Three Decades of Ecological Change: the 2020 Saguaro Census

Part I: Changes in the Saguaro Population 1990-2020

Report to Western National Park Association, Part I of Projects #19-06 and #20-09

Saguaro National Park interns and volunteer citizen scientists surveying saguaros in Tucson Mountain District, Saguaro National Park, February 2020

March 2021

Kara O'Brien and Don E. Swann

Saguaro National Park
3693 South Old Spanish Trail
Tucson, Arizona 85730-5601

Executive Summary

The Saguaro Census, conducted every 10 years since 1990 in Saguaro National Park, is the primary method the park uses to track the population health of its signature plant and associated vegetation community. The 2020 Census was a huge citizen science event that engaged more than 500 volunteers who donated more than 3,500 hours and collected data on over 24,000 saguaros in total. Although the Census ended early due to the Covid-19 pandemic, we were able to fully survey all 45 plots, plus 11 historic plots.

Results indicate that the park's saguaro population is healthy. Since 1990 the number of saguaros has nearly doubled, from an estimated 1.15 million in 1990 to 2 million in 2020. After more than a half century of poor establishment, survival of young saguaros began to increase in the 1960s, and establishment of new plants surged in the 1980s. At the same time, it is clear that the surge of new saguaros entering the population in the late 20th century has now mostly ended. In 2020 we detected only slightly more saguaros than in 2010. We did find some younger plants in foothills and slopes of both districts, where certain soils and rock crevices may retain moisture for longer than in lower, flatter areas. We attribute the overall decline in survival of young saguaros to extended drought that began in the 1990s and appears to be driven by higher temperatures.

Although the pandemic cancelled our ambitious plans for a large media roll-out of the Census in concert with publicity for the 2020 US Census, we still received significant local and national media coverage, and promoted the Census through the park's social media presence and a dedicated web site. Our long-term goal is to institutionalize the Census within the park and Tucson community so that it will continue to bring people and saguaros together in science for many decades to come.

Introduction

Research on the saguaro cactus (*Carnegiea gigantea*) in Saguaro National Park (Fig. 1) goes back more than 80 years, beginning soon after establishment of the national monument in 1933 (Ahmark and Swann 2009). This was partly due to Saguaro's association with the University of Arizona, but also due to concerns about the death of many saguaros in the late 1930s. The first study plots in the Rincon Mountain District (RMD) were established in 1941. Although additional sites were set up in the Tucson Mountain District (TMD) after it was added to the monument in 1962, most research occurred in an area in RMD known as the Cactus Forest. This magnificent stand of saguaros, located near the east end of Broadway Boulevard, had spurred the creation of the monument, which was elevated to national park status in 1994.

Results of long-term monitoring in the Cactus Forest (Pierson and Turner 1998, Orum et al. 2016, Conver et al. 2017) indicates that the saguaro population was in decline there for much of the 20th century, as older saguaros that died were not replaced by younger ones. However, in the late 1960s, young saguaros began to appear (Orum et al. 2016), and saguaro establishment surged in the 1980s. Why saguaros declined and then increased in the Cactus Forest can never be fully understood, but most scientists believe that the decline was due to environmental degradation caused by wood-cutting and cattle grazing,

in combination with cold climatic conditions in the mid-1900s. The re-growth of "nurse trees", and warmer winter temperatures and increased precipitation in the 1980s likely favored survival of young plants that protect saguaros.

Although saguaro research in the park prior to 1990 received some support from the National Park Service (NPS), most efforts were by University of Arizona scientists and occurred in the Cactus Forest, which was not necessarily representative of the entire park. However, in 1990, NPS established 45 randomly-located saguaro monitoring plots (Duriscoe and Graban 1991) as part of a larger effort to study air pollution impacts on park resources. In addition to focusing on epidermal browning, believed to be associated with air quality, the program was designed to monitor the long-term health of the saguaro population. Duriscoe and Graban (1991) did not specify how frequently sampling should occur, but park staff felt that every 10 years was an appropriate interval for this long-lived plant. Thus, in an effort that came to be known as the Saguaro Census (because it coincided with the decadal US Census) the Duriscoe-Graban plots were re-sampled in 2000 (Turner and Funicelli 2000) and 2010 (O'Brien et al. 2010, Winkler et al. 2018).

In 2020, our major goals were to fully survey all 45 Saguaro Census plots for the first time since 1990, as well as to survey 11 smaller historic plots re-located by Funicelli and Turner (2002). In addition, we surveyed perennial plants on 10 x 10 m subplots within each large plot to address other vegetation associated with saguaros; the results of these surveys will be reported in the Phase II report for WNPA. Education and citizen science were a major part of this project. We hoped to make long-term monitoring of saguaros at Saguaro National Park more relevant by bringing people together over a plant that means so much to the Tucson community, while providing new data on how the population is changing in response to on-going land use and climate change.

Methods

Field methods. We sampled the 45 plots established in 1990, 25 in RMD (Figure 2) and 20 in TMD (Figure 3). Each plot is 200 m x 200 m (4 ha). Plots within TMD are distributed randomly because the entire district is considered saguaro habitat, but RMD contains many areas where saguaros are absent or in very low numbers due environmental factors such as high elevation, floodplains, or very poorly drained soils. Therefore, RMD plots are located within areas considered saguaro habitat based on existing vegetation maps (Duriscoe and Graban 1991).

We followed a detailed protocol developed in 2010 based on interviews with Dale Turner and Carianne Funicelli Campbell (O'Brien et. al 2010). Due to limited resources, Turner and Funicelli (2000) sampled only 18 of the 45 study plots. O'Brien et al (2010) fully sampled only 37 plots, extrapolating results from subsamples of 8 plots. In 2020, we fully sampled all 45 plots, as well as the historic plots also studied by Funicelli and Turner (2002) that had been established either in 1941 or 1975.

We collected data with citizen scientists (Figure 4) on most plots during October 2019 – March 2020 (hereafter, we refer to all results as "2020"). Due to the Covid-19 pandemic we stopped volunteer surveys in March and completed the final plots using small

internship crews. Volunteer groups were typically 15-20 inexperienced volunteers divided into teams of 3-4 people, each led by an experienced park intern. Teams moved across the plot in swaths approximately 20 m wide, marking each saguaro with a numbered pin flag and recording GPS coordinates. We measured saguaros <4 m tall using a metric folding rule; for taller saguaros, we estimated height using a clinometer and metric tape measure. We also counted the number of bird holes (round holes that showed evidence of an inner chamber), branches, and cristate (crested) saguaros. After each pass, an independent team did a second pass to look for any unflagged saguaros.

Data analysis. We entered the data into an Excel spreadsheet, which was checked by a second technician. We examined changes in the saguaro population from 1990-2020 by directly comparing the number observed on each plot and summing by district and habitat. For comparisons with 1990 and 2000 data we excluded saguaros <10 cm in height because very small saguaros were not sampled in those surveys. In comparing saguaro totals among districts and habitat we used the habitat definitions of Turner and Funicelli (2000): "bajada", the lower slopes of each district, with fine soils present; "slopes", bedrock-dominated steep hills; and "foothills", intermediate areas with mixed bedrock, boulders, and generally coarse soils.

We estimated the number of saguaros in the park following the method of Turner and Funicelli (2000), which is based on the area of the park in 2000 even though it has expanded slightly since then. To estimate saguaro ages based on height, we used the Steenbergh-Lowe model for the Rincon and Tucson Mountain Districts (Steenbergh and Lowe 1983). To estimate the potential for flower and fruit production, we combined the number of saguaro stems ≥ 2 m tall with the number of their branches and divided by the number of saguaros ≥ 2 m in each district and habitat. Detailed survey and analysis methods are available in a technical report in currently in preparation.

Results

Population size. We counted and measured 21,517 saguaros on the 45 Census plots, 12,519 at TMD and 8,666 at RMD (Figure 5). We also collected data on 2,827 saguaros on 11, 2-ha historic plots that we analyzed separately. The number of saguaros observed on the 45 plots ranged widely, from a low of 56 in a bajada plot at RMD to a high of 1,746 on a foothills plot at TMD. The mean number of saguaros observed per plot was 350 (SE = 273) in the RMD and 626 (SE = 380) at TMD.

Excluding plants <10 cm we observed 8,773 more saguaros in 2020 than in 1990 and 1,145 more than in 2010. We estimate there are currently 2,032,306 saguaros (SE = 788,631) in the park, excluding individuals <10 cm. This is slightly higher than estimates in 2010 (1,896,030) and 2000 (1,624,821), and approximately 43% higher than the number estimated in 1990 (1,145,784) by Turner and Funicelli (2000). Saguaro density varies throughout the park (Figure 6). We observed fewer saguaros in the lower bajada areas of both districts than in other areas. While there is not a clear geographic pattern of where we found more young saguaros, they were most abundant in rocky slope areas of both districts. For saguaros >2 m, the mean number of stems/saguaro was highest on the bajada (3.14), intermediate in foothills (2.33) and lowest on slopes (2.28).

Age structure. In 2010, small saguaros (<1 m in height) were 44% of the total observed, and greatly outnumbered saguaros in other size classes in both districts (Figure 7). In 2020, this smallest size class still had the greatest number of saguaros, but was only 32% of the total observed, as small saguaros moved to larger size classes and were not all replaced. In all size classes >1 m and less than 11 m, we observed more saguaros in 2020 than in 2010 and 1990 (Figure 7).

Figure 8 shows the estimated year of germination for each of the 21,517 saguaros observed during 2020, based on the Steenbergh-Lowe growth models specific to each district. The curves for TMD and RMD are slightly different, as RMD had a longer period of poor establishment than TMD. A large number of new saguaros entered the population in the 1980s, but this surge ended in the early to mid-1990s and establishment has been low since, although we cannot reliably confirm the status of saguaro establishment since 2010 since it is so difficult to detect the smallest individuals.

Education, citizen science, and media

518 volunteers participated in the 2020 Saguaro Census, contributing 3,655 volunteer hours and 750 volunteer days. Groups were very diverse and included local high schools, businesses, hiking clubs, college groups, and outdoor and environmental groups (including WNPA staff – thank you!). We fulfilled all of the very ambitious education and citizen goals of the Census except that we did not offer a special Census program for elementary school groups due to the pandemic. A major success was our website (Saguaro Census 2020 - Saguaro National Park (U.S. National Park Service) (nps.gov), where volunteers could go before their Census event to learn how to prepare and why their work was important, and then visit afterwards to see photos of themselves at work and how their results compared to results from previous surveys on their plot.

We regularly provided updates through our social media pages, especially on Facebook and Instagram; some of our Instagram posts reached more than 50,000 people (Figure 9). We invited park staff and volunteers, and developed a range of interpretive products ranging from brochures to refrigerator magnets to recruitment posters. We gave a number of community talks and school pre-visits, and gave presentations to interpreters. We received significant media attention, with two front page articles in the Arizona Daily Star (Figure 10), and an episode on local public TV's Arizona Illustrated. The Census was also featured in an article on saguaros and climate change in the Washington Post.

Discussion

Changes in the saguaro population. Knowledge about the health of the saguaro population in Saguaro National Park is important for park managers, visitors, and the many people across the globe that are interested in this iconic plant and the national park that was created to preserve and interpret it. The results of the 2020 Saguaro Census confirm the patterns that emerged from the 2010 Census. The large number of relatively young saguaros just beginning to reach reproductive age is a positive sign, and reflects the survival of many saguaros that germinated, in both districts, in the last four decades

of the 20th century. While many areas of the park did not see the dramatic declines observed in the Cactus Forest, the surge of new saguaros, especially in the 1980s, occurred in both districts and all habitats.

Equally clear is that the low numbers of very young saguaros found in 2010 also reflects a long-term trend. Because saguaros are so hard to observe when they are less than 10 years old, the 2020 results are a reliable confirmation that establishment began to fall more than 20 years ago – and probably a few years earlier because of evidence that saguaros have been growing more slowly during the drought (J. Conver, unpubl. data). Winkler et al. (2018) found a strong association between saguaro establishment and the Palmer Drought Severity index, suggesting that declining establishment in the park is likely related to the long drought in Arizona since the mid-1990s, driven by both decreasing precipitation and higher temperatures (Seager and Vecci 2010), that is continuing even into 2021. However, we did find a few small saguaros during the 2020 Census, especially on plots located in the foothills and on rocky slopes where we also found young saguaros in 2010. These findings provide further confirmation of speculation by Winkler et al. (2018) that rock crevices provide unique hydrological conditions that allow saguaros to survive during dry periods.

The Saguaro Census complements long-term research in Saguaro National Park (e.g., Orum et al. 2016) that allows the park to make broad inferences about the health of the saguaro population over an appropriate time scale for a long-lived species in a national park. In addition, as a high-profile public event, the Census is a great way to bring science and the concept of long-term ecological change to broad community audience.

Acknowledgements

We are grateful for the support of Western National Parks Association, which also helped make the Saguaro Census possible in 2000 and 2010. Additional funds were provided by the Friends of Saguaro National Park and National Park Foundation.

Because the Saguaro Census is such a huge effort we cannot thank all of the many participants by name, but are grateful to everyone who contributed. We do want to call out our interns, including Austin Berry, Celeste Browne, Alexis Cardenas, Emily Fule, Julia Jones, Keeley Lyons-Letts, Adalee Martinez, Celeste Meyer, Lupe Sotelo, Maya Tainatongo, Olivia Thorp, Althea Weeks and Jaimin Wilson. Thanks especially to Jesus Duenas, who played a major role in organizing the crews. We thank superintendent Leah McGinnis and the other staff of Saguaro National Park who helped with logistics, safety, volunteer support, outreach, and other aspects of the Census. In particular: Dan Beckman, Steve Bolyard, Jeff Conn, Andy Fisher, Nicole Gonzalez, Perry Grissom, Luke Hetherington, Richard Hill, Nick Huck, Lauren Kramer, Meritt Kramer, Chip Littlefield, Jeff Martinelli, Nic Perkins, and Adam Springer. Thanks also to our regular volunteer leaders Martha Tullis, Alejandro Nicolette, Mely Bohlman, and Ted Rowen.

We're grateful for the support of the many organizations who helped contribute and organize volunteers, including Sky Island Alliance, Ironwood Tree Experience, Sunnyside School District, Arizona College Preparatory Academy, Arizona Conservation

Corps, University of Arizona Women in Science and Engineering, Tucson Electric Power, Academy of Tucson, Salpointe High School, Tucson Mountains Hiking Club, and Arizona Master Naturalists, and other informal groups. Adventure Scientists contributed a large number of enthusiastic volunteers who helped us complete the most distant, difficult plots.

Dan Duriscoe and Sandy Graban established the Saguaro Census in 1990. In 2000, Dale Turner, Pam Anning, Mark Holden, and Carianne Funicelli Campbell led the effort. Carianne, Mark, and Dale all volunteered in 2020 and we expect to see them again in 2030! We also benefitted from scientific guidance from Daniel Winkler, Theresa Foley, and Joshua Conver. We are forever in debt to saguaro scientists Tom Orum, Nancy Ferguson, Bill Peachy, and the late Ray Turner, Warren Steenbergh, Charles Lowe, Stan Alcorn, and Rod Hastings. We hope that we are as successful as they have been in passing the care of Saguaro National Park's saguaros to the next generation.

Literature cited

Ahnmark, E. and D. E. Swann. 2009. A history of saguaro cactus monitoring in Saguaro National Park, 1939–2007. Nat. Res. Tech. Rept.NPS/SODN/NRTR–2007/093.

Conver, J. L., T. Foley, D. E. Winkler, and D. E. Swann. 2017. Demographic changes over >70 yr in a population of saguaro cacti (Carnegia gigantean) in the northern Sonoran Desert. J. Arid Env. 139:41-48.

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. NPS.

Funicelli, C. S. and D. S. Turner. 2002. Relocation and restudy of historic saguaro plots at Saguaro National Park. Final report to Saguaro National Park, Tucson.

O'Brien, K., D. E. Swann, and A. Springer. 2010. Saguaro Census 2010 Final Report. Unpubl. rept., Saguaro National Park, Tucson.

Orum, T.V., N. Ferguson, and J.D. Mihail. 2016. Saguaro (*Carnegiea gigantea*) mortality and population regeneration in the Cactus Forest of Saguaro National Park: seventy-five years and counting. PLos ONE 11:e0160-899.

Pierson, E. A. and R. M. Turner. 1998. An 85-year study of saguaro *(Carnegiea gigantea)* demography. Ecology 79(8): 2676 – 2693.

Seager, R. and G. A. Vecci. 2010. Greenhouse warming and the 21st century hydroclimate of southwestern North America. Proc. of Am. Acad. Of Sci. 107:21277-21282.

Steenbergh, W. F. and C. H. Lowe. 1983. Ecology of the saguaro: III. Growth and demography. Scientific Monograph Series 17. NPS, Washington, D.C.

Swann, D.E., A.C. Springer, and K. O'Brien. 2011. Using citizen science to study saguaros and climate change at Saguaro National Park. Park Science 28(1): 65-68.

Turner, D. S. and C. S. Funicelli. 2000. Ten-year resurvey of epidermal browning and population structure of saguaro cactus (*Carnegiea gigantea*) in Saguaro National Park. Tech. Rept. 69, USGS Son. Des. Field Sta., The University of Arizona.

Winkler, D. E., J. L. Conver, T. E. Huxman, and D. E. Swann. 2018. The interaction of drought and habitat explain time-space patterns of establishment of saguaro (Carnegiea gigantea). Ecology 99:621-631.

Figures

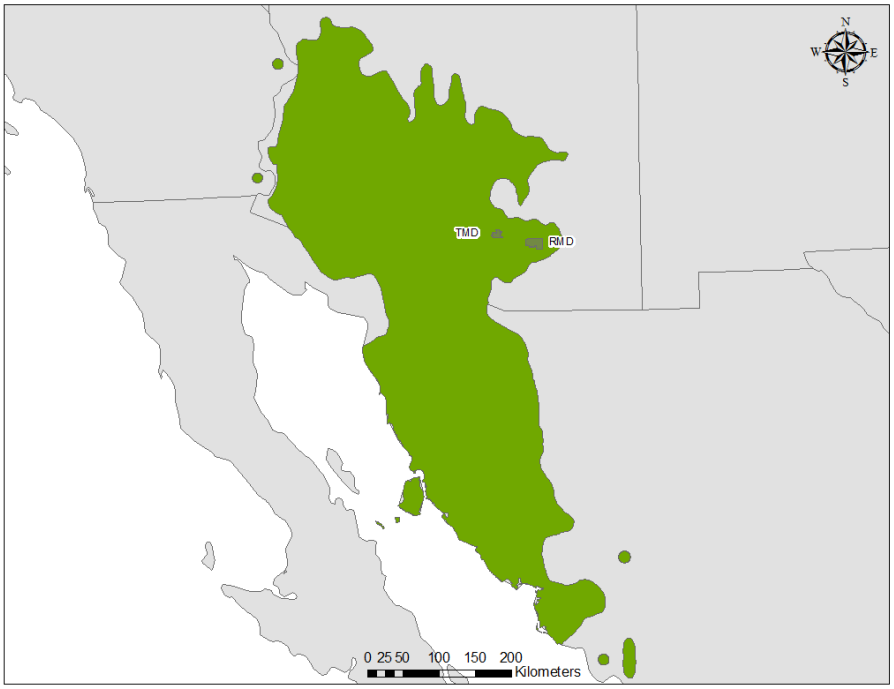

Figure 1. Range of the saguaro cactus, showing locations of the two districts of Saguaro National Park. Saguaros occur in Arizona and Sonora, Mexico, with a few in California.

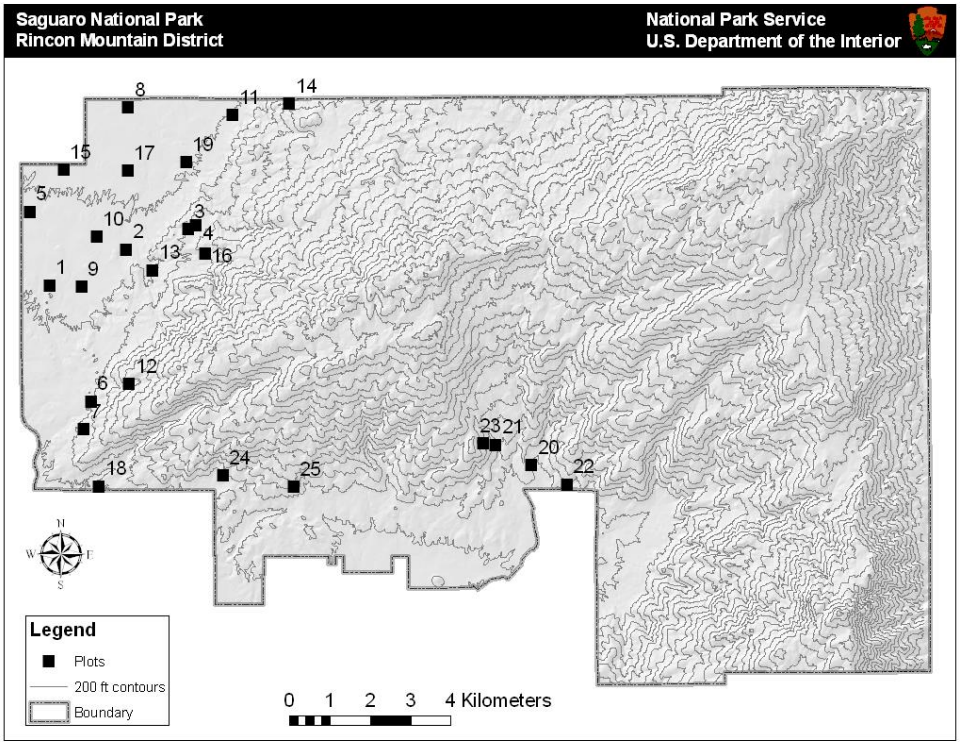

Figure 2. Location of 25 Saguaro Census plots in the Rincon Mountain District.

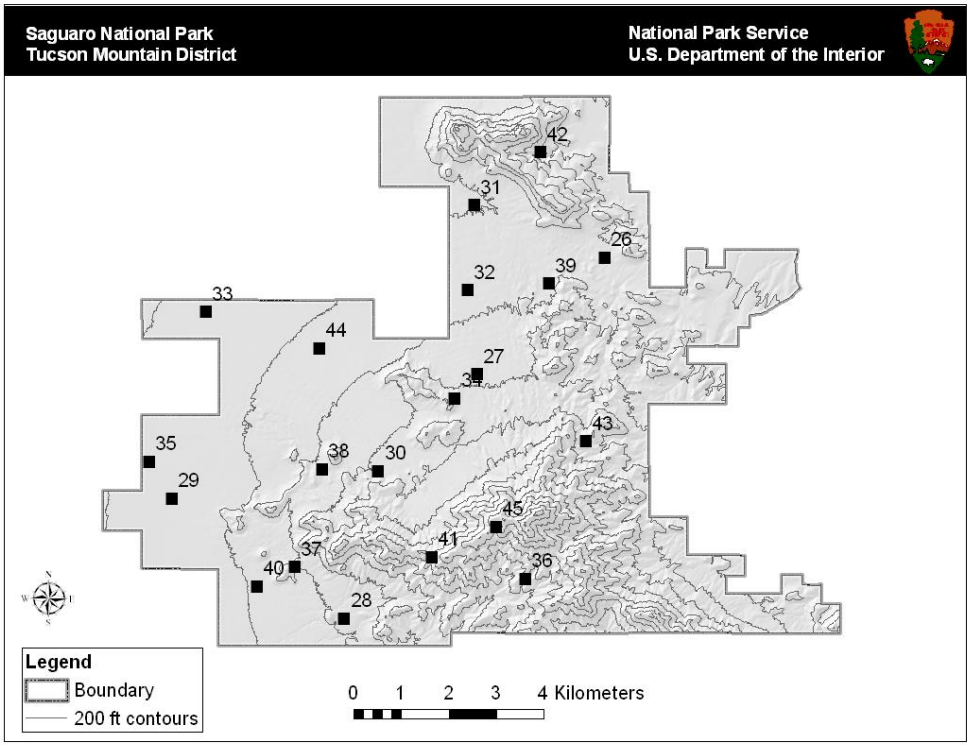

Figure 3. Location of 20 Saguaro Census plots in the Tucson Mountain District.

Figure 4. Measuring saguaros with a folding rule (left) and clinometer (right).

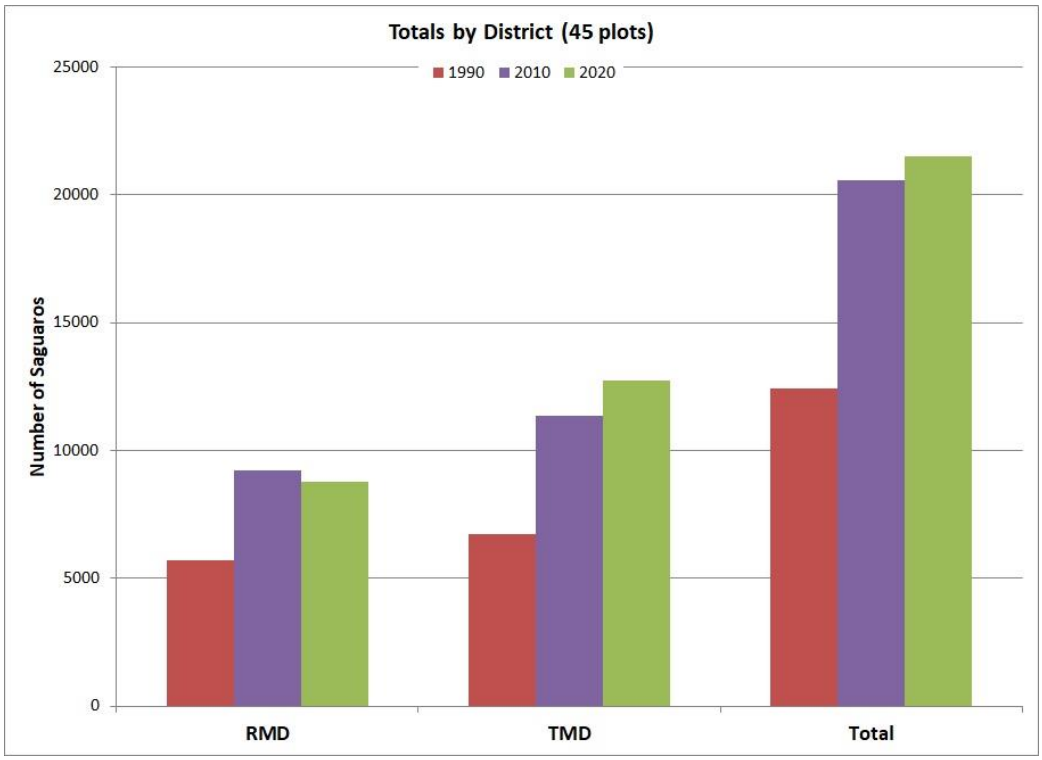

Figure 5. Number of saguaros recorded on Census plots, 1990, 2010, and 2020. 2010 results include extrapolation based on subsamples for 8 of the 45 plots.

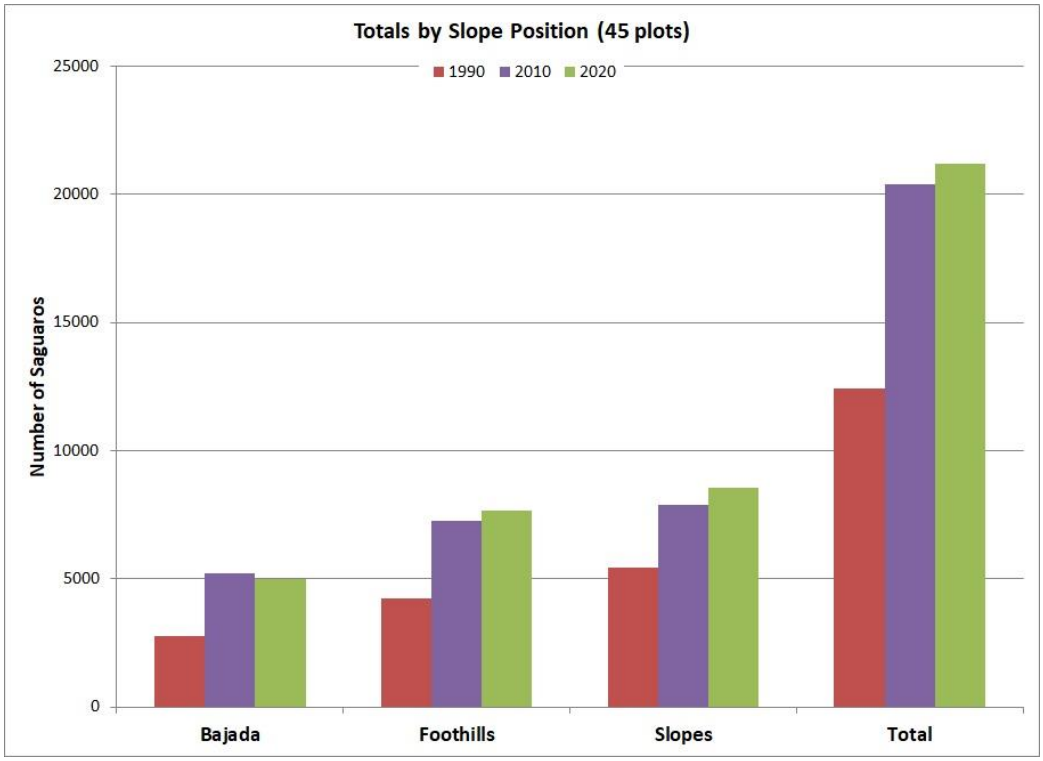

Figure 6. Number of saguaros observed by habitat type in 1990, 2010, and 2020.

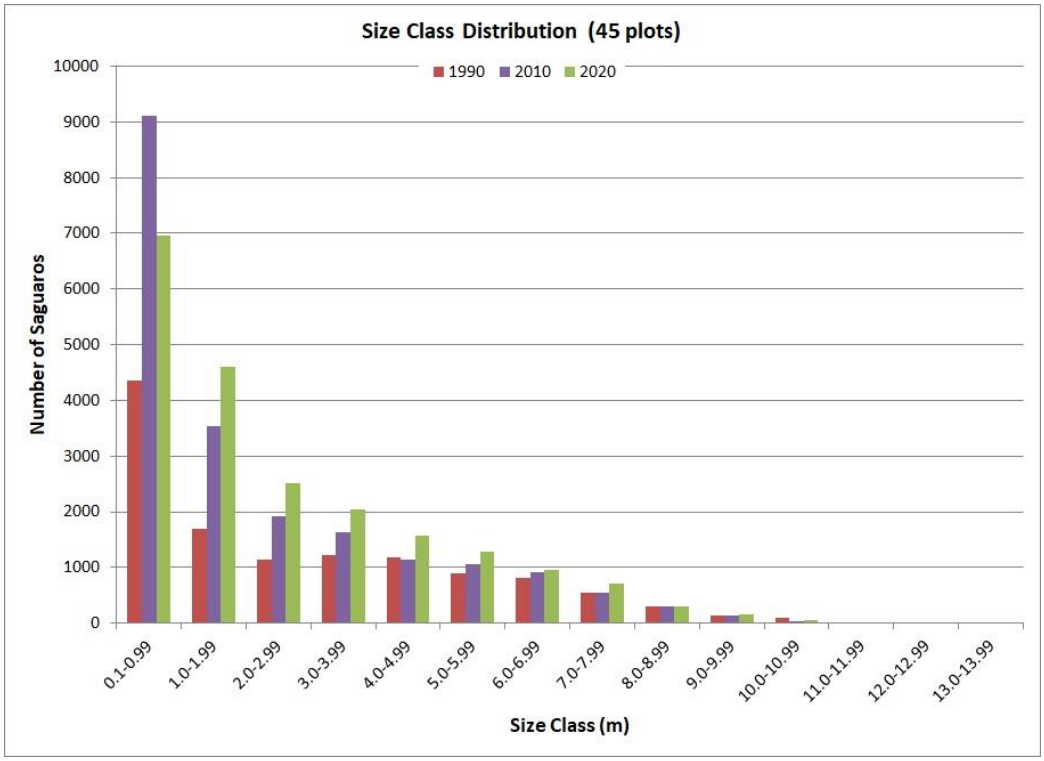

Figure 7. Distribution of saguaros in 1990, 2010, and 2020 by 1-meter size classes.

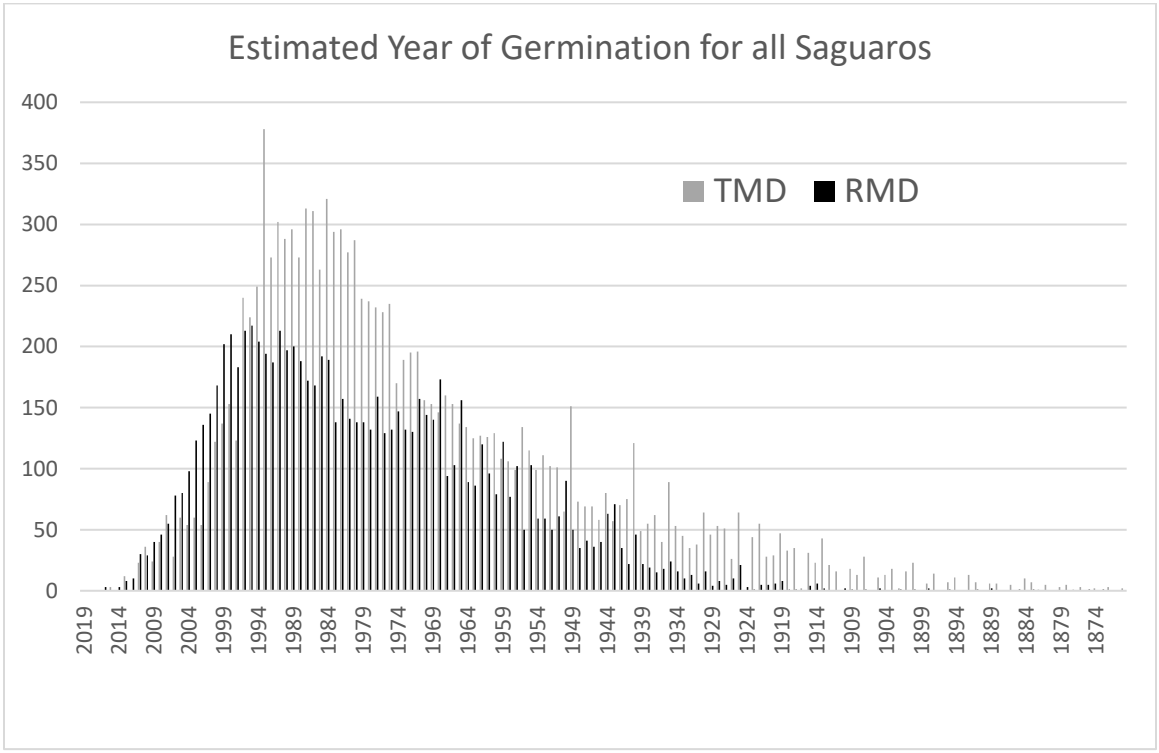

Figure 8. Estimated germination year of saguaros observed in 2020 in TMD (grey) and RMD (black). Germination peaked in both districts in the 1980s and early-mid 1990s.

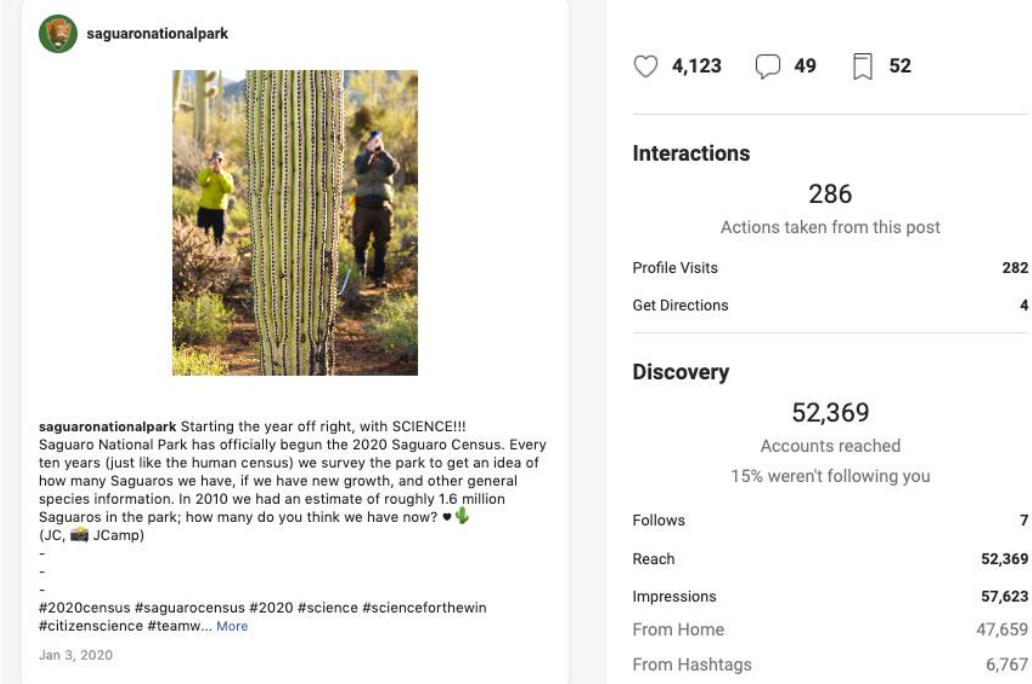

Figure 9. Social media was an important part of the educational aspect of the 2020 Saguaro Census; this is a post from January 2020 on the park's Instagram.

Figure 10. The 2020 Saguaro Census received significant media attention, including two front page articles in the local Tucson Daily Star (March 2021 shown here), the Washington Post, and a local PBS special on Arizona Illustrated.