Figure 3). The park is divided into two districts: the Tucson Mountain District (TMD) borders the west side of Tucson, while the Rincon Mountain District (RMD) is located on the east side of the city. The Tucson Mountain District comprises approximately 9,000 ha of dry desert mountain range, with elevations ranging from 670–1,429 m. RMD comprises approximately 27,233 ha of a more mesic mountain range, with elevations from 814–2,641 m. Saguaros occur throughout TMD and up to approximately 1,524 m in RMD.

We also surveyed established plots at Tonto NM and Organ Pipe Cactus NM. Tonto NM is located in east-central Arizona (Figure 3) near Roosevelt Lake. This small cultural site (453 ha) is on the northern edge of the range of the saguaro, and elevation spans 700 m to 1200 m. Organ Pipe Cactus NM is in southwestern Arizona, on the US-Mexico border, and ranges in elevation from 305–1465 m. It is the largest national park unit in the Sonoran Desert at 133,830 ha.

The four national park units (including both districts of Saguaro NP) vary considerably in the amount and timing of precipitation. Average annual precipitation is 24.3 cm in Organ Pipe Cactus NM (Schmidt et al. 2007), 26.1 cm in TMD (Steenbergh and Lowe 1983), 31.2 cm in the lower elevations of RMD (Steenbergh and Lowe 1983) and 40.6 cm in Tonto NM (Albrecht et al. 2007). Summer rains account for approximately 50% of annual rainfall at Organ Pipe Cactus NM, 43% at Saguaro NP, and 50% at Tonto NM.

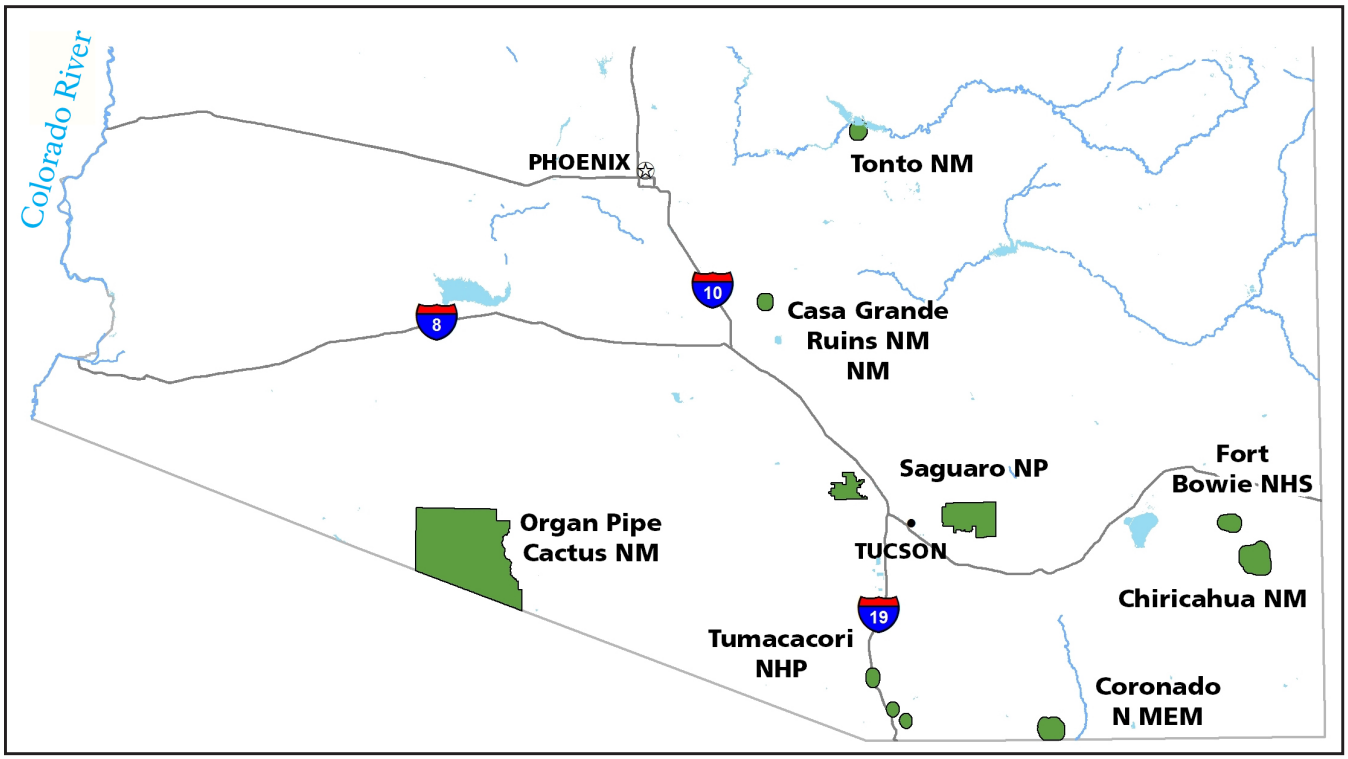

Figure 3. Map of southern Arizona, showing location of national park units in southern Arizona. Organ Pipe Cactus National Monument, Saguaro National Park, and Tonto National Monument were surveyed in this study.

Methods

Field Methods: Demographics and Establishment.

At Saguaro NP, we resurveyed 38 plots (25 at RMD and 13 at TMD; Figures 4 and 5) based on a random stratified sampling of 237 existing plots (212 at RMD and 25 at TMD; Appendix A) established during previous projects (Steenbergh and Lowe 1983; Duriscoe and Graban 1992; Springer et al. 2015). Plots from the Steenbergh and Lowe (1983) study were not randomly located; the authors placed plots in "representative habitats." However, the plots that were established in the Duriscoe and Graban (1992) and Springer et al. (2015) studies were randomly located. We classified all existing plots into three slope classes (0–10%, 11–25%, >25%), five aspect classes (N, E, S, W, and flat), and three elevation classes (TMD: 2000–2400 ft, 2401–3000 ft, >3000 ft; RMD: 2500–4000 ft, 4001-4800 ft, >4800 ft). We prioritized the selection of north/south aspects over east/west aspects because the north/south contrast is more influential in determining seedling survival (Steenbergh and Lowe 1977). Due to our focus on citizen science, plots that we deemed too difficult or dangerous for the average hiker were rejected and another plot was drawn at random from the same set of criteria.

Our "Next Gen" intern, Carolyn Harper, recruited and organized groups, with a focus on high school and college groups, of citizen scientists for this project. In the field, groups of four or five citizen scientists were led by an experienced volunteer intern from the University of Arizona and/or a NPS employee. Groups worked in a pre-defined plot boundary, delineated by flagging, in swaths approximately 10–20 meters apart (Figure 6). Each group counted and measured each saguaro encountered. in their plot. When a saguaro was found, it was flagged

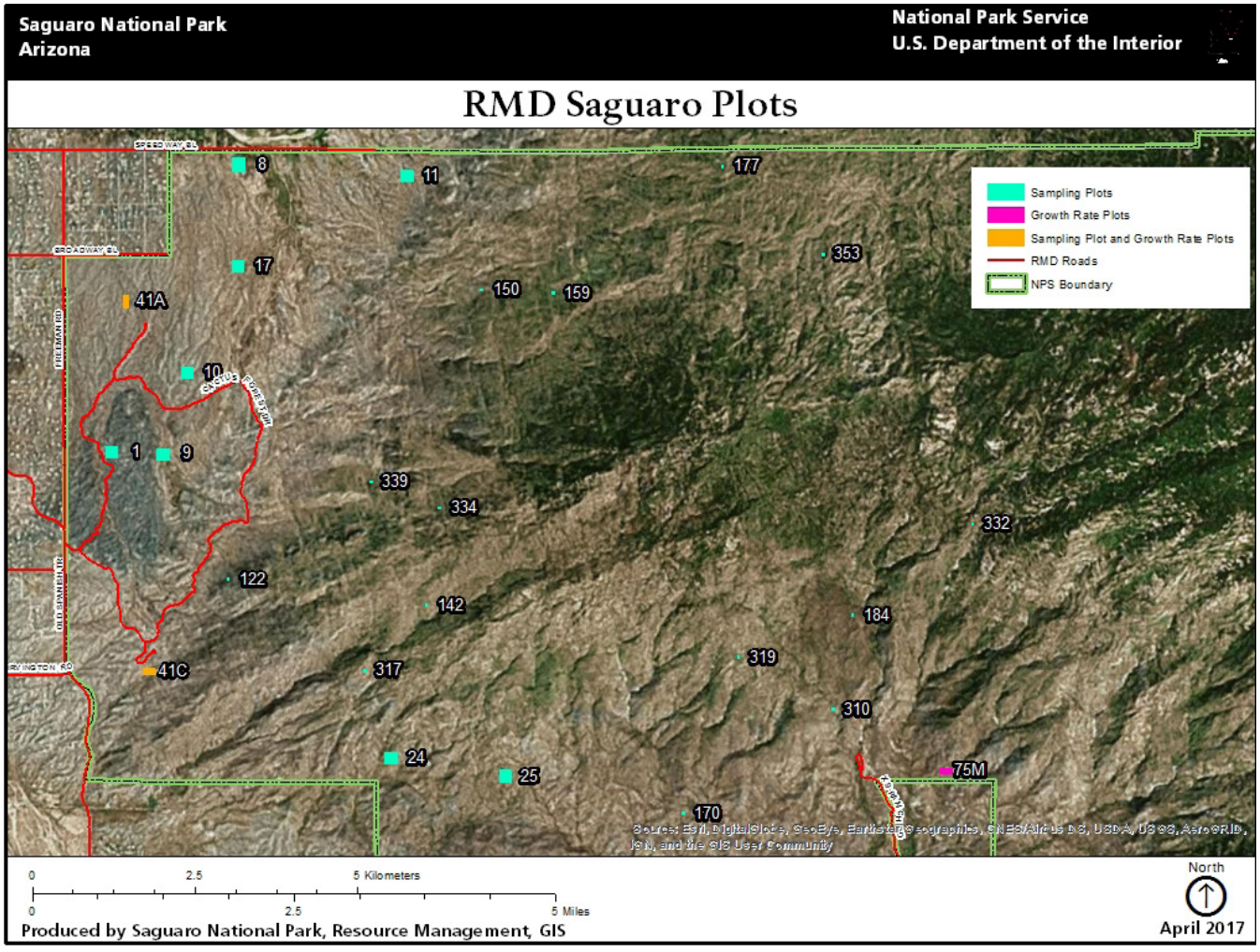

Figure 4. Map of Saguaro National Park East (Rincon Mountain District) showing study plots.

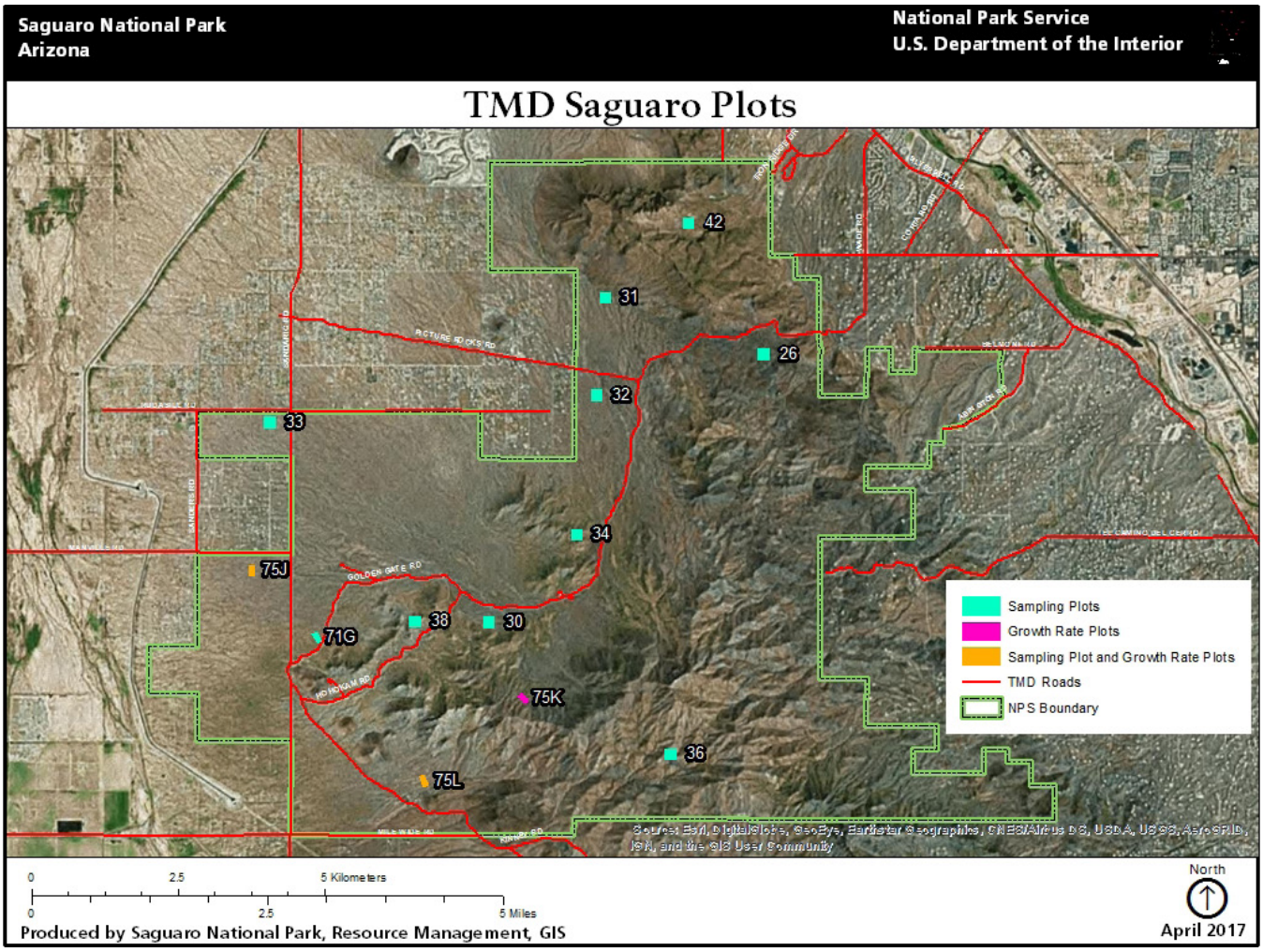

Figure 5. Study plots at Saguaro National Park, Tucson Mountain District.

with a numbered pin flag, measured using a 2-m wooden folding rule or estimated using a measuring tape and clinometer if the saguaro was greater than 4 m tall (Figure 7). Heights were recorded in meters to the top of the spines. The groups counted bird holes and stems, and recorded damage such as missing tops.

After the first survey pass, the groups changed survey lines and returned for a second pass while looking for any saguaros that were missed during the first pass. New saguaros were flagged and measured as before. After the second survey pass, volunteers completed one more pass to pick up the pin flags and plot flagging. Data were entered into an Excel spreadsheet immediately after the field day by a park biotech or intern and was then checked by a second person and uploaded to the Saguaro National Park website so that the groups could see their results in comparison to previous surveys.

At Tonto NM and Organ Pipe Cactus NM, we used an identical survey methodology as described above. The same group of researchers that established plots at Saguaro National Park in 1941 established them at Organ Pipe Cactus NM, and Steenbergh and Lowe (1977) also revisited these plots in the 1970s. As at Saguaro NP, the plots at Organ Pipe Cactus NM (five in total; Figure 8) have been periodically revisited and re-used for different research projects but had not been systematically surveyed in many decades; we resampled all five in their totality. A number of previous studies on saguaros have also been conducted at Tonto NM (Swann 2016), but only one study (Campbell et al. 2011) was done in a systematic way. Due to time and budget constraints, we sampled plot 15 only. This plot is located on a slope between the Visitor Center and Lower Cliff Dwellings and data date back to 1967. We re-sampled this plot and compared results from previous studies in 1967 and 1990.

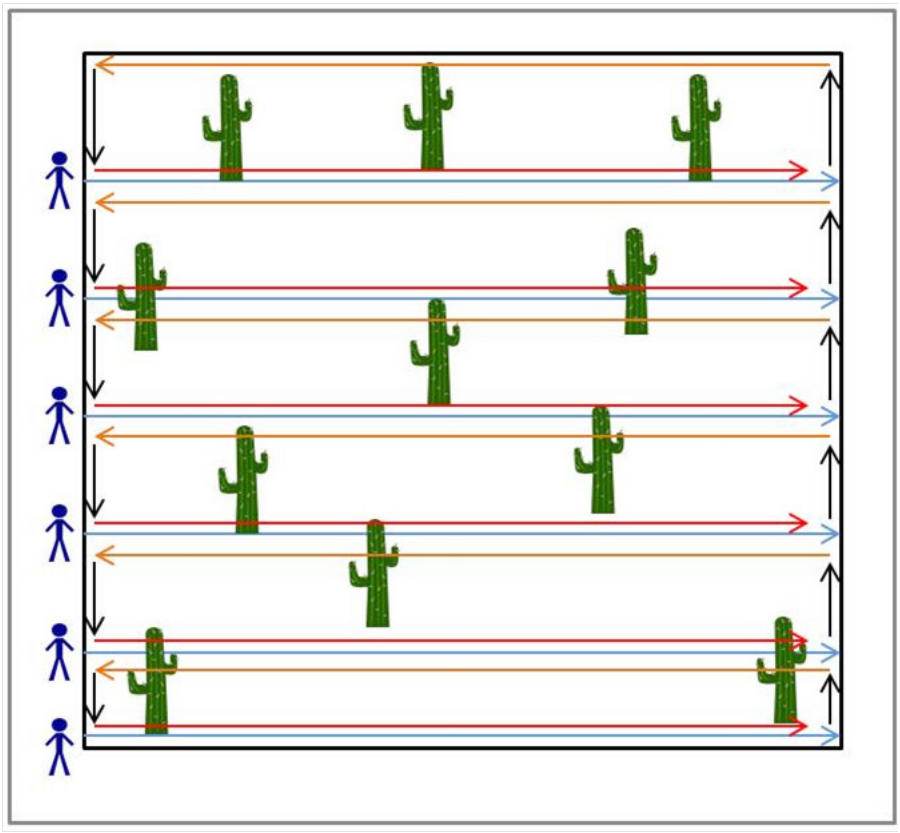

Figure 6. Approach to sampling study plots. Citizen scientists proceeded in teams with a trained leader across the plot, sampling and flagging saguaros. After one pass, the teams switched and checked for any saguaros not detected. On the third pass the flags were removed.

Figure 7. Typical team sampling saguaros. Citizen scientists measured height using a folding rule or a clinometer. One student recorded the data, another searched for small saguaros, and one recorded the location using GPS.

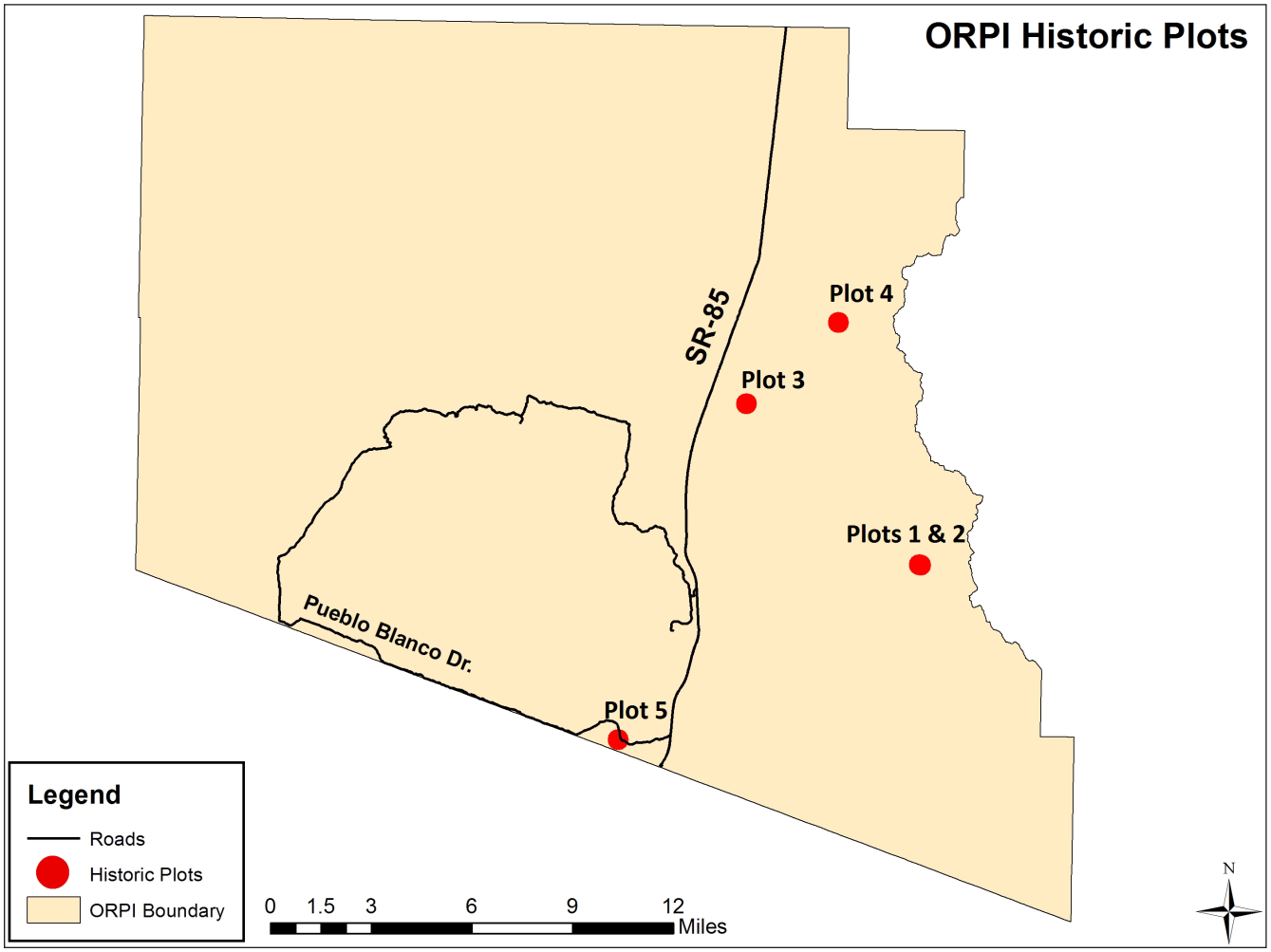

Figure 8. Location of plots surveyed at Organ Pipe Cactus National Monument.

Analysis

All data recorded by hand onto paper data sheets were entered into Excel by a trained intern. For quality assurance and control, all digital data were then checked against original data sheets by a second trained intern, and GPS locations of saguaros were checked by a third technician in ArcGIS. Because the probability of detecting small saguaros in the field ranges from close to 0% at year 1 to 80% at year 20, we used the equation of Orum et al. (2016), based on detectability of known saguaros at Saguaro NP, to adjust abundance of young saguaros based on imperfect detectability. In practice, this had little effect on the data because of the small number of very young saguaros.

We summarized data for each plot with data from previous surveys to create tables of changes in numbers of saguaros and their ages over time. Because plots varied in size (many high elevation plots at Saguaro NP were 0.25 ha while other plots were 4 ha), we converted these totals to number of saguaros/ha. For long-term demographic analysis, we created categories or "bins" based on 1-m size classes (e.g., 0–0.99 m, 1.00–1.99 m, etc) as well as 1.83-m classes to match the classes used in some historic studies at other parks (Gill and Lightle 1942). We established the age of each saguaro based on available growth models for the two districts of Saguaro NP and Organ Pipe Cactus NM (Steenbergh and Lowe 1983). For Tonto we used the Saguaro NP Rincon Mountain District model to calculate establishment year because we determined, based on growth rates of individuals measured in 2010 and 2016, that the rates were nearly identical (Figure 9).

To view demographic changes over time (more than 100 years), we created plot-specific and habitat specific charts of estimated establishment years at Saguaro NP, and NPS park-specific charts for the

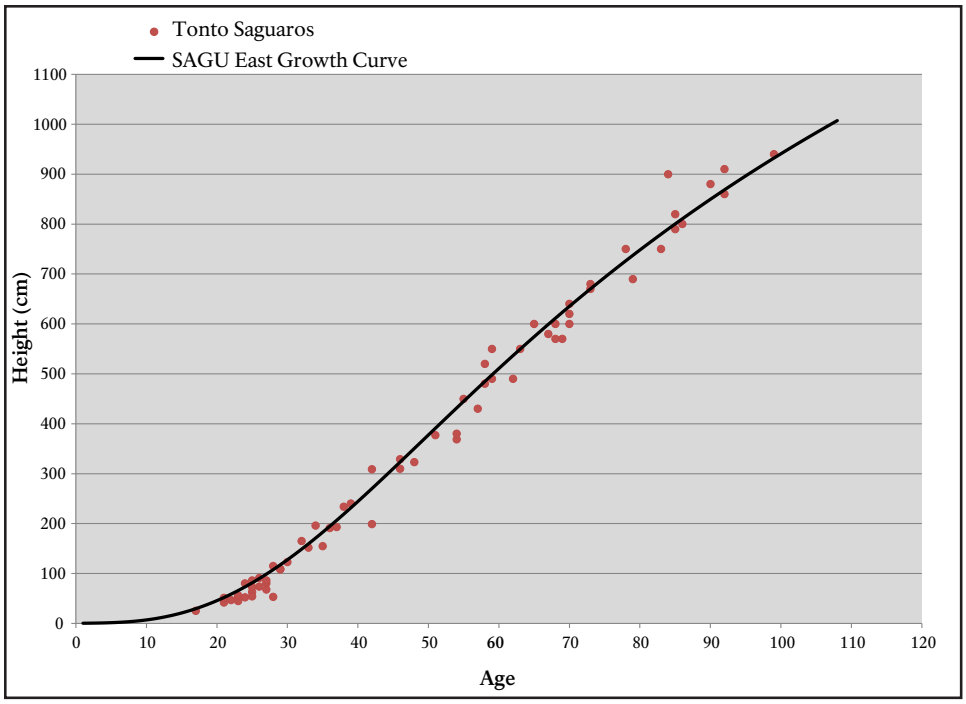

Figure 9. Age-height relationship between saguaros measured at Tonto National Monument in 2016 and Steenbergh-Lowe (1983) growth curve for RMD.

other parks. To evaluate whether there have been recent differences in establishment of saguaros at Saguaro NP that may be related to climate or the interaction between climate and habitat or other variables, we extracted data on 1,802 saguaros that we estimated to be less than 26 years old. We created "bins" of estimated saguaro age with 4-yr intervals and compared the number of saguaros per hectare among different plots. We also did a separate analysis of data from 13 plots from the 2010 Saguaro Census at Saguaro NP (O'Brien et al. 2011) that we re-surveyed in 2016 to determine whether the total number of saguaros declined from 2010 to 2016.

As part of this project we conducted additional analysis that are published elsewhere or that will be presented in future publications. In Conver et al. (2017), we summarized data from a 2.59-square-kilometer area of the Cactus Forest in Saguaro NP that was surveyed in 1941 and re-surveyed in 2011, and evaluated demographic changes of this saguaro population in the context of both climate and land-use change. In Winkler et al. (2017), we summarize data from randomly-located plots in both districts of Saguaro National Park collected during 1990, 2000, and 2010. We evaluated saguaro establishment year in relation to the Palmer Drought Severity Index and compared establishment prior to 2010 among different habitats in both park districts. We intend to publish the results of the 2015–2016 surveys (this report) in a peer-reviewed scientific journal, as well as the results of projects related to this study: one of climate and saguaro nurse trees by Daniel Winkler, and one of climate and saguaro flowering phenology by Theresa Foley.

Estimating Growth Rate

At Saguaro NP, we measured saguaro height monthly from December 2015 to December 2016 on six selected historic plots (established 1941 or 1975) to better understand the relationship between habitat, precipitation, and the initiation and growth rate of saguaros. It is anticipated that this will be a 4-year project in order to capture the variation of growth rate in response to climate and habitat. The 6 plots were subjectively chosen as representatives of bajada, foothills, and slopes habitats by Steenbergh and Lowe (1983) for both districts of the park (Figure 3). On each plot we randomly selected approximately 50 saguaros that were less than 2 m tall and noted any physical damage. The threshold for initial height was chosen based after we tested the ability of separate crews to repeat measurements with accuracy for a wider range of heights. Selected saguaros were measured 10 cm away from the base of the plant on the south side; where the standard distance and direction was not practical, a suitable alternative

distance and direction was chosen. On each plot we also measured precipitation using a standard calibrated rain gauge. Where data were missing (due to a gauge being tipped over by wind or an animal, for example) we used data from the nearest available rain gauge.

Analysis

To evaluate whether growth rates of saguaros vary across the landscape based on both precipitation and other factors, we calculated annual growth rates for individual size classes (0–0.49 m, 0.5–0.99 m, 1–1.49 m, 1.5–1.99 m, >2m). We then created average growth rates for each size class on each plot and correlated these rates with monthly rainfall on the plot. In this report we present preliminary data from this part of the study; further analysis of growth rates and habitat features will be conducted with additional years of data as part of Joshua Conver's PhD dissertation.

Results

Demographics and Establishment: Saguaro National Park

At Saguaro NP we mapped and measured 9,638 saguaros: 3,140 on 24 plots in the Rincon Mountain District and 6,498 on 12 plots in the Tucson Mountain District (Appendix A). Mean density of saguaros was 79.5 saguaros/ha at Rincon Mountain District (se = 17.7) and 154.7 saguaros/ha at Tucson Mountain District (se = 30.1; Figure 10). Two plots were incompletely sampled and dropped from the analysis.

Density varied among habitat types and by elevation. Density by habitat (Fig. 11) was highest on plots on slopes (n = 16), intermediate on bajadas (n = 13) and lowest on foothills (n = 7). Density was highest at lower and middle elevations, where younger size classes were very abundant (Figure 12).

Of the 9,638 saguaros sampled, 3,835 (39.8%) were less than 1 m in height, and 1,873 (19.4%) were less than 0.5 m. Using the height-age relationship for each district, we estimated that approximately 1,802 (18.7%) of saguaros had germinated in the last 25 years, since approximately 1991, and that approximately 70 (<1%) have germinated in the last 11-15 years. The majority of the younger saguaros, especially those less than 18 years old, have established between 1000-1200 m elevation in the Rincon Mountain District and 600-1000 m elevation in the Tucson Mountain District (Figure 13).

Of the 17 Duriscoe and Graban (1991) plots that were sampled in both 2010 and 2016, there was a decline in the total number of saguaros from 5,474 saguaros in 2010 to 5,224 in 2016. In 2016 there were fewer saguaros on nine plots than in 2010 and more saguaros on four plots (two in the Rincon Mountain District and two in the Tucson Mountain District) than in 2010. Few new saguaros have entered the population at Saguaro NP since the middle and late 1990s (Figure 14).

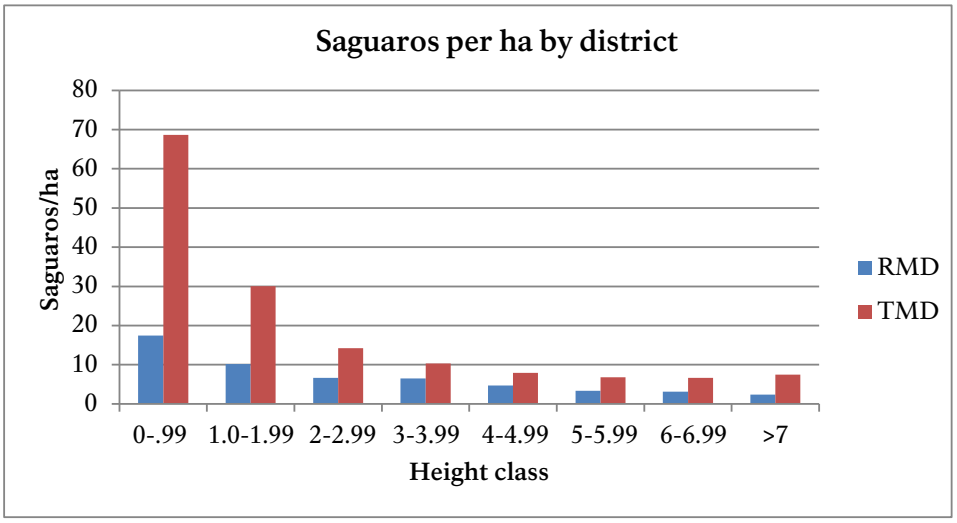

Figure 10. Number of saguaros per ha by district and height class at Saguaro National Park, 2015–2016. Total number measured was 9,638. Bars represent standard error.

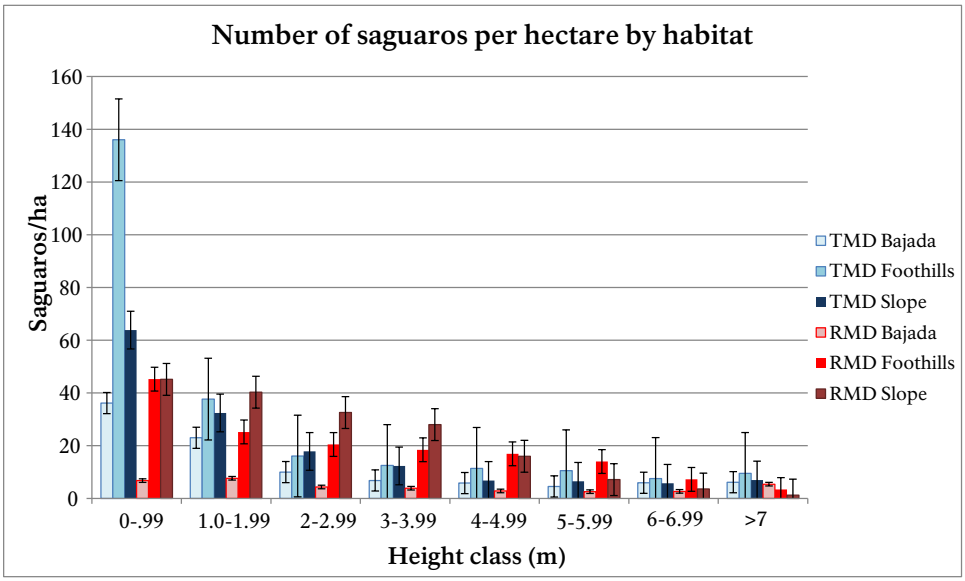

Figure 11. Number of saguaros per hectare by habitat type at Saguaro National Park's Rincon Mountain District (RMD) and Tucson Mountain District (TMD). For bajada, n=13 (7 at RMD and 6 at TMD); for foothills, n=7 (4 at RMD and 3 at TMD); and for slopes, n=16 (13 at RMD and 3 at TMD). For habitat definitions, see Methods section.

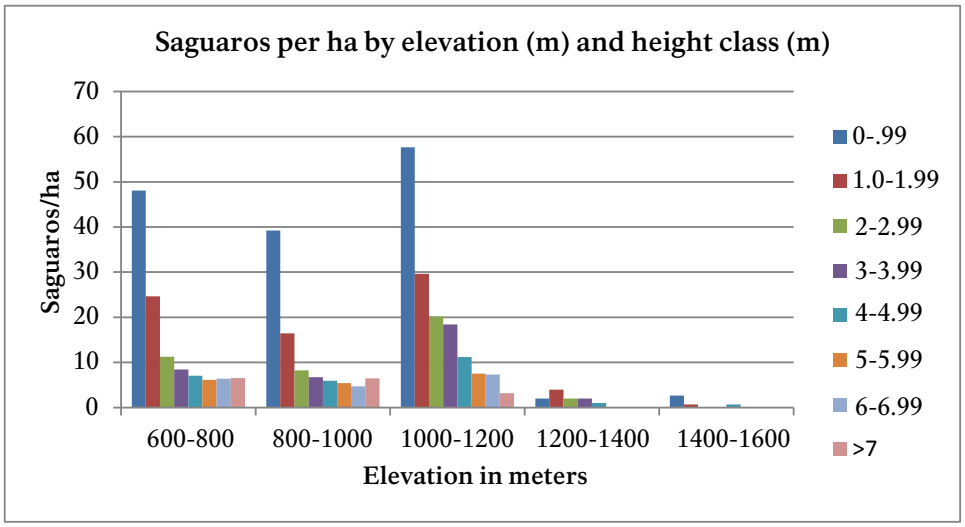

Figure 12. Number of saguaros per hectare by elevation and height class at Saguaro National Park. Plots at Rincon Mountain District ranged from 818 m to 1600 m. Plots at Tucson Mountain District ranged in elevation from 686 m to 1086 m.

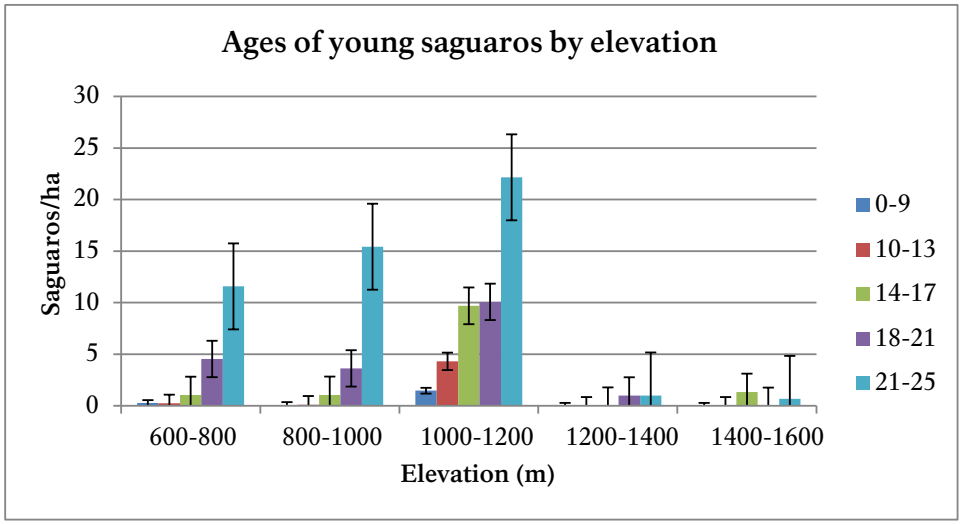

Figure 13. Estimated ages (in years) of young saguaros by elevational range at Saguaro National Park. Error bars represent standard error.

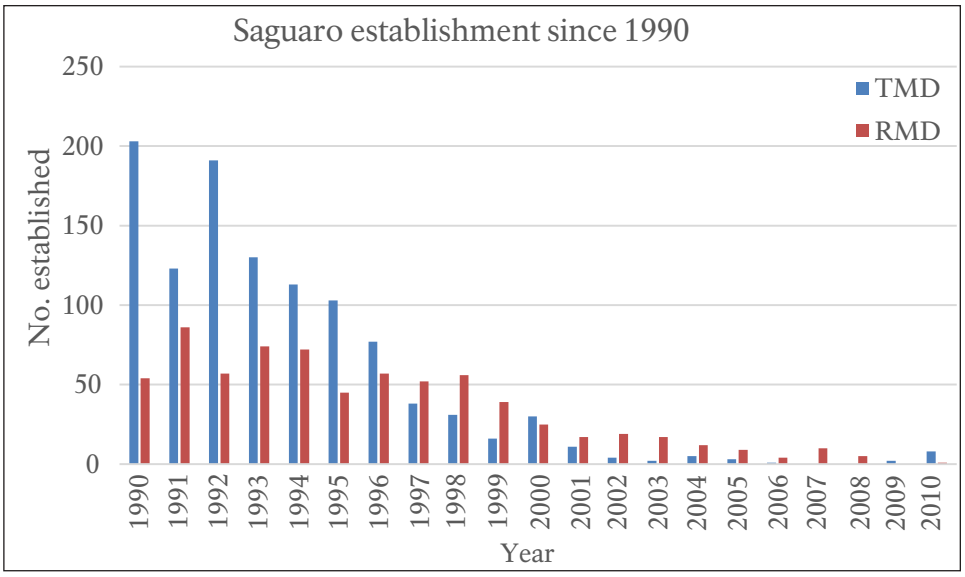

Figure 14. Estimated year of establishment of young saguaros at Saguaro National Park measured during 2015-2016 at Tucson Mountain District (TMD) and Rincon Mountain District (RMD). Ages estimated from height for each district based on Steenbergh and Lowe (1983).

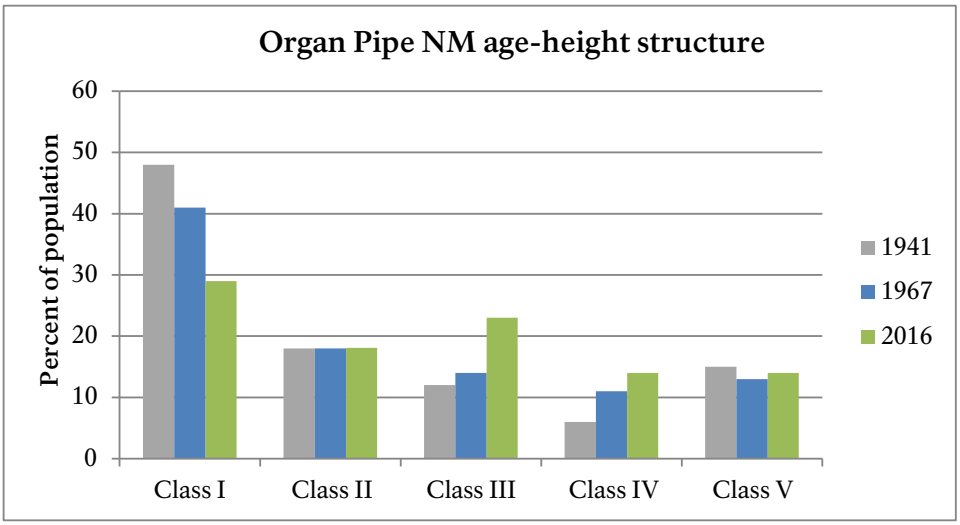

Figure 15. Age-height structure for 5 plots in Organ Pipe Cactus National Monument in 1941, 1967, and 2016. Classes are based on 6-foot (1.83 m) intervals established in 1941. Class I saguaros are approximately 0-70 years in age, Class II are 71-88, Class III are 89-109, Class IV are 110-132, and Class V are >133.

Demographics and Establishment: Organ Pipe Cactus and Tonto National Monuments

We measured and mapped 195 saguaros on five plots at Organ Pipe Cactus NM. We found saguaros on all plots in 2016, but because no saguaros were found on plots 1 and 2 in the 1941 and 1967 surveys, we performed the age-height class analysis only on data from plots 3, 4, and 5 (Figure 15).

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 Organ Pipe Cactus NM. In general, and compared to Saguaro NP and Tonto NM, the population structure at Organ Pipe Cactus NM is fairly even, not dominated by young individuals, with a number of individuals present that established in the early 20th century (Figures 15 and 16).

We measured and mapped 82 saguaros on plot 15 at Tonto NM, including 10 new saguaros that were not detected on the plot in 2010. In addition, we searched for and located other plots for future reference, but did not sample them. Plot 15 at Tonto NM has seen a surge in establishment in recent years that has persisted longer than the surge at Saguaro NP. In contrast to Organ Pipe Cactus NM, but similar to Saguaro NP , Campbell et al. (2011) found that the saguaro population has gone from a more evenly-aged population in the past (1961) to one with a large number of younger saguaros (Figures 16 and 17), and our survey of plot 15 suggests a similar result.

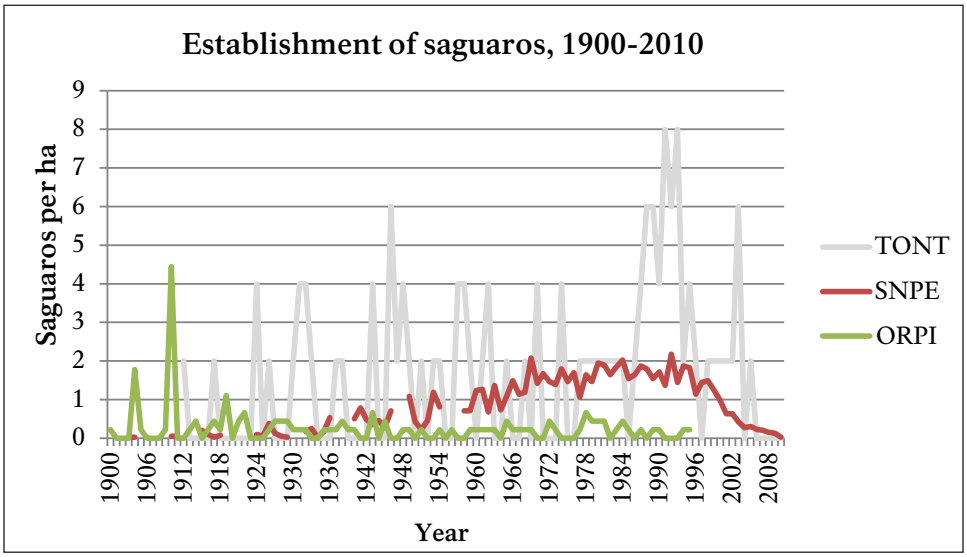

Figure 16. Number of saguaros per hectare estimated to have established per year at Tonto National Monument (TONT), Saguaro National Park East (SNPE; Rincon Mountain District) and Organ Pipe Cactus NM (ORPI) during 1900-2010, based on this study. Age of establishment based on age-height models of Steenbergh and Lowe (1983).

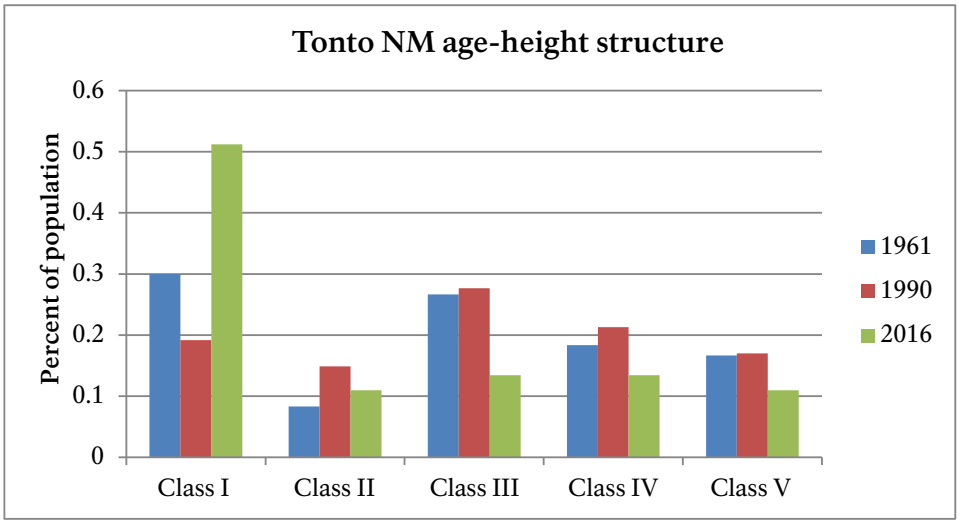

Figure 17. Age-height structure for saguaros on plot 15 in the vicinity of the Visitor Center and Lower Cliff Dwellings in Tonto National Monument in 1961, 1990, and 2016. Classes are based on 6-foot (1.83 m) intervals established in 1941. Class I saguaros are approximately 0-35 years in age, Class II are 35-49, Class III are 50-63, Class IV are 64-78, and Class V are >78. No data are available from prior to 1967.

Precipitation and Growth: Saguaro National Park

In 2016, winter rains primarily fell during January at Saguaro NP, with some rain later in the spring, including April. Summer rains first started during late June at Rincon Mountain District, and then both districts had significant precipitation in August-October (Figure 18). Rincon Mountain District received more total rainfall and more monthly rainfall than Tucson Mountain District, with the exception of February and July.

On long-term growth rate plots, saguaros grew very little or not at all during the cooler months, but growth was initiated in late spring, possibly due to precipitation events during April at Rincon Mountain District. Major growth episodes were strongly associated with periods of greatest summer precipitation, which came slightly earlier at Rincon Mountain District than at Tucson Mountain District (Figure 19). Growth rates were not significantly correlated with summer precipitation ($P = 0.6963$).

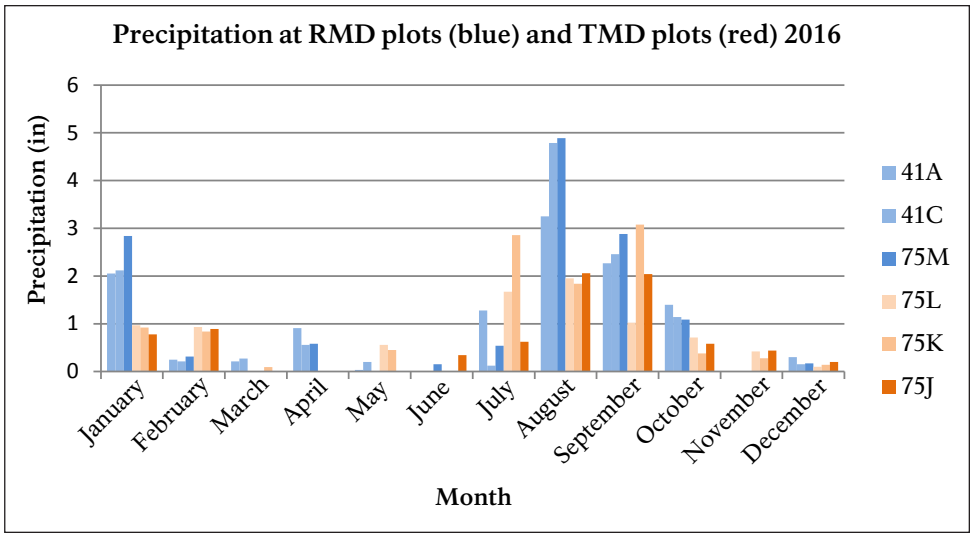

Figure 18. 2016 precipitation at six saguaro growth rate monitoring plots at Saguaro National Park in Rincon Mountain District (RMD) and Tucson Mountain District (TMD).

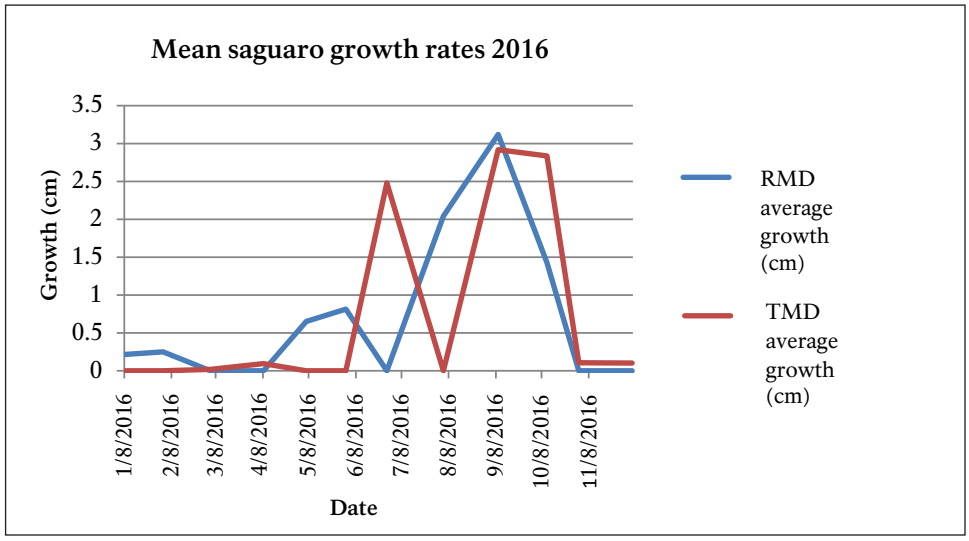

Figure 19. Mean growth rates for 3 monitoring plots (approximately 50 saguaros/plot) in Rincon Mountain District (RMD) and Tucson Mountain District (TMD) at Saguaro National Park. Growth began with late spring rains and continued through October, with greatest growth during August-September.

Discussion

Climate and Saguaro Demography in Saguaro National Park

Our results are consistent with findings from previous studies that suggest that the interactions between the saguaro cactus and climate are nuanced, with plant response to climate varying by development stage. Establishment and growth of saguaros appears to be strongly influenced by drought and high temperatures, whereas mortality—especially in the northern areas of the saguaro's range—appears to be strongly influenced by winter freezing events. However, while climate provides an overall framework for saguaro natural history, local populations may also be strongly influenced by human land uses such as cattle grazing, wood-cutting, and fire, as well as by interactions between animals and saguaros. Changes in population structure are typically long-term and last for decades rather than individual years. As conditions within the saguaro's range become increasingly hotter, drier, and less predictable, we expect that these interactions may become more complex.

At Saguaro NP, we found evidence that increasing temperatures are contributing to extended drought conditions that may be reducing establishment of new plants. Only about 19% of the saguaros in the park have germinated since 1994; more strikingly, less than 1% of the saguaros we sampled would have germinated in the past 11 to 15 years. Our study confirms that the major surge in establishment of

saguaros seen throughout the park during the past 50 years (Duriscoe and Graban 1992; Turner and Funicelli 2001; Turner and Funicelli 2004; O'Brien et al. 2011) has now ended, presumably in response to drought conditions since the mid-1990s.

Long-term studies in the Cactus Forest area of the Rincon Mountain District (Orum et al. 2016; Conver et al. 2017) have shown a near complete halt of establishment since the 1990s. Park-wide, establishment of new saguaros has clearly slowed dramatically, although not quite as dramatically as in the Cactus Forest area where very young saguaros are almost impossible to find (Orum et al. 2016). Similarly, bajada areas in both districts have very few young saguaros, whereas more have established on slopes, especially in the Rincon Mountain District (Figure 13). Field observations suggest that increased recruitment on upper slopes may be due to local soil and topographic conditions such as small perched aquifers and bedrock cracks which may provide additional soil moisture. We will explore this pattern in future research.

In addition to the decrease in recruitment, we found—on the subset of plots that have been monitored every 10 years since 1990 as part of the Saguaro Census (Duriscoe and Graban 1992; Turner and Funicelli 2001; O'Brien et al. 2011)—that the total number of saguaros has declined on nearly every plot for the first time since 1990. Of the 13 plots sampled, saguaros declined on nine plots, with an overall decline of about 5%. This decline may reflect park-wide conditions, and is likely the result of a combination of lower recruitment and higher mortality of adults.

Elevated adult mortality of saguaros at Saguaro NP since 2010 is probably related to a single event, a severe freeze in February 2011 that was the first major extended period of below-freezing temperatures in southern Arizona since the 1970s (Orum et al. 2016). Immediately following the event, Tom Orum and Nancy Ferguson (pers. communication) found that approximately 36% of older adults—that is, saguaros that were present on their long-term monitoring plot when it was established in 1941 and still living—died immediately after the freeze. This freeze also appears to have killed substantial numbers of adult saguaros at Tonto NM, but few at Organ Pipe Cactus NM, which would be consistent with climate patterns and warmer temperatures in southwestern Arizona compared to eastern and central Arizona.

The relationship between saguaro demographics and freezing temperatures was the focus of a number of studies by Steenbergh and Lowe in the 1960s and 1970s, who considered extended freezing to be the major limiting factor for saguaros in the northern part of their range. Their work provided compelling evidence that freezes, not disease, were the proximate cause of saguaro die-offs in the Cactus Forest in the early 1940s and 1970s that caused alarm among park managers. The extended warm period following the end of Steenbergh and Lowe's studies in the late 1970s is probably a factor that led to the surge of saguaro establishment in the 1980s, although precipitation patterns are also a likely proximate cause of recruitment success. This warm period extended to 2011 when a hard freeze occurred. The 2011 freeze did not seem to affect these younger individuals but killed enough older saguaros to cause a park-wide decline in the total population.

Our study suggests that in recent years climate has impacted saguaros at Saguaro NP both by drought, which has probably been driven by the long-term trend of higher temperatures in the Sonoran Desert related to anthropogenic climate change, as well as by the occurrence of extended, extreme freezing events. The frequency of freeze events may be reduced in the future given a more arid climate (Weiss and Overpeck 2005), but some climatological modeling suggests an increase in the frequency of both hot and cold extremes (Guido 2011). Because saguaros are a long-lived species that can store water for extended periods and reproduce for more than a century, they are presumably much more resistant to extended drought than many other species. In addition, many previous studies have shown that saguaro establishment is episodic and tied to extended periods of warmer, wetter conditions. For example, Drezner and Balling (2008) found a strong correlation between saguaro establishment and global climate patterns associated with cool, wet summers, indicating a potential historic link between establishment and periods of intense volcanism that add dust to the atmosphere and reduces summer temperature. Nevertheless, the reduction in establishment at Saguaro NP is concerning and should continue to be monitored by the park.

Climate and Saguaro Demography in Southern Arizona Parks

Our initial results at Tonto NM suggest similar trends in saguaro recruitment as has been documented for Saguaro NP. Although our evidence is currently limited to one south-facing plot, it appears that the population contains a large number of young individuals, including some that have germinated in the past few decades. Tonto NM also saw mortality of older individuals as a result of the 2011 freeze, although many older saguaros survived. Additional sampling on other historic plots at Tonto NM will help to confirm or refute these preliminary results.

At Organ Pipe Cactus NM, where the record extends back further in time than at the other two parks, establishment of saguaros was high during the 19th century, consistent with cooler and wetter conditions. However, Organ Pipe Cactus NM experienced its last substantial establishment episode in the 1910s; the major periods of regional establishment in the late 1960s and the 1980s, seen in this study at Saguaro and Tonto, as well as elsewhere by other researchers (Danzer and Drezner 2010; Pierson et al. 2013) apparently did not occur at Organ Pipe Cactus NM. Despite this, the saguaro population seems able to maintain itself outside of favorable germination conditions for decades because the establishment 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 the population is shorter than 2.13 m and younger than 70 years old, the largest percentage for any age-height class. In addition, the population at Organ Pipe Cactus NM is also well-situated for an establishment 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.

The initial results of our study suggest that the saguaro's response to a warming climate will vary across its range. Organ Pipe Cactus NM is generally hotter and drier than Saguaro NP and Tonto NM, so saguaros are less abundant, grow more slowly, and enter the population at a reduced rate (Steenbergh and Lowe 1977). However, adult survival rates are much higher at Organ Pipe Cactus NM due to low freeze mortality. The park is virtually free from catastrophic freeze events, and freezing nights in general have become less frequent over the last 50 years, decreasing from 20 to fewer than 10 freezing nights annually (Munson et al. 2012).

If air temperatures—and by extension, evapotranspiration—continue to increase, we might expect that the long-term prognosis for saguaros at Organ Pipe Cactus NM to be poor, as conditions for establishment of new saguaros will be rarely met. In turn, we might expect that the saguaro population at Saguaro NP and Tonto NM may come to resemble that of Organ Pipe Cactus NM, with fewer individuals, less frequent establishment due to dry conditions, but decreased adult mortality due to decreasing freeze events.

However, it is important to recognize that 70 years represents only approximately two generations for saguaros, even at relatively fast-growing sites like Saguaro NP and Tonto NM, and that many other human factors may be important in the future, as they have in the past. Grazing appears to have greatly influenced saguaro populations in the past century in all parks, and at both Saguaro NP and Tonto NM fire has recently played a major role in saguaro distribution (Springer et al. 2015). Saguaro NP and Organ Pipe Cactus NM have significant issues with the invasive buffelgrass, which has the potential to change the fire regime in a plant community where many plants, including saguaros, are not fire-adapted and are often killed by it (Stevens and Falk 2009). Buffelgrass has also been detected at Tonto NM, but is currently very rare, with new occurrences a focus of early detection monitoring and treatment (Sarah Studd, personal communication).

Climate models predict mixed effects for the future of the saguaro cactus in the southwestern United States. Saguaro NP is located near the U.S. environmental optimum of the species' range (Niering et al. 1963; Drezner 2006) so any significant climatological change could have important implications for the distribution this cactus throughout this area. Most models predict warming temperatures for the southwestern United States on the order of five to seven degrees Fahrenheit by the year 2100 (Christensen et al. 2007; Lenart et al. 2007). Temperature increases may reduce the number of freeze events (Archer and Predick 2008) that result in saguaro mortality but the frequency of drought is expected to increase along with temperature over the next century (Seager et al. 2007; Archer and Predick 2008), which may have the effect of changing the limiting factor for saguaros from freezing temperature to water availability.

Citizen Science, Education, and Outreach

A major theme of this project was community outreach related to saguaros and climate change. Our goal was to communicate that saguaros are a slowly-changing, but vulnerable species in the Sonoran Desert and that we can, as a community, work to ensure that the iconic saguaro populations remain viable for future generations. Specifically, we sought to increase public understanding of the complex relationship between saguaros and their ecosystem and how human-induced changes in the environment affect that relationship. To accomplish this, we used citizen science as a non-political and collaborative approach to understanding environmental change (Swann et al. 2011; Figures 20 and 21).

Figure 20. Centennial Saguaro interns Amy Beisley and Lia Ossanna with biotech Joshua Conver and ACE intern Brian Cropper.

Figure 21. High school interns Aisha Irfan and Kei Ann Mandales.

Our specific objectives were to reach a broad and diverse cross-section of public participants, including local youth who have never experienced the park, and to create a model that could be useful for outreach in other national parks. In addition, we proposed to accomplish our educational goals through activities such as providing prizes for Sonoran Desert research at a regional science fair, scientific talks, traditional interpretive talks to park and community audiences, video exhibits, and a dedicated web page. Finally, we hoped to use social media in all aspects of the project, so that we could connect more effectively with new, non-traditional NPS audiences.

Citizen Science.

We hired a dedicated "Next Gen" ranger intern, Carolyn Harper, with a background in volunteerism, interpretation, and resource management to lead the Citizen Science aspects of the project. Carolyn, a number of biological technicians and interns, and a team of approximately 11 "Centennial Saguaro Survey" volunteer interns from local colleges and high school senior intern programs oversaw the saguaro surveys (Figures 20-21). The Centennial Saguaro Survey team was trained in safety, saguaro biology, and the field protocol so that they could lead small sub-groups in the field. The team remained in place throughout the year, typically volunteering about 12 hrs/wk.

We recruited volunteer citizen scientists through active targeting of local middle and high schools, community colleges, the University of Arizona, and community groups such as local companies and outdoor groups (Figures 22-23). For more difficult plots that required longer hikes and work in steep terrain, we targeted hiking and canyoneering groups.

In total, more than 475 volunteers contributed more than 3,000 volunteer hours while helping the park collect data on the nearly 10,000 saguaros measured on 38 plots. Seventy-five percent of the volunteers were over 25 years of age. Although we did not keep statistics on diversity of volunteers, most of the schools reflected the social, economic, and cultural diversity of the city of Tucson, which is over 40% Hispanic.

All participants received either an in-person or web-based introduction to the project prior to coming into the field (https://www.nps.gov/sagu/getinvolved/centennial-saguaro-survey.htm), as well as an orientation at the start of each survey that included our goals, how climate change might be effecting the saguaro; the history of saguaro monitoring at the park; safety; and logistics. Each individual was trained to measure saguaros directly and indirectly, using a clinometer and trigonometry, as well as how to use GPS to map saguaro locations and other methods of data collection.

Soon after each survey, we posted our results to the park's web site, so that participants could view photos of their group and a graph that compared their results with previous surveys of the same plot (https://www.nps.gov/media/photo/gallery.htm?id=A0580BA5-155D-451F-6726AA9A5ABD94E5). We particularly encouraged teachers, to visit the site and review and use the data and other park saguaro data in the NPS Data Store.

Figure 22. High school group from Arizona College Prep Academy, winter 2016.

Figure 23. Arizona Conservation Corps group, March 2016.

Interpretive Programs

We provided more than 15 interpretive programs to park groups, schools, park visitors, and community groups throughout the year. We gave six presentations on the project to schools and university classes, three to community groups, two at the NPS Centennial at the Philadelphia Flower Show, and four to visitors at the park, including to the Junior Ranger Camps. In addition, we gave at least eight presentations at scientific conferences and to managers, described below. We also provided a number of interpretive brochures and other products for the Visitor Center, including a popular handout on cristate saguaros, and a brochure about the Centennial Saguaro Survey itself.

Outreach Events

We included the Centennial Saguaro Survey in the park's many outreach events, and interns supported by this project were active participants in literally dozens of events in the city of Tucson, including the Tucson Book Festival, Reid Park Zoo Summer Nights, and other projects. Three summer high school interns—Kei Ann Mandales, Aisha Irfan (Figure 21), and Giovanna Almaguer—helped support outreach at the park related to saguaros.

An important community event was the Southern Arizona Regional Science and Engineering Fair (SARSEF). In 2015, 2016, and 2017 we provided four $100 prizes, were judges for the fair, and sponsored a booth. We selected winning projects for both elementary and high school on topics ranging from climate change to wildlife and light pollution. Some students also visited the park and exhibited their posters at the Visitor Center (Fig 24).

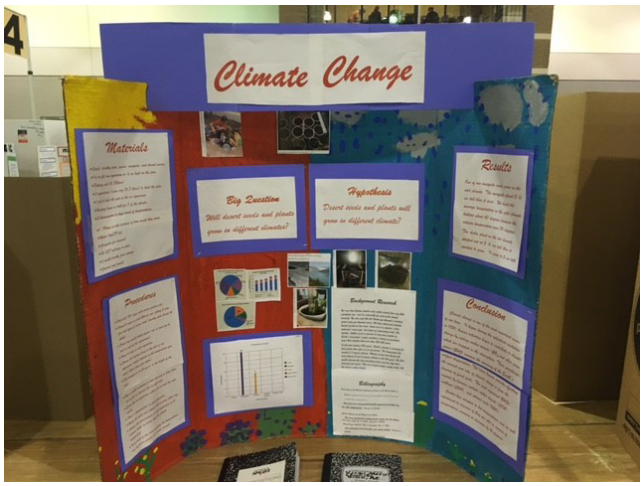

Figure 24. One of the Saguaro National Park science fair award winning projects.

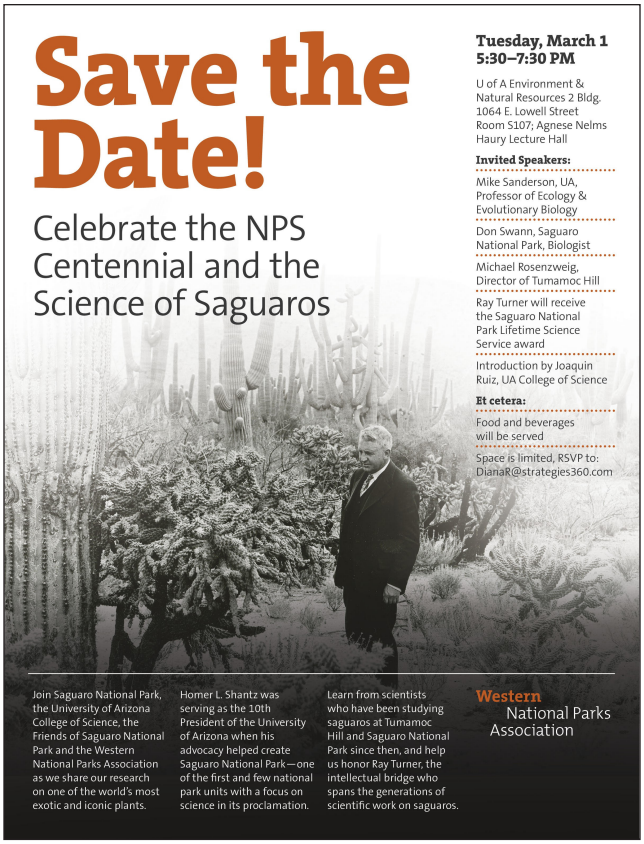

Figure 25. Advertisement in Arizona Daily Star for the Science of Saguaros Centennial Celebration with support of University of Arizona and Western National Parks Association.

Figure 26. Facebook post (over 48,000 people reached) of the park's celebration of the famous "Centennial Saguaro" that is estimated to have germinated in the year the National Park Service was created.

This project directly resulted in the development of a major public event with the College of Science at the University of Arizona. To celebrate the NPS Centennial, we co-sponsored a Saguaro Science Symposium (Figure 25) at the Tucson Electric Company building in downtown Tucson attended by Sue Masica, NPS Intermountain Regional Director. The event was over-capacity with approximately 300 participants. Don Swann, one of two keynote speakers, highlighted science, saguaros, and climate change during the past 75 years at Saguaro National Park. At this event we also presented an award to Ray Turner, who has studied saguaros at the park for more than 50 years.

The saguaro survey project was an important part of three other Centennial events as well: At Rincon Mountain District on March 1, 2016, an event featured saguaro science in celebration of the "Centennial Saguaro" in front of the Visitor Center, which is believed to be 100 years old (Figure 26); on March 6, in the Tucson Mountain District a public event featured a talk on saguaros by Don Swann; and an event to celebrate the NPS Centennial at the Arizona-Sonora Desert Museum on Founder's Day in August. We received extensive media coverage of these events and this project in local and national print, radio, and web media coverage (Appendix B).

Social Media

A major focus of our outreach was on social media; we produced stories for Facebook, Snapchat, and Instagram from the inception of this project. The stories focused directly on the project and a range of topics related to the saguaro and climate change that appealed to youth audiences (Appendix B). Some stories were translated into Spanish by our Spanish-speaking interns. We posted over 120 posts related to the project: 39 on Twitter, three on Snapchat, 39 on Facebook and 32 on Instagram (Figure 27). In addition to the saguaro posts, we presented a number

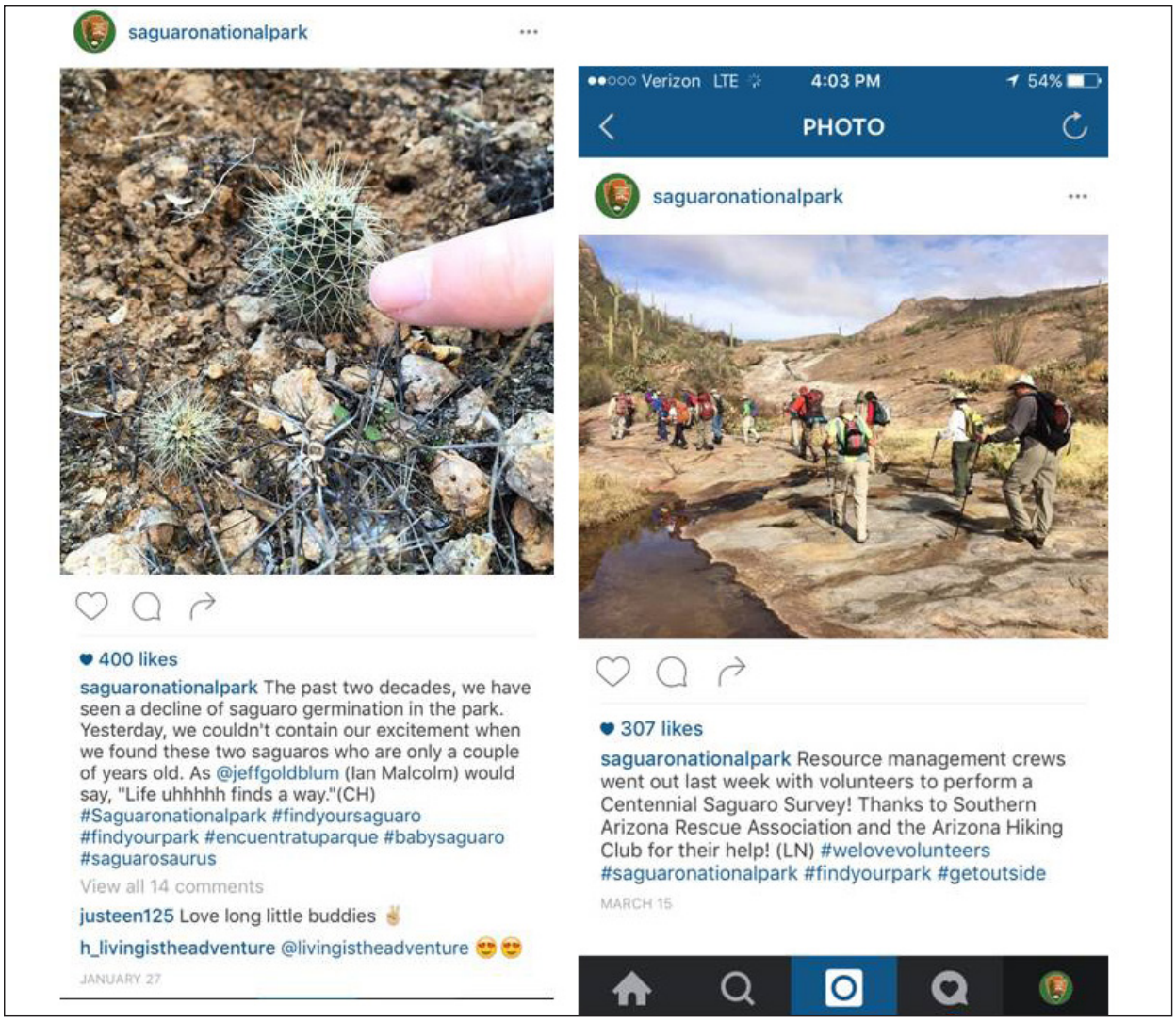

Figure 27. Examples of (Instagram (Left) and Facebook (right) posts from the project; we posted more than 100 posts on social media.

of other posts related to climate change and water resources. Our social media posts were immensely popular. For example, one Facebook post on saguaro flowering season reached nearly 65,000 people, and in 2016, our first year on Instagram, we gained 30,000 new followers.

Special Events and Videos

By tying science, education, and the saguaro directly to the 100th Anniversary Celebration of the National Park Service, this saguaro survey project provided a number of exciting opportunities to expand the park's capacity in interpreting the saguaro through different cultural lenses. This project supported the expansion of education associated with the Native American harvest of saguaro fruit, which is an annual event conducted by members of the Tohono O'odham Nation with Tina Vavages, a Next Gen intern in the interpretive division who has been bringing fruit harvest and wildlife program to schools on the nation.

We also worked closely with Borderland Theatre and local artist Kimi Eisele on a project called "Standing with Saguaros" that included a number of events encouraging high school students and the public to spend time alone with saguaros, reflecting on them and sharing the experience. In addition to these

Figure 28. High school intern Jessica Ledesma in Outside Science video about the Saguaro Climate Change project.

private events, Standing with Saguaros had public events (http://kimieisele.com/portfolio/standing-with-saguaros/) and a series of radio interviews called "The Saguaro Minute" that included Carolyn Harper, Don Swann, and Tina Vavages (https://kxci.org/dj/kimi-eisele/).

We worked with videographer Dan Bell to produce a video about saguaros at the park for the "Science Corner" in the Rincon Mountain Dstrict visitor center that starred biotech, Joshua Conver, biologist, Don Swann, and high school interns, Kei Ann Mandales and Yesenia Gamez Valdez (https://www.nps.gov/sagu/learn/photosmultimedia/videos.htm). Our project was featured in an Outside Science video (Figure 28) by videographer Ron Bend produced by NPS (https://www.youtube.com/watch?v=q6nunGg1L7c).

Science Communication

One of our major accomplishments was to summarize more than 75 years of scientific data on saguaros collected at the park and to make these data publicly available, especially to teachers and professors, through the NPS data store. A dedicated Student Conservation Association intern, Valerie Seeton, gathered data from a large number of sources and scanned historic reports. As part of our Centennial celebrations in March, 2016, these data and reports were posted and accompanied by a guide for educators. The guide (https://irma.nps.gov/DataStore/Reference/Profile/2227261) allows easy and open access to different spatial and non-spatial datasets and reports that accompany them. We have received a number of inquiries from teachers and professors who plan on using (or may be already using) these materials in their classrooms.

We worked with a volunteer research librarian, Phyllis Morgan, who has made compiling a bibliography of the saguaro cactus part of her life-long work. Phyllis came to the park and donated her materials for our archive; she also gave an interpretive talk on her project at the visitor center that was well-attended.

We disseminated information on this project through talks at scientific conferences and to management groups (Appendix B). These included talks by park biologist, Don Swann, park biological research technician, Joshua Conver, climate change intern, Daniel Winkler, and Next Gen intern, Carolyn Harper. Don Swann spoke at the Parks for Science, Science for Parks conference in Berkeley, California in 2015; Joshua Conver presented a poster at the American Association of Geographers conference in Boston, Mass in April 2017; and Daniel Winkler presented a talk at the George Wright Society conference in April in 2017. In addition, both Don Swann and Carolyn Harper shared the project results at several management meetings in the park and Tucson.

As mentioned previously, we analyzed data for scientific publications throughout this project, and collaborated with several PhD students who are continuing work related to this project. During the next several years we anticipate completing additional publications with Daniel Winkler (PhD candidate at UC Irvine, working on the relationship between saguaros, climate and nurse trees), Joshua Conver (PhD candidate at University of Cincinnati, working on the relationship between saguaro establishment, growth, and climate), and Theresa Foley (recent PhD from University of Arizona, working on the timing of saguaro flowering phenology related to climate). These projects were initiated as a result of this project and have received additional funds from the Western National Parks Association, Friends of Saguaro National Park, and other sources.

Conclusion

This project made several important and lasting contributions to Saguaro National Park and the National Park Service. First, the project helped clarify the relationship between climate and saguaros. Although there is still much to learn, we did confirm that the pattern of reduced establishment since the early 1990s is occurring park-wide, and that it appears to be strongly associated with drought, which is probably driven by temperature extremes. Second, we were able leverage the funds from this project to support two PhD students and a third recent PhD candidate to initiate longer-term projects related to climate and the relationship between saguaros and nurse trees, precipitation and growth rates, and flowering phenology. We believe that the results of these projects, when they are complete, will also provide great insights into the relationship between the saguaro, the park's signature plant, and a changing climate. Third, through our outreach efforts we helped to provide more accurate information about changes in the saguaro population in Saguaro National Park to our visitors and our community. Finally, through our Citizen Science efforts and social media, we reached many young people who would not otherwise have learned about science and the saguaro, and what it may teach us about how the Sonoran Desert is changing and will continue to change in our lifetimes. We are very grateful to the Climate Change Response Program and Friends of Saguaro National Park for providing the opportunity to make it happen.

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Appendix A: Plot Selection Matrix

Table A-1. Plot selection matrix for Saguaro National Park. Rincon Mountain District = RMD. Tucson Mountain District = TMD.

Slope class*	Aspect class**	Elevation class***	# of RMD Plots	# of TMD Plots	RMD Selected Plots	TMD Selected Plots
1	0	1	26	4	1, 8, 9, 10, 11, 17	33, 71G, 75J
1	0	2	0	6	–	31, 32
1	0	3	0	0	–	—
1	1	1	11	0	41A	
1	1	2	2	1	159	26
1	1	3	0	0	–	–
1	2	1	5	0	–	–
1	2	2	1	1	–	–
1	2	3	0	1	–	–
1	3	1	6	0	170	–
1	3	2	4	2	184	38, 75L
1	3	3	2	0	319	–
1	4	1	14	0	41C	–
1	4	2	1	4	–	30
1	4	3	3	0	–	–
2	0	1	0	0	–	–
2	0	2	0	0	–	–
2	0	3	0	0	–	–
2	1	1	9	0	150	–
2	1	2	8	0	177	–
2	1	3	12	1	334	75K
2	2	1	3	0	–	–
2	2	2	3	1	–	42
2	2	3	5	0	–	–
2	3	1	11	0	24, 25. 75M	–
2	3	2	14	1	317	–
2	3	3	13	2	332	34, 36
2	4	1	8	0	–	–
2	4	2	11	0	–	–
2	4	3	8	2	–	–
3	0	1	0	0	–	–
3	0	2	0	0	–	–
3	0	3	0	0	–	–
3	1	1	6	0	122	–
3	1	2	4	0	–	–

*Slope classes: 1 = 0–10%, 2 = 11–25%, 3 = >25%

**Aspect classes: 0 = flat, 1 = N, 2 = E, 3 = S, 4 = W

***Elevation clases
RMD: 1 = 2,500–4,000 ft, 2 = 4,000–4,800 ft, 3 = >4,800 ft
TMD: 1 = 2,000–2,400 ft, 2 = 2,400–3,000 ft; 3 = >3,000 ft

Table A-1 (continued). Plot selection matrix for Saguaro National Park. Rincon Mountain District = RMD. Tucson Mountain District = TMD.

Slope class*	Aspect class88	Elevation class***	#ofRMDPlots	#ofTMDPlots	RMD Selected Plots	TMD Selected Plots
3	1	3	4	0	353	–
3	2	1	0	0	–	–
3	2	2	1	0	–	–
3	2	3	2	0	–	–
3	3	1	6	0	310	–
3	3	2	0	0	–	–
3	3	3	2	0	142	–
3	4	1	1	0	–	–
3	4	2	3	0	339	–
3	4	3	3	0	–	–

*Slope classes: 1 = 0–10%, 2 = 11–25%, 3 = >25%

**Aspect classes: 0 = flat, 1 = N, 2 = E, 3 = S, 4 = W

***Elevation clases
RMD: 1 = 2,500–4,000 ft, 2 = 4,000–4,800 ft, 3 = >4,800 ft
TMD: 1 = 2,000–2,400 ft, 2 = 2,400–3,000 ft; 3 = >3,000 ft

Appendix B: Outreach Summary

The following is a list of all the social media stories, interpretive programs, scientific talks, and media coverage resulting from the Saguaro Climate Change project, 2015–2016.

Social media

Facebook posts

- June 9, 2015: Saguaro Trivia about pollinators.
- June10, 2015: Saguaro Trivia answer.
- July 29, 2015: Crested saguaro citizen search.
- August 5, 2015: Saguaro spines adaptation.
- August 10, 2015: Myth Busting Mondays: Saguaro Ep1 English
- August 10, 2015: Myth Busting Monday: Saguaro Ep2 Spanish
- August 17, 2015: MBM: Saguaro Ep2 English
- August 17, 2015: MBM Saguaro Ep2 Spanish
- August 20, 2015: About CSS webpage
- August 24, 2015: MBM: Saguaro Ep3 English
- August 24, 2015: MBM: Saguaro Ep3 Spanish
- August 31, 2015: MBM: Saguaro EP4 English
- August 31, 2015: MBM: Saguaro Ep4 Spanish
- September 14, 2015: MBM: Saguaro EP5 English
- September 14, 2015: MBM: Saguaro Ep5 Spanish
- September 21, 2015: MBM: Saguaro Ep6 English
- September 21, 2015: MBM: Saguaro Ep6 Spanish
- September 28, 2015: MBM: Saguaro Ep7 English
- September 28, 2015: MBM: Saguaro Ep7 Spanish
- October 28, 2015: Statue of Liberty and saguaro height.
- November 4, 2015: Saguaro water absorption.
- December 30, 2015: Phyllis Morgan
- January 7, 2016: Daily Sun article
- February 8, 2016: CSS post
- March 2, 2016: Saguaro Birthday Post
- March 23, 2016: REI CSS recap
- April 1, 2016: Saguaro blooms
- April 7, 2016: Saguaro blooms
- April 9, 2016: Saguaro blooms
- April 25, 2016: SARSEF contestant
- May 7, 2016: Resolution to surveys.

- June 12, 2016: End of saguaro blooms.
- June 16, 2016: Explore Nature Video
- June 22, 2016: Pollination week.
- August 2, 2016: Saguaro behavior.
- August 4, 2016: White-winged dove and saguaro fruit.
- August 5, 2016: Saguaro growth in monsoon season
- August 11, 2016: Young saguaro growth
- August 20, 2016: Celebrating saguaros

Twitter posts:

- June 9, 2015: Saguaro Trivia about pollinators.
- June10, 2015: Saguaro Trivia answer.
- July 29, 2015: Crested saguaro citizen search.
- August 5, 2015: Saguaro spines adaptation.
- August 10, 2015: Myth Busting Mondays: Saguaro Ep1 English
- August 10, 2015: Myth Busting Monday: Saguaro Ep2 Spanish
- August 17, 2015: MBM: Saguaro Ep2 English
- August 17, 2015: MBM Saguaro Ep2 Spanish
- August 20, 2015: About CSS webpage
- August 24, 2015: MBM: Saguaro Ep3 English
- August 24, 2015: MBM: Saguaro Ep3 Spanish
- August 31, 2015: MBM: Saguaro EP4 English
- August 31, 2015: MBM: Saguaro Ep4 Spanish
- September 14, 2015: MBM: Saguaro EP5 English
- September 14, 2015: MBM: Saguaro Ep5 Spanish
- September 21, 2015: MBM: Saguaro Ep6 English
- September 21, 2015: MBM: Saguaro Ep6 Spanish
- September 28, 2015: MBM: Saguaro Ep7 English
- September 28, 2015: MBM: Saguaro Ep7 Spanish
- October 28, 2015: Statue of Liberty and saguaro height.
- November 4, 2015: Saguaro water absorption.
- December 30, 2015: Phyllis Morgan
- January 7, 2016: Daily Sun article
- February 8, 2016: CSS post
- March 2, 2016: Saguaro Birthday Post
- March 23, 2016: REI CSS recap
- April 1, 2016: Saguaro blooms
- April 7, 2016: Saguaro blooms

- April 9, 2016: Saguaro blooms
- April 25, 2016: SARSEF contestant
- May 7, 2016: Resolution to surveys.
- June 12, 2016: End of saguaro blooms.
- June 16, 2016: Explore Nature Video
- June 22, 2016: Pollination week.
- August 2, 2016: Saguaro behavior.
- August 4, 2016: White-winged dove and saguaro fruit.
- August 5, 2016: Saguaro growth in monsoon season
- August 11, 2016: Young saguaro growth
- August 20, 2016: Celebrating saguaros

Instagram posts

- July 24, 2015: Monitoring greenness of saguaros
- September 10, 2015:Saguaro description video
- October 2, 2015: Crested Saguaro
- October 3, 2015: Citizen Scientist orientation
- October 4, 2015: Saguaro arm growth
- October 31, 2015: Saguaro Bat pollination
- November 12, 2015: Saguaro Freeze Damage
- December 26, 2015: Saguaro density
- January 14, 2016: Prickly pear seed germination in Saguaro
- January 22, 2016: Young saguaro arm
- January 26, 2016: Saguaro vandalism
- January 27, 2016: Saguaro germination
- February 13, 2016: Organ Pipe Trip
- February 28, 2016: Saguaro damages
- March 15, 2016: Saguaro survey
- April 4, 2016: Saguaro flower buds
- April 4, 2016: Saguaro flower
- April 7, 2016: Crested Saguaro
- April 9, 2016: Saguaro blooms
- May 11, 2016: Top of a saguaro
- May 13, 2016: Rain gauges
- May 17, 2016: Saguaro flowers
- May 20, 2016: Saguaro height
- May 22, 2016: Saguaro pollinator
- May 25, 2016: Tonto Trip

- May 29, 2016: BioBlitz2016
- June 5, 2016: Crested Saguaro
- June 7, 2016: End of saguaro blooms
- June 9, 2016: Saguaro fruit
- June 17, 2016: Saguaro fruit
- July 12, 2016: Saguaro fruit consumer
- July 16, 2016: Saguaro growth

Snapchat stories

- December 16, 2015: Saguaro themed snapchat story (usinterior account)
- September 2, 2016: Life of an intern at Saguaro NP (TheHill account)
- September 2, 2016: Why I love Saguaro NP (usinterior account)

Interpretive programs and scientific talks

By DonSwann (DS), Carolyn Harper (CH), Joshua Conver (JC), and Daniel Winkler (DW)

Interpretive talks

- August 25, 2015: The UA Welcome Back Fair (CH)
- September 2, 2015: The University of Arizona Volunteer Fair (CH)
- November 2, 2015: Empire High School (CH)
- November 5, 2015: Tucson Magnet High School (CH)
- November 10, 2015: Cascabel Conservation Association (DS)
- November 24, 2015: Arizona College Prep Academy (DS)
- January 2016: Interpretive training, SNP (DS)
- January 22, 2016: Lauffer Middle School (CH)
- March 1, 2016: Saguaro NP Centennial Celebration RMD (DS)
- March 6, 2016: Saguaro NP Centennial Celebration TMD (DS)
- March 12, 2016: Philadelphia Flower Show (CH)
- March 13, 2016: Philadelphia Flower Show (CH)
- April 8, 2016: UA Environmental Journalism class (DS)
- June 7, 2016: Junior Ranger Camp (CH, interns)
- June 14, 2016: Junior Ranger Camp (CH, interns)
- June 21, 2016: Junior Ranger Camp (CH, interns)
- November, 2016: UA Environmental Ethics class (DS)

Scientific and management talks

- March 1, 2016: UA Science and Saguaro Symposium (DS)
- March 26, 2015: Parks for Science conference, Berkeley CA (DS)
- February 4, 2016: UA Herbarium (DS)
- April 2016: All Employee Meeting SNP (CH)
- April 2016: Sonoran Desert Network (DS)

- December 2016: Landscape Conservation Cooperative (DS)
- April 2016: GW Society Conference, Norfolk VA (DW)
- April 2016: AAG Conference, Boston (JC)

Media coverage (selected list)

Print media, radio and TV

- Arizona Daily Star, Dec. 25 2015. "Young 'Citizen Scientists' help with saguaro survey at park." http://tucson.com/news/local/young-citizen-scientists-help-with-saguaro-survey/article_ae362495-7042-5c17-b7bc-7e6525c4bd88.html
- Arizona Daily Star, January 24, 2016, "Leaders in Saguaro Science" (feature ad for UA College of Science Lecture Series with Saguaro NP).
- Arizona Daily Star, March 1, 2016, "Saguaro Park is 83, birthday blowout, with cake, is today."
- Arizona Daily Star, Feb. 26, 2016, "Genetic blueprint of the saguaro is an odd one."
- Arizona Daily Star, February 27, 2016, "Freak of nature (the Saguaro)."
- Arizona Trail News, Spring 2016, "Centennial saguaro survey."
- Green Valley News, June 1, 2016, "Centennial saguaro survey data collection." http://www.gvnews.com/get_out/centennial-saguaro-survey-data-collection/article_fb1732fe-2d97-11e6-b1c5-3713c161948e.html
- Edible Baja Arizona Magazine, Green Valley News, June 1, 2016, "Centennial saguaro survey data collection."
- Edible Baja Arizona Magazine, July/August 2016, "Wild Life: Saguaro National Park."
- Sierra Club News, 2015, "Interview with an NPS employee, Don Swann, Saguaro NP."
- Arizona Highways Magazine, August 2016, "Saguaro National Park – Discovering Arizona's National Parks." Featuring Carolyn Harper and citizen science.
- Tucson News Now. "Saguaro NP popularity continues to grow." http://www.tucsonnewsnow.com/story/32844945/saguaro-np-popularity-continues-to-grow-as-park-service-celebrates-centennial
- KXCI Tucson: Standing with Saguaros: the Saguaro Minute. https://kxci.org/programs/the-saguaro-minute/

Web stories

- Arizona.edu, "Inside the 'Turtles of the plant world."
- Arizona Daily Star, May 17, 2016, "Despite wide-open spaces, some saguaros thrive on togetherness."
- Saguarita Sun. "Centennial saguaro survey data collection." http://www.sahuaritasun.com/fun/centennial-saguaro-survey-data-collection/article_318e8d8a-2d9a-11e6-9315-9fdf05d57e5b.html
- Sky Island Alliance, "Centennial saguaro survey." https://www.skyislandalliance.org/event/centennial-saguaro-survey/
- Earth View. "Wrapping up the Centennial Saguaro Survey." https://earthviewblog.wordpress.com/2016/05/19/wrapping-up-the-centennial-saguaro-survey/
- University of Arizona. "Lia Ossanna: internship with Saguaro NP." https://swes.cals.arizona.edu/Lia_Ossanna_internship
- Friends of Saguaro National Park. "Monitoring saguaros at the park." http://www.friendsofsaguaro.org/index.asp?SEC=767ED70C-95C2-479E-858B-7AB4B363C76D&Type=B_BASIC

NPS stories

- Call to Action story, March 2016, "Centennial Saguaro Survey, posted March 2016: (see Fidler email of 3/11/12016 for link)
- Inside NPS.com, June 24, 2016, "Citizen scientists participate in Saguaro NP's Centennial Saguaro Survey."
- IMR Intercom, June 18 2016, "Citizen science @ Saguaro Centennial saguaro survey."
- Call to Action story, accessed June 27, 2016, "Celebrating 100 years of national parks and 83 years of saguaro science."
- Call to Action story, accessed June 27, 2016, "2016 Citizen Science interns."
- Call to Action story, accessed June 27, 2016, "Centennial celebrations at Saguaro National Park."
- Call to Action story, accessed June 27, 2016, "Saguaro NP at the Philadelphia Flower Show."

Videos

- "Saguaros of Section 17," video by Dan Bell for Saguaro NP Visitor Center (https://vimeo.com/138337826)
- "Exploring the great outdoors: Saguaro NP Citizen Science," a video by Ron Bend (https://www.youtube.com/watch?v=q6nunGg1L7c).

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