Saguaro Census 2010 Final Report

Report to Saguaro National Park and the Friends of Saguaro National Park

Saguaro student interns and volunteer citizen scientists, Saguaro Census in Tucson Mountain District, Saguaro National Park, April 2010

August 2011

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Acknowledgements
This project was made possible by grants from the Western National Parks Association, the Friends of Saguaro National Park, and the Tucson Cactus and Succulent Society. We are particularly grateful for the support of the Friends and WNPA for all that they do to support monitoring and protection of natural resources at Saguaro National Park. In addition, educational aspects of this project were supported by entrance fees paid by visitors to the park.

We thank superintendent Darla Sidles and the entire staff of Saguaro National Park, who helped with logistics, safety, volunteer support, outreach, and many other aspects of the Census. Key staff are too numerous to list, but include in particular Mike Ward, Mike Jones, Kris Ratzlaff, Mike Montalvo, Justin Kolb, Paul Austin, Robert Stinson, Becky MacEwen, Chip Littlefield, Tarah Bigger, Johnny Ortiz, Alexis Sanchez, Chris Pruden, Emma Fajardo, Rafael Rojas, Tiffany Alvarez, Kelly Flickinger, and Richard Hill. We are also grateful to NPS personnel from the Sonoran Desert Network Inventory and Monitoring Program, including Jeff Balmat, Andy Hubbard and Cheryl McIntire, and to teachers Dan Bell and Lynne Dehner. SCA intern Kimberly Diamond organized volunteers and educational aspects of the Census and did a terrific job.

Most importantly, we thank the more than 300 volunteers who did most of the actual field work for Census. It was a pleasure working with them! Special thanks go to Albi von Dach, Martha Tullis, Susan Paul, Fred Roberts, Matt Christensen, Bernice Isaacs, Gene Isaacs, Tom Kimmel, Rick Fawcett, Patty Fawcett, Katie Gray, and Carianne Funicelli Campbell, who contributed hours above and beyond. A special thanks to Paul Rosenberg, who explained the Census to many volunteers and helped edit the written protocols. Thanks also to Sarah Williams and the Sky Island Alliance for providing a large number of great volunteers.

Finally, we are grateful for Dan Duriscoe and Sandy Graban, who established the Saguaro Census in 1990, and Dale Turner, Pam Anning, Mark Holden, and Carianne Funicelli Campbell for their efforts in the 2000 Census.

Last but not least, the Saguaro Census is largely due to the vision and dedication to long-term monitoring of Sonoran Desert vegetation by Tom Orum, Nancy Ferguson, and Ray Turner, as well as by the late Warren Steenbergh, Charles Lowe, Stan Alcorn, and Rod Hastings. We are grateful for their many contributions to Saguaro National Park, and hope that we are as successful as they have been in passing the park's saguaros onto the next generation.

Executive Summary
We studied the demographics of the saguaro cactus (*Carnegiea gigantea*), Saguaro National Park's signature species, at the park during the 2010 Saguaro Census. The Census is based on 45 plots of 4 ha each that were originally established in both districts of the park in 1989-1990 by Duriscoe and Graban (1991, 1992), and re-surveyed in 2000 by Turner and Funicelli (2000).

Compared to 1990 and 2000, we observed many more saguaros on Census plots, particularly young saguaros (<1 m in height). In the Rincon Mountain District, the number of saguaros observed has increased 60.0% since 1990 and 40.7% since 2000. In the Tucson Mountain District, the number has increased 67.4% since 1990 and 10.3% since 2000. Using the same method as Turner and Funicelli (2000), we estimated that there are approximately 1,896,030 saguaros in Saguaro National Park. In 2000, they estimated that there were 1,624,821 saguaros in the park, and had been 1,145,784 in 1990.

Based on height-age models, we estimated when young saguaros have entered the population. Our results indicate that saguaro recruitment was high during the 1970s through the early 1990s throughout the park, but has declined during the past 10-15 years. Nevertheless, the saguaro population in both districts of Saguaro National Park now has a large number of young saguaros. Given the current trends, we expect that the landscape view of the park, particularly in the Rincon Mountain District's "Cactus Forest" area near the Visitor Center and Loop Road, will once again begin to resemble the view seen by visitors when the park was first created in the 1930s.

The 2010 Saguaro Census was the first in which volunteer "Citizen Scientists" conducted nearly all of the field work under the direction of student employees and interns, and this aspect of the Census was a great success. It is hoped that the Census will continue as a long-term monitoring effort at Saguaro National Park, with plots surveyed every 10 years into the future.

Introduction

Studies of the saguaro cactus (*Carnegiea gigantea*) in Saguaro National Monument (Figure 1; the monument became Saguaro National Park in 1995) began soon after the monument was established in 1933. This was in part due to the association of the park with the University of Arizona, but largely due to concerns about the death of many large saguaro cacti in the late 1930s. The first study plots in the Rincon Mountain District (RMD) were established in the early 1940s, and plots were established in the Tucson Mountain District (TMD) soon after it was protected in 1962.

Research and monitoring of the saguaro in Saguaro National Park dates back nearly to the beginning of the park and has a complex history (McAuliffe 1993, Ahnmark and Swann 2009). Several programs stand out. Most notably, in 1941, every saguaro in an entire 1 mi^2 (640 acres) section ("Section 17") east of Freeman Road was measured and mapped as part of a long-term study to determine whether removing saguaros showing signs of mortality would increase the survival of healthy saguaros (Gill and Lightle 1942). Within Section 17, several smaller study areas were also established. Five of six 2-ha study plots created in 1941 by Lance Gill and Paul Lightle were re-located and re-surveyed by Warren Steenbergh and Charles Lowe in the 1970s (Steenbergh and Lowe 1977, 1983), who also added six similar plots; all 11 of these plots were re-surveyed by Carianne Funicelli Campbell and Dale Turner in 2001 (Funicelli and Turner 2002). On six other 4-ha plots in Section 17, annual measurements of individual saguaros were taken by a series of researchers, most notably plant pathologist Stan Alcorn. These saguaros are currently being monitored by Tom Orum and Nancy Ferguson, providing a continuous 65-year record (Orum et al., *in review*). In addition, in the 1960s, Ray Turner and Rod Hastings set up a series of 9 long-term monitoring plots in Arizona and Sonora, Mexico, including one plot in RMD and one in TMD. These plots have been re-surveyed approximately every decade and provide the best record of changes in saguaro populations across the species range (Turner 1995).

Although these and many other research activities have received some support by the National Park Service (NPS), most were independent efforts by non-NPS scientists and focused on lower elevation areas in the RMD. In 1989-1990, as part of a larger effort to study epidermal browning sponsored by the NPS Air Quality Division (see review in McAuliffe 1993), Dan Duriscoe and Sandra Graban established 45 saguaro study plots in the park (Duriscoe and Graban 1991). In addition to providing data on epidermal browning, the new study program was intended to provide baseline data for long-term monitoring. Unlike other long-term study plots in the park, the 45 plots were randomly located throughout prime saguaro habitat in both districts, although those at RMD were limited to previously-identified high quality habitat for saguaros. Duriscoe and Graban (1991) measured the heights of all small saguaros (< 2 m) on each of the 45 plots. They also estimated the heights of 30 saguaros that were $\geq$ 2 m and used these data to estimate the heights of all larger saguaros on each plot.

Although Duriscoe and Graban (1991) did not specify how frequently the 45 plots should be re-sampled, the importance of their effort was immediately recognized. In an

otherwise-critical review of saguaro research at Saguaro National Park, McAuliffe (1993) wrote that "These plots represent a considerable monitoring effort, and the data collected from them over time will provide extremely valuable information about saguaro recruitment and mortality throughout the monument." Park staff determined in 1999 that every 10 years would be an appropriate interval for monitoring. The Duriscoe-Graban plots were sampled again in 2000 (Funicelli et al. 2001, Turner and Funicelli 2000). Because sampling in both 1990 and 2000 coincided with the U.S. Census, the Duriscoe-Graban effort was named the "Saguaro Census," probably in 2000.

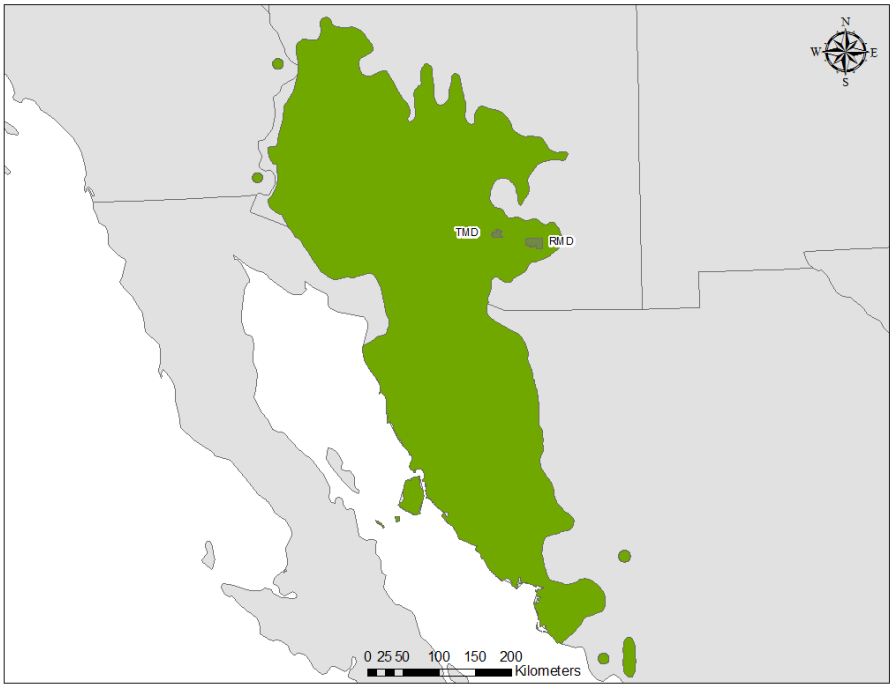

Figure 1. Range of the saguaro cactus, showing location of Saguaro National Park. Spatial data from Little (1976).

It is important to note that both Duriscoe and Graban (1991) and Turner and Funicelli (2000) conducted a large number of activities now associated with the Saguaro Census (Table 1). Some of these activities, such as the mortality transects established by Duriscoe and Graban (1991), have never been repeated. Others, such as vegetation transects, were not part of the 1990 activities but were added in 2000. In addition, due to limited resources, Turner and Funicelli (2000) only counted and measured saguaros on 18 of the original 45 study plots.

Table 1. Summary of Saguaro Census activities in 1990, 2000, and 2010.

Monitoring Component	1990	2000	2010
Census plots (n=45)– count and measure saguaros	Yes	Yes[‡]	Yes[†]
Intensive surveys of 30 selected saguaros on the 45 plots (epidermal browning, # branches, etc.)	Yes	Yes	No
Detailed vegetation map (10 m^2 within the 45 plots)	Yes	Yes	Yes
"Mortality transects" - surveys to compare mortality rates of green and brown saguaros	Yes	No	No
Vegetation transect (50 m) associated with the 45 plots	No	Yes	No
Re-survey of 11 historic plots established in 1941 and 1975	No	Yes	Yes
Survey of high elevation saguaro plots outside of prime saguaro habitat	No	No	Yes

[‡]The 2000 Census was conducted on 18 plots.
[†]The 2010 Census was conducted on 37 plots. Subsamples were taken from 8 plots.

Similarly, because our resources in 2010 were even more limited than in 2000, we selected some activities but not others. We chose to re-survey the permanent 10 x 10 m vegetation subplots (reported separately in Funicelli et al. 2001). However, after discussion with these authors we decided not to measure epidermal browning on the 30 large saguaros selected on each plot. We also did not re-sample Duriscoe and Graban's (1991) mortality transects, or Funicelli et al.'s (2001) vegetation transects. However, we re-sampled historic plots (Funicelli and Turner 2002), and established plots in new locations at RMD that were outside the original area selected by Duriscoe and Graban (1991). In addition, we mapped the distribution of the invasive grass buffelgrass (*Pennisetum ciliare*) on all 45 plots. Results from other Census activities in 2009-2010 are reported in separate reports for vegetation subplots (Springer et al. 2011a), historic plots (MacEwen et al., *in prep*.), and new "ecotone" plots (Springer et al., 2011b).

Long-term monitoring at Saguaro National Park (Turner 1995, Orum et al. in review) indicates that, at least in low desert areas of the RMD, the saguaro population declined throughout the decades from the 1940s throughout the 1960s. In the early 1970s, a surge of recruitment began, even as larger saguaros continued to decline. In 2000, Turner and Funicelli (2000) estimated that this increase was continuing, and that saguaros had increased 35% in both districts since 1990. Why the saguaros declined and then increased is not well 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 middle years of the 20th century (McAuliffe 1993). Increasingly warmer winter temperatures since the 1970s combined with increased precipitation in the 1980s likely favored survival of young saguaros. However, warmer temperatures may also favor buffelgrass and other invasive grasses (Stevens and Falk 2009) and promote low elevation wildfires that may adversely impact saguaros, a species that is killed by fire.

The major goal of the 2010 Census was to focus on demographic change in the saguaro community since 1990 and 2000. In addition, an important secondary goal in 2010 was to better establish the Census as a monitoring program by creating written sampling protocols. Finally, we sought to make long-term monitoring of saguaros at Saguaro National Park more relevant by recreating the Census as a public-based Citizen Science program. We hoped to involve large numbers of volunteers who could talk about the Census to others, and we especially wanted to involve young people in the Census through the creation of educational and Service Learning programs.

Study Area

This project was conducted in Saguaro National Park, located near Tucson, Arizona (Figure 1). Forty-five plots were placed (in 1990), 25 in the RMD (Figure 2) and 20 in the TMD (Figure 3). The plots within the TMD are distributed randomly (using a spatial stratification method) throughout the district because the entire area is considered saguaro habitat. However, RMD contains considerable area where saguaros do not grow, or occur in low numbers, due to unfavorable environmental conditions such as high elevation (>8600 feet), riparian vegetation, or other reasons such as poorly drained soils. Here, the saguaro habitat was delineated using vegetation maps, before distributing plots spatially within that area (Duriscoe and Graban 1991).

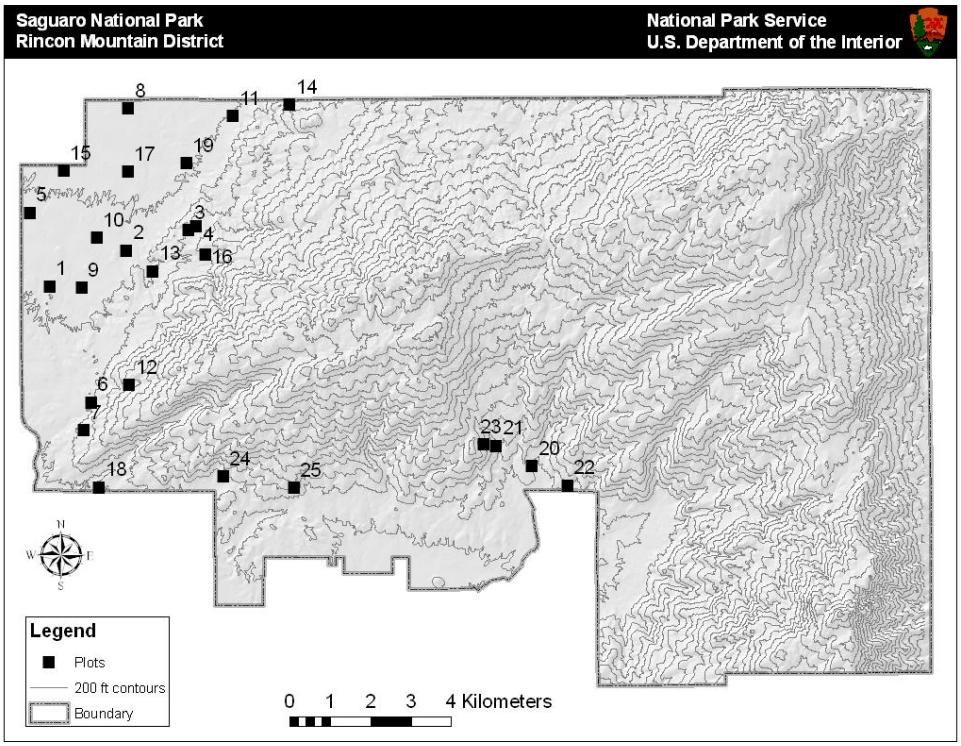

Figure 2. Saguaro Census plot locations in the Rincon Mountain District of Saguaro National Park.

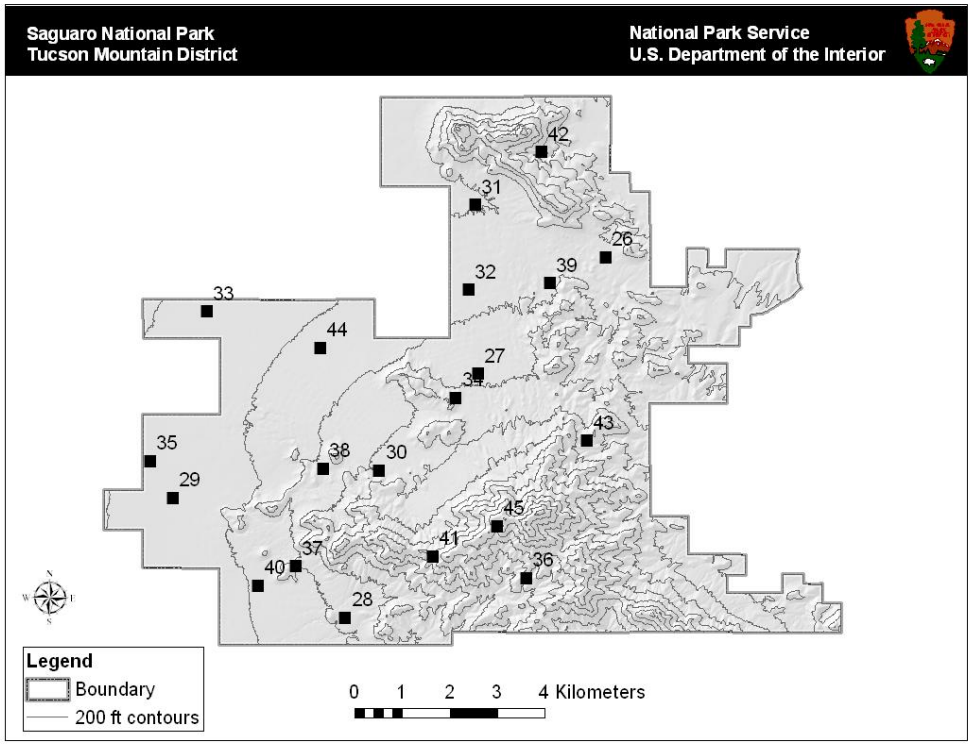

Figure 3. Saguaro Census plot locations in the Tucson Mountain District of Saguaro National Park.

Methods

Field methods. We used the 1990 and 2000 Census reports (Duriscoe and Graban 1991, Turner and Funicelli 2000) and interviewed Dale Turner and Carianne Funicelli Campbell in order to follow as closely as possible the methods used in previous studies. For detailed sampling protocols, see Appendix D. We sampled saguaro plots from August 2009 through October 2010, with the majority of plots sampled between November 2009 and March 2010 (hereafter, for simplicity, we refer to all results as "2010'). We located individual plots using Garmin 76S GPS units and corner coordinates (Appendix A). In most cases these corners were still marked with a piece of rebar with a silver-colored cap from the 2000 Census, but where they were not we estimated the location using GPS. We did not replace missing rebar and caps in 2010. We used the GPS unit to locate all the plot corners and sides, and placed flagging at approximately 20 m intervals along each of the four sides in preparation for each survey.

Within each plot, we systematically searched for, then counted and measured all saguaros. We generally worked with large groups of approximately 15-25 experienced and inexperienced volunteers, visiting a plot that had been flagged in advance. Following a short training, we broke volunteers into teams of approximately four people, with at least one experienced volunteer or park staff per group who could train volunteers and coordinate with the day's crew leader. The crew leader was responsible for data quality control, safety, and managing the teams' progress across the plot, including flagging the within-plot perimeter of each search effort.

As teams moved across the plot in a swath approximately 20 m wide, they marked each saguaro encountered with a numbered pin flag, then measured it (Photos 1 & 2). We measured saguaros < 4 m tall using a metric tape measure or folding rule, to within 0.01 m. For taller saguaros, we estimated height within 0.1 m using clinometers and metric tape measures (Appendix D).

Photos 1 & 2. Student Conservation Association intern Kim Diamond and volunteer Lindsey Sloat flag small saguaros in the Rincon Mountain District, bajada habitat (L). Volunteer intern Tarah Bigger measures a saguaro in the Rincon Mountain District, rocky foothills habitat (R).

In addition, we counted the number of bird holes (round holes that showed evidence of an inner chamber) and branches (including all sizes of branches, ranging from "buttons" to fully developed branches). We recorded data on paper data sheets. Like Turner and Funicelli (2000), but unlike Duriscoe and Graban (1991), we measured or estimated the height of all saguaros on each sampled plot, regardless of their height. When all teams had completed a swath of approximately 20 x 200 m, the teams traded places and re-searched a different team's area to look for any unflagged saguaros. We measured any new saguaros and noted that they had been found on the return survey. We then made a third pass through the plot to pick up flags. This process was continued until the entire plot had been surveyed.

Due to time constraints, we did not completely survey all 45 plots. We completely surveyed 37 plots and surveyed subsamples of 8 plots (4, 12, 23, 25, 36, 41, 42, and 43). For subsampled plots, we sampled either 1/4 of the plot (4, 23, 36, 42), 1/8 of the plot (41) or 1/16 of the plot (12, 25, and 41); we determined the size of the sample based on the number of saguaros counted in that same plot during the previous Census. For sub-sampled plots we subdivided the 200 m x 200 m plots into a grid of 50 m x 50 m plots and then randomly selected one area. To estimate detectability of saguaros over time, including change of season from the early dry winter to the wet, green spring, we surveyed two plots twice during the study period.

Data analysis

All data were entered into an Excel spreadsheet by one technician, and then checked by a second technician. During the Census, beginning early in 2010, the raw data were graphically summarized for each plot and posted on Saguaro National Park's website for viewing by volunteers. For analysis, we followed the methods of Turner and Funicelli (2000). All saguaros < 2 m were categorized into size classes of 0.5 meters (e.g., 0.1-0.49 m, 0.5-0.99 m, 1-1.49 m, 1.5-1.99), and saguaros $\geq$ 2 m were categorized into size classes of 1 meter (e.g., 2-2.99 m, 3-3.99 m, etc.).

We examined the number of saguaros between 1990 and 2010 by directly comparing the number observed on each plot (excluding saguaros <10 cm; see below) and summing by district and habitat by age class. For the 8 plots that were sub-sampled in 2010, we estimated the total number of saguaros for the plot by multiplying the number of saguaros observed in each height class by the portion of the plot surveyed (i.e. a 1/16 subsampled would be multiplied by 16). For comparisons between 2000 and 2010 we directly compared the number observed on the 18 plots that were sampled during both surveys. We compared saguaro totals among districts and habitat. We defined habitat similar to Turner and Funicelli (2000) and retained their plot classifications: "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 also compared the number estimated for the entire park in 1990, 2000, 2010 using the methods of Turner and Funicelli (2000), which was based on the areas (all of TMD, and 5,253 ha considered to be saguaro habitat at RMD) sampled by the Saguaro Census, as well as additional areas of newly acquired lands that they considered to also be saguaro habitat. For this 15,331 ha, they assumed that their 18 plots formed a representative sample, and multiplied the mean density of these plots in each district by the saguaro habitat area in each district to estimate population size. Similarly, we assumed that our 45 plots and subplots formed a representative sample, and for consistency we also used 15,331 ha even though the area of the park has expanded slightly since 2010, and considerably since 1990.

To estimate the number of small saguaros not detected by our surveys, we used a detectability model based on data from six study plots in the RMD that are sampled annually (Orum et al., *in review*). This model estimates mean detection probability based

on age (using a growth model based on height) of known saguaros; that is, saguaros are assumed to have been present (but not observed) from their estimated year of germination until the year they were first observed. For example, Orum and Ferguson observed a mean of approximately 20% of 10-year old saguaros and 80% of 15-year old saguaros. We believe that this model is appropriate and conservative for the Saguaro Census, because although Orum and Ferguson are more experienced in finding small saguaros than our volunteers, we employ a much larger number of observers per unit area.

To estimate age distribution of saguaros in the park based on height, we used the Steenbergh-Lowe model for the Rincon Mountain District (Steenbergh and Lowe 1983). We used the RMD model for saguaros in both districts because saguaro growth is dependent on precipitation (Steenbergh and Lowe 1977, 1983). We were primarily interested in the age of saguaros less than 20 years old, and precipitation has been nearly identical in TMD and RMD during the past decade (Rojas et al. 2011).

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 this number by the number of saguaros ≥ 2 m in each district and habitat. We also compared the number of stems per plot for each district and habitat. We did a similar analysis (also using only saguaros ≥ 2 m in height) for bird cavities. To estimate the number of bird cavities in the park, we extrapolated the raw number cavities per plot to each district and the entire park, similar to how we estimated the number of saguaros in the park.

Results

We counted and measured a total of 20,372 saguaros on 37 plots and 8 sub-plots during 2010, 11,245 at TMD and 9,127 at RMD (Table 2, Figure 4). This total includes estimates based on subplots, but not saguaros (211 total) <10 cm in height. The number of saguaros observed on the 4-ha plots ranged widely, from a low of 65 saguaros in a bajada plot at RMD to a high of 1,772 on a foothills plot at TMD. The mean number of saguaros observed per plot was 365 (SE =75.86) in the RMD and 562 (SE = 82.62) at TMD. Due to the high variability among plots, the differences in number of saguaros in the two districts was not statistically significant ($t_{43} = 1.76$, $p = 0.086$). For a complete summary of all 2010 Saguaro Census data by plot, see Appendix C.

The number of saguaros observed on the 45 plots sampled in both districts in 1990 and 2010 was 7,960 greater in 2010 than in 1990 (Table 2). The number observed on the 18 plots sampled during all three surveys in 1990, 2000, and 2010 increased by approximately 1,700 saguaros between 2000 and 2010 (Table 2, Figure 4).

Using the same methods as Turner and Funicelli (2000), we estimate that there are approximately 1,896,030 saguaros in Saguaro National Park, 1,416,589 in TMD and 479,411in RMD (Table 2). This represents a 65.5% increase in saguaros in the park since 1990, and a 16.7% increase since 2000.

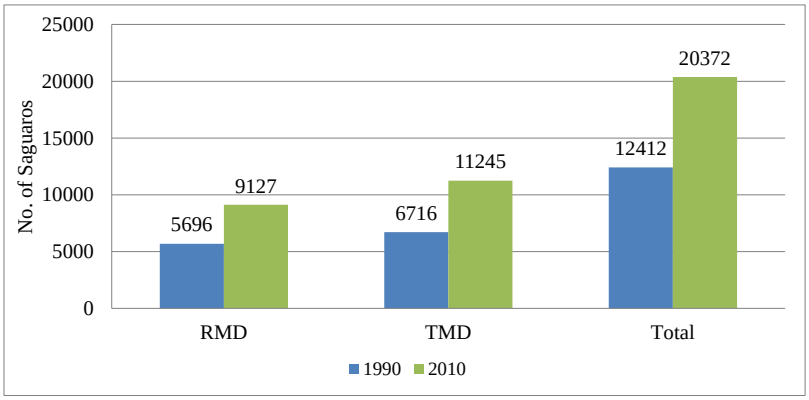

Figure 4. Number of saguaros observed on 45 plots sampled or sub-sampled in 1990 and 2010. Number of saguaros > 2 m on each plot estimated based on sub-sample in 1990; number of total saguaros estimated on 8 plots based on sub-sample in 2010.

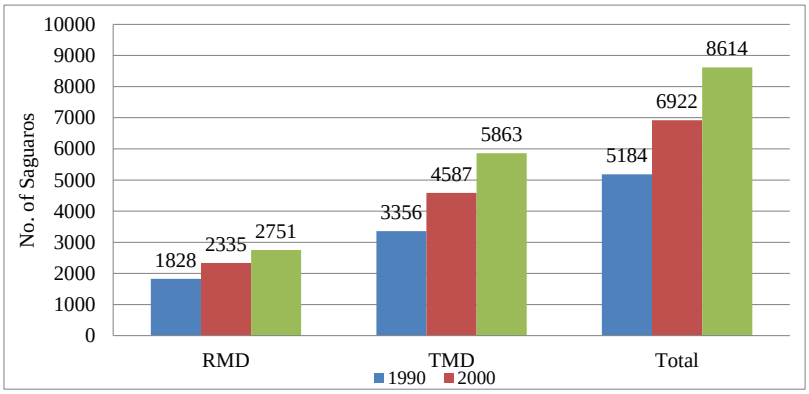

Figure 5. Number of saguaros observed on the 18 plots sampled or sub-sampled during all 3 Saguaro Census surveys, 1990, 2000, and 2010. Number of saguaros ≥ 2 m on each plot estimated based on sub-sample in 1990; all others are actual counts.

Table 2. Population estimates from the 1990, 2000, and 2010 Saguaro Census.

Year	District	No. observed	No. plots	Total ha surveyed	Saguaros per ha (st. err.)	Estimated no. of saguaros (st. err.)
2010 (45 plots)	RMD	9127	25	100	91.3 (19.2)	479,441 (100,753)
	TMD	11245	20	80	140.6 (22.4)	1,416,589 (225,546)
	Total	20372	45	180	112.7 (14.9)	1,896,030 (228,163)
2000 (18 plots)	RMD	2335	9	36	64.9 (12.9)	340,715 (67,729)
	TMD	4587	9	36	127.4 (25.1)	1,284,105 (252,456)
	Total	6922	18	72	96.1 (15.6)	1,624,821 (239,631)
1990 (45 plots)	RMD	5706	25	100	57.1 (10.7)	299,736 (56,139)
	TMD	6716	20	80	84.0 (12.0)	846,048 (121,307)
	Total	12422	45	180	70.5 (8.2)	1,145,784 (125,024)

The number of saguaros observed increased in all habitats over both the 20-year and 10-year periods (Figure 6); however, we did observe a decrease on one plot in the bajada at RMD (#5) that was sampled during both 2000 and 2010. Mean number of saguaros observed per plot was 273 (SE=34.28) in bajada, 519 (SE=114.76) in foothills, and 658 (SE=137.65) on slope. We found significantly more saguaros in bajada than in foothill and slope habitats combined ($t_{43} = 2.89$, $p = 0.006$). In general, saguaros were most abundant in foothills in TMD and least abundant in bajada in RMD, but considerable variability occurred within habitats.

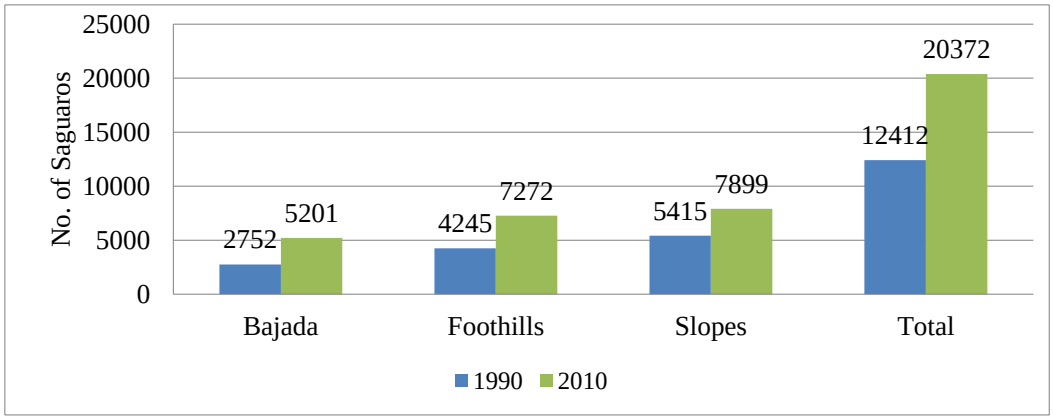

Figure 6. Number of saguaros counted on 45 plots, showing distribution across major habitat classifications (bajada, foothills and slopes).

Size and age structure. The number of saguaros in the smallest size classes (< 1 m) greatly outnumbered the number of saguaros in other size classes in both districts (Figures 7 & 8). In 2010, approximately 62% of all measured saguaros in Saguaro National Park were < 2 m in height. In addition, the number of saguaros observed in the two smallest size classes (0.1 m-0.99 m, and 1.0 m-1.99 m) consistently increased in both districts during 1990 and 2000, as well as between 2000 and 2010. In contrast, the number of taller saguaros counted (those ≥ 3 m in height) during the three surveys has generally remained similar over the past 20 years, with some size classes increasing and others decreasingly slightly (Figures 7 & 8).

Similarly, the overall age structure of the population of saguaros >10 cm in height, based on the Steenbergh-Lowe growth model, shows a population that is strongly skewed toward younger individuals (Figure 12). The largest spike is for individuals17-24 years old, which would have germinated in the late 1980s and early 1990s.

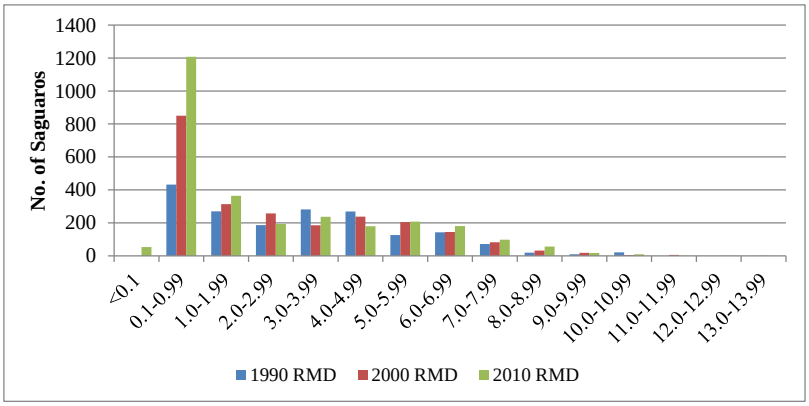

Figure 7. Saguaro size distribution in the Rincon Mountain District of Saguaro National Park for all 18 plots surveyed in 1990, 2000, and 2010. Note that saguaros <0.1 m were not recorded in 1990 or 2000.

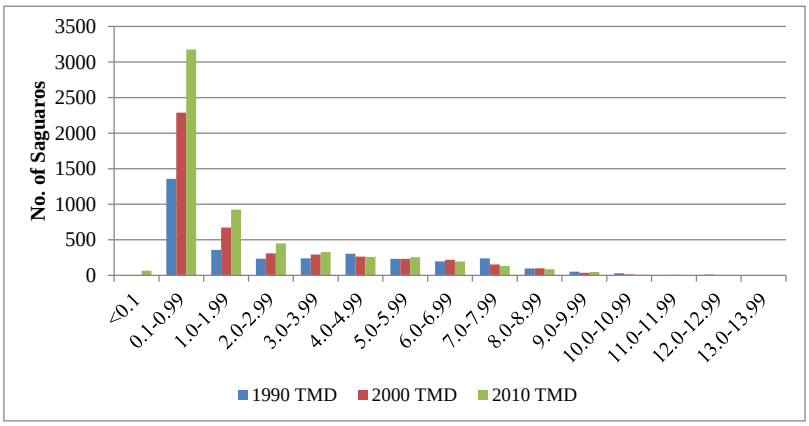

Figure 8. Saguaro size distribution in Tucson Mountain District of Saguaro National Park for all 18 plots surveyed in 1990, 2000, and 2010. Note that saguaros < 0.1 m were not recorded in 1990 or 2000.

Detectability. Using the Orum-Ferguson detectability model, we estimated that we failed to detect 3,484 saguaros that were actually present on the 45 plots (Appendix B, Figure 10). Between the two plots that were surveyed twice to compare detectability among the fall/winter and spring seasons the mean difference between surveys was 5 saguaros, or a mean of 3.24% of the total saguaros on the plot. We detected slightly more saguaros on the second survey on one plot, and slightly fewer on the second survey on the other plot.

The number of saguaros that we observed on the second pass that we did not detect on the first pass ranged from 0 to 112, and was related to the total number of saguaros on the plot. The mean number of "new" saguaros observed on the second pass was 15.5. If we discard a small number of large saguaros as outliers, the mean height of the "new" saguaros was 0.31 m.

Detectability data can be combined with models that correlate saguaro height with age (Steenbergh and Lowe, 1983) to estimate the number of saguaros not being detected in surveys.

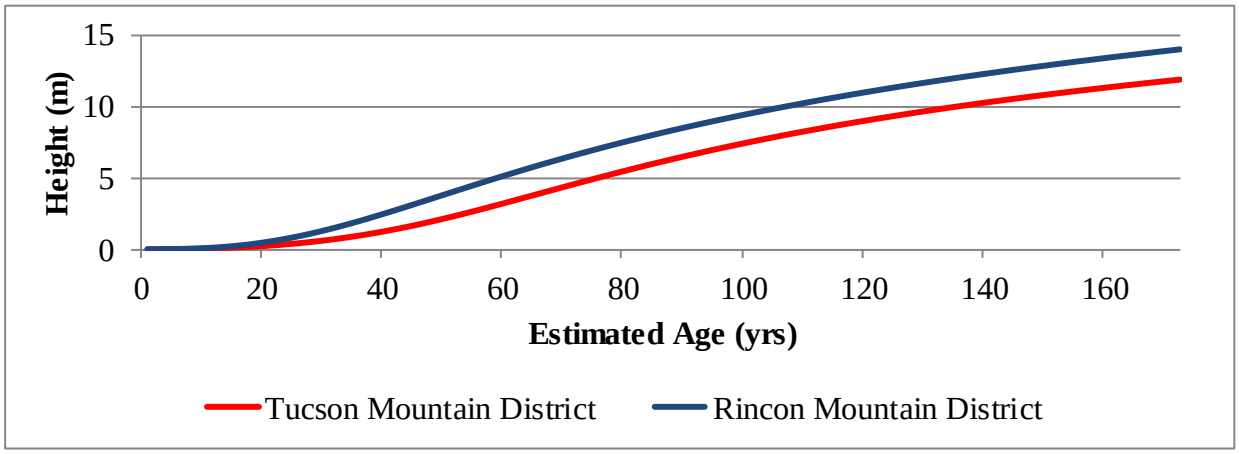

Figure 9. Estimated saguaro age at specified height. Data from Steenbergh and Lowe (1983).

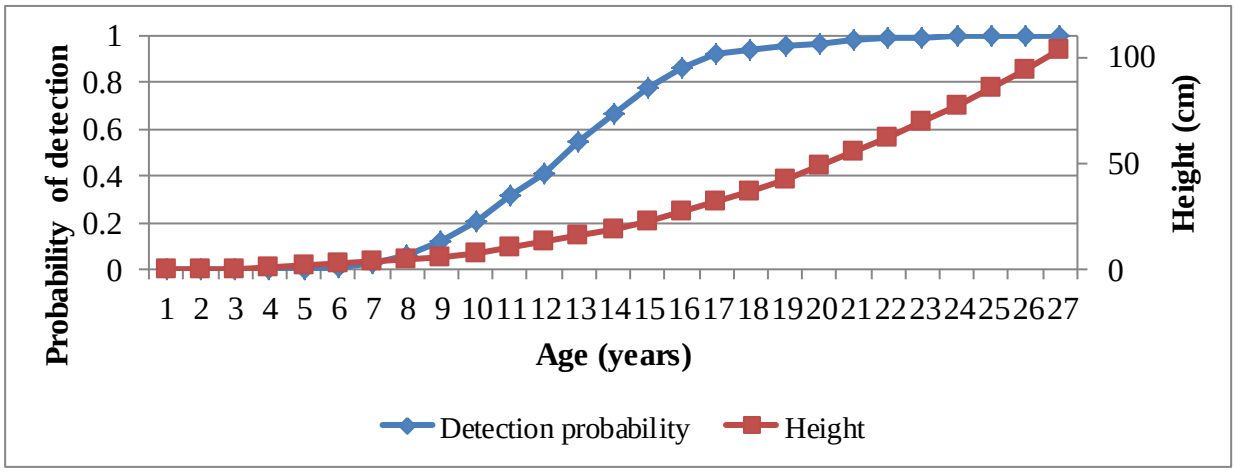

Figure 10. Probability of detecting saguaros at the Rincon Mountain District of Saguaro National Park. Estimates based on Orum-Ferguson detectability model for RMD; ages based on the Steenbergh-Lowe model for RMD.

By applying these models to our empirical data, our estimated age structure for saguaros 27 years and younger in 2010 is shown in Figure 12.

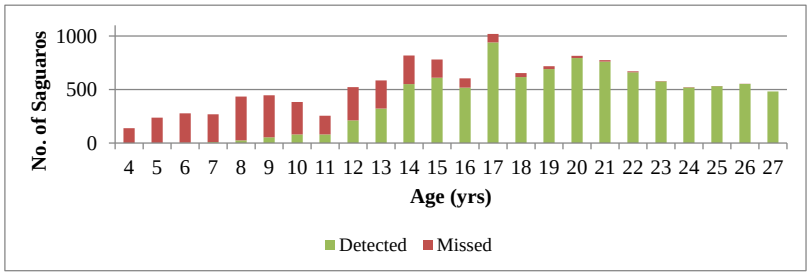

Figure 11. Estimated number of saguaros in 2010 for each year class <27 yr on 45 Census plots. Estimates based on Orum-Ferguson detectability model for RMD; ages based on the Steenbergh-Lowe model for RMD.

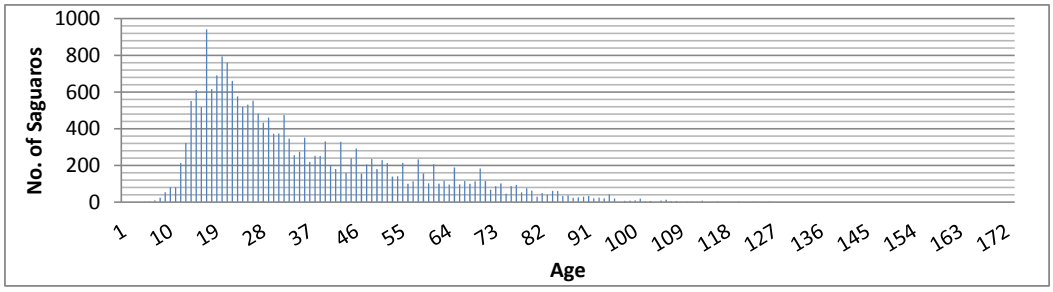

Figure 12. Age structure for all saguaros observed on 45 plots during the 2010 Saguaro Census. Age estimates are based on the Steenbergh-Lowe age-height model for RMD.

Potential for flower and fruit production. The mean number of saguaro stems/plot at RMD (x = 427, SE = 55.68) and TMD (x = 399.15, SE =43.9) was not significantly different (t_{43} = 0.38, p = 0.708). The mean number of stems/saguaro $\geq$ 2 m was also similar for the two districts (RMD = 2.50, TMD = 2.13).

The mean number of stems/plot was highest on slopes (x= 516, SE= 99.61), lowest on the bajadas (x = 337.05, SE = 29.98), and intermediate in foothills (x = 433, SE = 63.87); there was a trend for fewer stems/plot on the bajada compared to the other habitats, but the difference was not significant (t_{43} = -1.90, p = 0.064). The number of stems/saguaro $\geq$ 2m was 3.40 on bajadas, 2.27 in foothills, and 1.94 on slopes.

Bird cavities. The mean number of bird cavities/plot at RMD (Figure 13; x = 37.9, SE = 5.63) and TMD (x = 48.8, SE = 7.89) was not significantly different (t_{40} = -1.152, p = 0.256). The mean number of holes/saguaro $\geq$ 2 m was similar for the two districts (RMD = 0.21, TMD = 0.25).

The mean number of bird cavities per plot was highest in bajada habitats (x= 58.1, SE= 6.86), lowest on the slopes (x = 30.7, SE = 9.06), and intermediate in foothills (x = 33.7, SE = 6.58); the number of bird cavities per plot was significantly higher on the bajada compared to the other two habitats combined (t_{40} = 3.18, p = 0.003). The number of cavities/saguaro $\geq$ 2m was 0.55 on bajadas, 0.15 in foothills, and 0.11 on slopes. Based on extrapolation, we estimate that there are 163,166 bird cavities in Saguaro National Park.

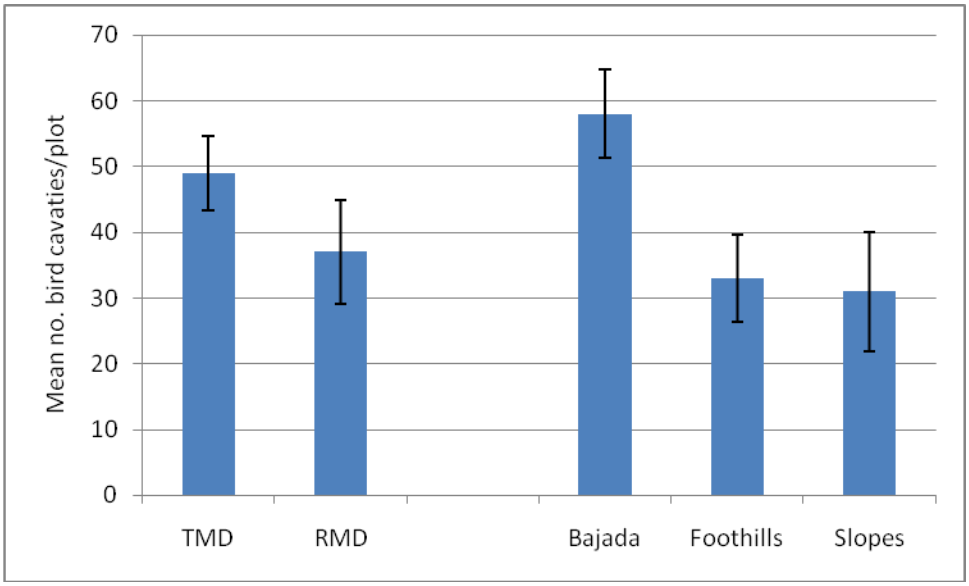

Figure 13. Mean number of bird cavities/plot (+1 SE) by district and habitat, 2010 Saguaro Census.

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 famous plant and the national park that was created to preserve and interpret it. The decades-long decline of the saguaro in the Cactus Forest during the mid-1900s was troubling to many people, and why it was occurring and how it could be reversed was a major focus at Saguaro National Park for many years (McAuliffe 1993). The park uses the Saguaro Census to complement existing non-NPS long-term programs (e.g. Turner 1995, Orum et al., 2010) and make broad inferences about the health of the saguaro population over a time scale that is appropriate for a long-lived species in a national park. In addition, the Census is a high-profile event that is a great way to teach a large number of people about saguaros, long-term ecological change, and resource management.

Although most early research on the Cactus Forest decline was concerned with disease, by the 1970s the focus had shifted to ecological factors such as grazing, nurse trees, pollination, and climate. Steenbergh and Lowe's 3-part series on saguaro ecology (1976, 1977, and 1983) emphasized that the species occurred in Saguaro National Park within a mosaic of long-term climatic change, responding to prolonged wet and dry periods as well as periodic, catastrophic freezes. Interestingly, this research program ended at a time when the saguaro population was undergoing a fundamental change. By the 1990s, after many decades of poor recruitment, researchers were noticing the appearance of large numbers of small saguaros (Turner 1995).

We can see now that the Saguaro Census was initiated in 1990 during the height of this surge in recruitment. Census results to date indicate that the saguaros from this period have survived in large numbers. From 1990 to 2010, the number of saguaros observed

has increased dramatically in both districts and across all habitat types. Figures 7 and 8 indicate that this increase is mostly in the height classes between 0.1-1.99 meters, with large numbers of small individuals detected for the first time in 2010. If survival of these young saguaros continues to be high, the number of mature plants visible to park visitors should explode in the coming decades as they increase in height, push through the shrub and tree canopy, and grow branches.

It is important to note that the Census results are generally more revealing about conditions 15-20 years ago than they are of today. Young saguaros grow very slowly, and are easy to miss until they are more than a decade old. Therefore, our finding a large number of young saguaros in 2010 reveals only that conditions were optimal in the years when these saguaros germinated, but says little about more recent conditions. However, by adjusting raw data using models for growth rates (Steenbergh and Lowe, 1983) and detection probability (Orum et al., 2010) we can estimate the number of small saguaros we are missing and make inferences about recruitment during the past few decades, at least up to the past few years. Estimates based on these models and our data from 2010 Census suggest that the surge in survival of germinating saguaros that began in the 1960s and peaked in the early 1990s has slowed in recent years. These estimates suggest recruitment especially slowed from the mid-1990s to the mid-2000s, although some recruitment did occur during these years.

What caused the surge in recruitment in the 1960s (Figure 12), and what has caused the apparent recent decline? The Census data bolster other studies (e.g., Turner 1995, Orum et al., 2010) that suggest that the combination of cattle grazing, wood-cutting, drought, and colder climate during the mid-1900s led to the long decline in the Cactus Forest. Recruitment of saguaros throughout the species range is episodic and naturally tied to drought and wet cycles (Drezner 2006). At Saguaro National Park, recruitment is also influenced by freezing temperatures, which can kill the youngest and oldest plants (Steenbergh and Lowe 1976). However, it seems unlikely that climatic conditions would be solely responsible for the extended period of poor recruitment observed in the Cactus Forest, and that grazing and wood-cutting played an important role. The increase in recruitment coincided with the end of drought conditions in the 1950s, the phase-out of cattle grazing in the park, and the continued recovery of nurse trees such as palo verdes.

Saguaro recruitment continued to increase during the late 1970s and early 1980s, as Tucson entered a wetter, warmer period, reaching a high level in the early 1990s. Following this period, drier conditions returned. Indeed, the RMD experienced a particularly hard drought during 2005-2006, a time when many plants were observed to have been chewed on by rodents that were apparently desperate for any moisture. This drought coincides with the period of lower recruitment observed in our data from the 2010 Census. The period since July 2006 has again been relatively wet, but saguaros that germinated during this period would still be almost impossible to detect using our methods.

It will be interesting, of course, to see what the current period will look like in retrospect following the Census in 2020 and 2030. On February 2-4, 2011, the Tucson area

experienced a hard freeze – the first since 1978. Temperatures were among the coldest ever recorded in Tucson (http://www.wrh.noaa.gov/twc/climate/monthly/feb11.phpcite). Although at the time of the writing of this report we do not know the extent of the damage caused to saguaros and other subtropical plants by this freeze, there is evidence that some mortality is occurring in the population, particularly in younger individuals at higher elevations and drainage bottoms. The Saguaro Census data provides a means for evaluating this event on the park's saguaro population across a range of elevations and habitats.

Epidermal browning. A major reason for the establishment of the Saguaro Census in 1990 was to study epidermal browning, and this was also the focus in 2000 (Turner and Funicelli 2000). For a variety of reasons, in 2010 we chose not to repeat Census activities that focused on epidermal browning. As in 2000, we had limited resources and had to focus our efforts. We felt that surveying the population on all 45 plots was important, especially since only 18 were surveyed in 2000. In addition, we felt that including both a deeper time series (the historic Gill-Lightle-Steenbergh-Lowe plots, surveyed last in 2001 [Funicelli and Turner 2002]) and a broader geographic scope (adding new plots at higher elevations in the RMD) would improve the ability of the Census to capture long-term changes throughout the park. In addition, Turner and Funicelli (2000) raised valid concerns about the repeatability of the methods used for the epidermal browning aspect of the Saguaro Census. It remains unclear what causes epidermal browning and if there are long-term conservation implications of this tissue condition. We recommend revisiting this question in the future, particularly to determine if there is an interaction with epidermal browning and the 2011 freeze, which appears to have damaged some tissue along spine rows on larger saguaros.

Reproductive potential. Turner and Funicelli (2000) found that the potential for flower and fruit production varied widely among plots, but that there were no statistical differences among habitats or between TMD and RMD. They found a mean of 92 reproductive stems/ha, slightly less than we found. Similarly, we did not find any statistical differences between habitats or districts. If survival remains high among the current crop of saguaros < 2 m, we expect that reproductive potential will increase during the coming decades.

Bird cavities. We were surprised to find significant differences in the number of bird holes, both per saguaro and per plot, among the three habitats and the two districts. The number of cavities is higher at TMD and in bajada areas, which we suspect is related to the distribution of Gila Woodpeckers and Gilded Flickers. These birds create the holes and use them for one season only (in subsequent years, the cavities are re-occupied by other species such as Elf Owls and Purple Martins). It is important to note that the Saguaro Census does not evaluate occupancy of bird cavities, which may vary based on other factors beside the number of cavities.

Due to time constraints, we did not fully sample all 45 plots, but instead sub-sampled 8 plots during the study. Although we selected a random area of each plot to sample (either 1/4, 1/8 or 1/16 of the plot, depending on the number of saguaros present), it seems very

likely that sample sizes on these plots were inadequate due to within-plot variability related to aspect and geology. For example, extrapolation based on our subsample of plot 12 led to an estimate of 66 fewer saguaros since 2000, which was unlikely based on results of similar plots that were fully sampled.

Although we believe that most of our field methods were very similar to those of Turner and Funicelli (2000), based on discussions with the authors, in some cases we were uncertain about how they collected data. For example, there was some uncertainty about whether they included spines in their height measurements, and we were inconsistent in this and other specifics as we began the project. Therefore, we decided that it was important to build a specific sampling protocol for the Census, which is included in this report in Appendix D. We did make one important change from Turner and Funicelli (2000), which was to label all flags and record the flag number on data sheets, to avoid double-counting saguaros that the team may have measured, but forgotten to flag on the first pass. As in previous studies, we struggled to know what to do with the number of "double" saguaros, where two saguaros grew very closely together, often fused at the base. We defined doubles as being one saguaro if they were fused at the base; if the basal stems were separate, we defined them as two saguaros. However, this was often a judgment call and it seems probable that some saguaros that were doubles could become fused as they grow. In general we found few errors in the work by Turner and Funicelli (2000); we found one minor error in the number of saguaros on plot 15 (only 10 saguaros difference) and corrected it in the database and this report.

Citizen Science. Using "citizen scientists" to collect data on the Saguaro Census plots was a great success. Two major concerns with using volunteers to gather scientific data are the safety of the volunteers and the quality of the data. We learned and improved in both areas as the study progressed. We began the season with a safety plan that included pre-visit information, daily safety briefings, and many other features, and improved it through safety reviews during the year. Fortunately, we had no major safety incidents or injuries during the 2010 Census. While we feel in general that our data quality control was good at the start of the season, we definitely improved our data collection methods as the season continued. We documented our data quality lessons learned in Appendix D, and urge that this appendix be read carefully prior to starting the 2020 Census.

Citizen scientists were recruited through a single press release in September, 2009, and then by word of mouth. We hired a student intern (Kim Diamond) to be responsible for the educational and volunteer aspects of the Census. Kim organized and directed volunteers, created a series of interpretive and educational products related to the Census, led educational programs with students, and posted results of the Census and other information on the park's web site. Kim's work made it possible to effectively mobilize large numbers of excellent volunteers.

Photo 3. Group of Southwest Conservation Corps members working on a Saguaro Census plot in the Rincon Mountain District, April 2010.

Using volunteer citizen scientists to collect data is less expensive than using paid staff, although a core group of paid staff is essential. We believe that a far more important benefit of citizen science is that it connects a large number of people with saguaros and the park in a meaningful way. During the Census we received volunteer support from more than 300 individual volunteers who contributed more than 3,000 hours. Typically, we worked with groups of volunteers from hiking clubs, local businesses, University of Arizona classes and clubs, high schools, environmental volunteer organizations (particularly the Sky Island Alliance), and others. In addition, during the season we had a cadre of experienced volunteers who became team leaders as they increased their skills. Finally, we had less-frequent individual volunteers and monthly "public" Census events.

Through orientation, but more importantly through directly interacting with and recording scientific data on the saguaro, these volunteers learned about the plant and gained an understanding of its long-term dynamics at the park. Volunteers who worked on the Census were able, by the spring of 2010, to view the results of their work by going on to the park's web site, visiting the Census page, and then clicking on a specific plot and date. For each plot and date we created a page with a group photo (Appendix E), photos of work in the field, and a graph showing the results from the 2010 Census and previous surveys of that plot. We believe that the real gains from this approach will be in the future as some of these volunteers return to this and other similar citizen science projects in the park.

Publicity. As in 2000, the Saguaro Census received a large amount of local and national publicity. Several local television stations came out into the field to film, and the Census and results were featured in the Arizona Daily Star and the Desert Leaf. Articles about the Census also appeared in a number of newspapers in different cities around the United

States. Staff involved with the Census, particularly Don Swann and Adam Springer, have given talks on the results at several pubic and scientific meetings, including a symposium on climate change at Saguaro National Park, the Tucson Cactus and Succulent Society, Pima Association of Governments, park volunteers and visitors, the George Wright Society, and others. We have written an article on the project for the magazine Park Science (Swann et al., 2011) and anticipate writing up the results in a peer-reviewed scientific journal. Thanks to these efforts, knowledge about the Saguaro Census is continuing to increase, which we believe will help to ensure that it continues into the future.

Conclusion

The results of the 2010 Saguaro Census indicate that saguaros have increased substantially in numbers in the past few decades, although recruitment has recently declined. This Census most notably differed from previous surveys in the engagement of the public as partners. As Saguaro National Park works to manage its natural resources under the uncertainty of changing climatic conditions, we need the public more than ever as advocates and partners in the management of these protected lands.

Recommendations

A great advantage of the Census is that it is large in scope – more than 20,000 saguaros were measured in 2010 – and based on random plots in both districts of the park. However, the size of the effort requires a full commitment from park staff, as well as adequate funding. Even with significant funding, the number of activities associated with the effort (Table 1) means that choices must be made among them. Our focus on demographics in 2010 was less costly than the work in 2000 because the work was simpler than taking detailed measurements of epidermal browning on individual saguaros, and so we could rely heavily on volunteers. However, there is still significant cost in terms of staff time for this activity. We received grants from the Friends of Saguaro National Park, Western National Parks Association, the Tucson Cactus and Succulent Society, and also relied on fee monies and support from the Youth Intern Program. Nearly all of this funding went to pay the salaries of student interns who led volunteer groups, organized the field work, entered and organized the data, and assisted in environmental education. In addition, one staff person in Resource Management (Don Swann) focused approximately half of his time on the Census for about one year.

In 2006-2007, with support from the Friends of Saguaro National Park, we sampled a small number of Saguaro Census plots using volunteers. This was a great project because it reminded the park of the upcoming Census; provided food for thought in planning the Census; initiated interest among volunteer groups; and pre-trained the staff who later worked on the Census. We recommend a similar activity in 2016-2017.

We are hesitant to recommend specific activities for the 2020 Census, because surely much will be learned about saguaros in Saguaro National Park during the next 9 years that will influence these decisions. In addition, it seems likely that technological advances will change the way the Census is conducted. However, we do urge that Citizen Science be again included as an important component in 2020 because of its educational value.

The saguaro cactus, with its unusual appearance, deep cultural meanings, and interesting natural history, is a revered plant in America's desert. In addition, as Saguaro National Park ages, the plant has also developed an interesting ecological and monitoring history. We believe that the Saguaro Census is an excellent way to highlight the outstanding natural and cultural resource values of this plant in Saguaro National Park. We hope that the saguaros measured by citizen scientists in 2010 will be re-measured in 2020 by the next generation of park stewards, and that the Census will continue to be relevant long into the future.

Literature cited

Ahnmark, E. and D. E. Swann. 2009. A history of saguaro cactus monitoring in Saguaro National Park, 1939–2007. Natural Resource Technical Report NPS/SODN/NRTR–2007/093. National Park Service, Fort Collins, Colorado.

Drezner, T. D. 2006. The regeneration of a protected Sonoran Desert cactus since 1800 A.D. over 50,000 km2 of its range. Plant Ecology 183:171-176.

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

Duriscoe, D. M. and S. L. Graban. 1992. Epidermal browning and population dynamics of giant saguaros in long-term monitoring plots. Pages 237 – 258 in C. P. Stone and E. S. Bellantoni, editors. Proceedings of the Symposium on Research in Saguaro National Monument, 23-23 January, 1991. Southwest Parks and Monuments Association, Globe, Arizona.

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 and the Desert Southwest Cooperative Ecosystems Studies Unit (CESU), Tucson.

Funicelli, C.S., P. J. Anning, and D. S. Turner. 2001. Long-term vegetation monitoring at Saguaro National Park: a decade of change. United States Geological Survey. Technical Report No. 70.

Gill, L. S. and P. C. Lightle. 1942. Cactus disease investigations: an outline of objectives, plans, and accomplishments on project j-2-8. Report to the Bureau of Plant Industry. Reprinted as p. 158 – 188 in W. F. Steenbergh and C. H. Lowe. 1983. Ecology of the saguaro: III, growth and demography. Scientific Monograph Series, No. 17. USDI, National Park Service, Washington, D. C.

Little, E. L., Jr., 1976, Atlas of United States trees, volume 3, minor Western hardwoods: U.S. Department of Agriculture Miscellaneous Publication 1314, 13 p., 290 maps.

McAuliffe, J.R. 1993. Case study of research, monitoring, and management programs associated with the saguaro cactus (*Carnegiea gigantea*) at Saguaro National Monument, Arizona. Tech. Rept. NPS/WRUA/NRTR-93/01. Coop. NP Res. Study Unit, Tucson.

MacEwen, R., D. E. Swann, K. O'Brien, and T. Alvarez. In preparation. Re-survey of 1940s and 1970s historic saguaro plots in Saguaro National Park, 2010. Unpublished report to National Park Service, Saguaro National Park, Tucson, AZ.

Orum, T.V., N. Ferguson, J.D. Mihail, and S.M. Alcorn. 2010. A multi-decadal episode of saguaro (*Carnegiea gigantea*) population. *Unpublished manuscript*.

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

Rojas, R., D. Swann, and T. Alvarez. 2011. Summary of Precipitation at Saguaro National Park (2000-2010). Unpublished report to National Park Service, Saguaro National Park, Tucson, AZ.

Springer, A. C., C. Hannum, and D. E. Swann. 2011a. Two decades of vegetation change in Saguaro National Park, 1990-2010. Unpublished report to National Park Service, Saguaro National Park, Tucson, AZ.

Springer, A.C., C. Pruden, B. MacEwen and D. E. Swann. 2011b. The saguaro cactus in a sky island ecotone. Unpublished report to National Park Service, Saguaro National Park, Tucson, AZ.

Steenbergh, W. F. and C. H. Lowe. 1976. Ecology of the saguaro: I. The role of freezing weather on a warm-desert plant population. Pp 69-92 in Research in the Parks. National Park Service symposium series no. 1. Government Printing Office, Washington, D.C.

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

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

Stevens, J. and D.A. Falk. 2009. Can buffelgrass invasions be controlled in the American Southwest? Using invasion ecology theory to understand buffelgrass success and develop comprehensive restoration and management. *Ecological Restoration* 27(4): 417-427.

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, R.M. 1992. Long-term saguaro population studies at Saguaro National Monument. Pages 3–5 *in* C. P. Stone and E. S. Bellatoni, editors. Proceedings of the Symposium on Research in Saguaro National Monument, 23–24 January 1991. Southwest Parks and Monuments Association, Globe, Arizona, USA.

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. Technical Report 69, USGS Sonoran Desert Field Station, The University of Arizona, 29 pp.

Appendix A. Plot coordinates (coordinate system: UTM; datum: NAD 83).

PLOT	NE_E	NE_N	NW_E	NW_N	SE_E	SE_N	SW_E	SW_N
1	525514	3562029	525316	3562017	525517	3561826	525323	3561830
2	527422	3562922	527229	3562919	527433	3562724	527231	3562720
3	528957	3563429	528761	3563427	528961	3563228	528759	3563221
4	529158	3563516	528958	3563510	529162	3563317	528960	3563310
5	525038	3563851	524823	3563858	525038	3563649	524828	3563650
6	526529	3559166	526345	3559143	526547	3558967	526348	3558955
7	526362	3558458	526171	3558460	526366	3558262	526176	3558263
8	527476	3566456	527270	3566447	527480	3566232	527277	3566228
9	526323	3561978	526098	3561997	526329	3561790	526103	3561795
10	526676	3563225	526491	3563219	526680	3563040	526494	3563038
11	530063	3566258	529861	3566254	530064	3566058	529864	3566057
12	527490	3559589	527309	3559582	527493	3559407	527311	3559393
13	528075	3562410	527880	3562409	528079	3562210	527880	3562206
14	531471	3566540	531266	3566530	531472	3566336	531262	3566335
15	525874	3564892	525676	3564889	525877	3564693	525675	3564691
16	529383	3562816	529175	3562821	529380	3562625	529180	3562612
17	527456	3564866	527270	3564867	527461	3564679	527280	3564675
18	526748	3557051	526550	3557043	526746	3556854	526545	3556851
19	528916	3565077	528713	3565072	528918	3564886	528725	3564877
20	537468	3557585	537280	3557569	537481	3557374	537287	3557365
21	536586	3558070	536402	3558074	536589	3557897	536401	3557890
22	538343	3557094	538150	3557097	538354	3556901	538165	3556907
23	536276	3558105	536097	3558106	536279	3557913	536097	3557910
24	529823	3557312	529624	3557308	529829	3557127	529625	3557116
25	531558	3557030	531378	3557036	531571	3556838	531378	3556838
26	487627	3576263	487424	3576263	487617	3576052	487424	3576051
27	484892	3573673	484685	3573671	484878	3573470	484680	3573467
28	482140	3568708	481938	3568707	482138	3568508	481938	3568509
29	478497	3571095	478302	3571094	478492	3570900	478302	3570904
30	482943	3571694	482748	3571691	482939	3571489	482745	3571487
31	484926	3577235	484722	3577230	484924	3577026	484723	3577035
32	484776	3575562	484583	3575572	484778	3575366	484580	3575367
33	479199	3575104	479000	3575107	479195	3574904	479000	3574908
34	484439	3573189	484241	3573192	484441	3572990	484236	3572989
35	478124	3571920	477921	3571922	478121	3571724	477923	3571727
36	486036	3569444	485832	3569448	486031	3569251	485831	3569246
37	481216	3569606	481017	3569605	481214	3569412	481015	3569409
38	481685	3571704	481481	3571711	481678	3571509	481480	3571509

39	486490	3575607	486288	3575606	486487	3575402	486288	3575405
40	480422	3569229	480223	3569231	480419	3569029	480218	3569031
41	484055	3569854	483857	3569859	484055	3569662	483856	3569663
42	486347	3578499	486152	3578501	486346	3578303	486149	3578306
43	487268	3572414	487071	3572412	487264	3572215	487067	3572213
44	481724	3574395	481527	3574396	481718	3574202	481527	3574197
45	485459	3570559	485256	3570553	485455	3570373	485254	3570361

In July 2010, we determined that we would not have sufficient resources to complete all of the plots. To gather some information from all plots, we decided to subsample the remaining plots. Subsamples of plots with low numbers of saguaros (e.g. plots 4 and 23) were made 100 m x 100 m and plots with high numbers of saguaros were made 50m x 50m (e.g. plots 12 and 25). The plots were divided into sixteen quadrants and random selections of the quadrants were chosen. Below are the coordinates for the subsample plots.

Plot	**Subsample location & size**	**Southwest**	**Southeast**	**Northeast**	**Northwest**
4	Southeast quarter (100 m x 100m)	529063 3563313	529161 3563317	529159 3563417	529059 3563414
12	Northeast quarter of the southeast quarter (50m x 50m)	527441 3559453	527491 3559457	527490 3559506	527441 3559503
23	Northeast quarter (100m x 100m)	536178 3558005	536277 3558004	536276 3558104	536176 3558105
25	Southwest quarter of the southeast quarter (50m x 50m)	531471 3556838	531521 3556838	531518 3556888	531467 3556889
36	Southwest quarter (100m x 100m)	485831 3569246	485931 3569247	485931 3569348	485831 3569346
42	Northeast quarter (100m x 100m)	486247 3578399	486346 3578398	486347 3578499	486247 3578498
43	Southern half of northwest quarter (50x100)	487069 3572362	487169 3572362	487068 3572312	487169 3572312

Appendix B. Estimated number and height of small saguaros present but not detected during the 2010 Saguaro Census. Estimates are based on Orum-Ferguson detectability model (Tom Orum, pers. comm.).Results are reported for the Rincon Mountain and Tucson Mountain District combined.

Age	Height	Number Detected	Detectability	Estimated Count	Estimated no. missed
4 yrs	<1.265	1	0.0025	400	399
5 yrs	<1.795	2	0.005	400	398
6 yrs	<2.51	4	0.01	400	396
7 yrs	<3.45	10	0.03	333	323
8 yrs	<4.655	25	0.06	417	392
9 yrs	<6.165	54	0.12	450	396
10 yrs	<8.015	81	0.21	386	305
11 yrs	<10.225	81	0.32	253	172
12 yrs	<12.815	213	0.41	520	307
13 yrs	<15.805	323	0.55	587	264
14 yrs	<19.21	551	0.67	822	271
15 yrs	<23.04	611	0.78	783	172
16 yrs	<27.305	518	0.86	602	84
17 yrs	<32.01	941	0.92	1023	82
18 yrs	<37.15	616	0.94	655	39
19 yrs	<42.74	691	0.96	720	29
20 yrs	<48.775	794	0.97	819	25
21 yrs	<55.255	761	0.98	777	16
22 yrs	<62.18	661	0.99	668	7
23 yrs	<69.54	576	0.995	579	3
24 yrs	<77.34	520	0.9975	521	1
25 yrs	<85.565	531	0.999	532	1
26 yrs	<94.205	553	0.9999	553	0
27 yrs	<103.255	483	1	483	0

Appendix C. 2010 Saguaro Census Plot Summary Statistics

Saguaro Census Plots

Plot	Sample area (ha)	Total saguaros (saguaros per ha)	Mean height (Std. Dev.)	Mean branches (Std. Dev.)	Mean bird holes (Std. Dev.)
1	4	100 (25)	1.57 (1.67)	0.67 (1.74)	0.28 (1.41)
2 (1st survey)	4	153 (38.25)	3.79 (3.09)	2.27 (3.24)	0 (0)
2 (2nd survey)	4	144 (36)	3.73 (2.93)	2.38 (3.39)	0.57 (1.48)
3	4	248 (62)	1.85 (1.87)	0.42 (1.22)	0.06 (0.38)
4 (subsample)	1	29 (29)	1.59 (1.38)	0.24 (0.69)	0 (0)
5	4	196 (49)	2.53 (2.08)	0.93 (2.35)	0.3 (1.57)
6	4	298 (74.5)	2.7 (2.08)	0.64 (1.48)	0.1 (0.47)
7	4	451 (112.75)	2.24 (1.93)	0.38 (1.15)	0.05 (0.39)
8	4	65 (16.25)	5.26 (3.25)	7.17 (7.61)	1.43 (3.35)
9 (1st survey)	4	163 (40.75)	2.63 (2.4)	1.27 (2.87)	0.34 (1.3)
9 (2nd survey)	4	164 (41)	2.64 (2.42)	1.4 (3.06)	0.37 (1.66)
10	4	135 (33.75)	2.15 (2.59)	1.45 (2.95)	0.35 (1.35)
11	4	178 (44.5)	4.15 (2.44)	2.25 (2.77)	0.15 (0.55)
12 (subsample)	0.25	19 (76)	2.22 (2.84)	0.89 (2.05)	0.37 (1.16)
13 (1st survey)	4	334 (83.5)	2.99 (2.42)	0.96 (1.82)	0 (0)
13 (2nd survey)	4	361 (90.25)	2.71 (2.33)	0.95 (1.9)	0.11 (0.54)
14	4	86 (21.5)	3.4 (2.49)	1.76 (2.29)	0.29 (1.18)
15	4	417 (104.25)	1.93 (1.85)	0.56 (1.85)	0.07 (0.58)
16	4	705 (176.25)	1.85 (1.85)	0.22 (0.77)	0 (0)
17	4	266 (66.5)	3.02 (2.7)	1.43 (3.16)	0.23 (0.95)
18	4	203 (50.75)	2.38 (2.38)	0.93 (1.99)	0.15 (0.99)
19	4	456 (114)	2.5 (2)	0.71 (1.61)	0.08 (0.93)
20	4	313 (78.25)	2.91 (2.42)	1.04 (2.01)	0.08 (0.62)
21	4	813 (203.25)	1.97 (2.45)	0.58 (1.71)	0.03 (0.33)
22	4	494 (123.5)	2.94 (2.53)	1.16 (2.03)	0.01 (0.13)
23 (subsample)	1	22 (22)	4.46 (2.62)	1.68 (1.89)	0.27 (1.28)
24	4	702 (175.5)	2.36 (1.93)	0.49 (1.33)	0.01 (0.09)
25 (subsample)	0.25	120 (480)	2.56 (1.74)	0.18 (0.69)	0.02 (0.13)
26	4	725 (181.25)	1.84 (2.15)	0.29 (0.98)	0.04 (0.37)
27	4	285 (71.25)	2.18 (2.41)	0.63 (1.86)	0.19 (0.83)
28	4	515 (128.75)	3.22 (2.9)	0.76 (1.51)	0.08 (0.63)
29	4	219 (54.75)	2.2 (2.49)	0.76 (1.82)	0.1 (0.49)
30	4	474 (118.5)	2.58 (2.81)	0.77 (1.76)	0.18 (1.31)
31	4	520 (130)	1.56 (2.08)	0.31 (1.1)	0 (0)
32	4	239 (59.75)	2.21 (2.6)	0.71 (1.56)	0.35 (1.3)
33	4	235 (58.75)	2.24 (2.21)	0.82 (2)	0.17 (1.06)
34	4	329 (82.25)	3.07 (2.83)	0.95 (1.91)	0.13 (0.63)

35	4	416 (104)	2.01 (2.13)	0.54 (1.72)	0.25 (1.68)
36 (subsample)	1	238 (238)	1.63 (1.47)	0.08 (0.44)	0.05 (0.36)
37	4	921 (230.25)	2.62 (2.5)	0.63 (1.62)	0.08 (0.53)
38	4	1820 (455)	1.29 (1.82)	0.14 (0.69)	0.01 (0.17)
39	4	715 (178.75)	2.34 (2.5)	0.52 (1.45)	0 (0)
40	4	608 (152)	2.26 (2.73)	0.56 (1.37)	0.13 (0.61)
41 (subsample)	0.25	36 (144)	1.31 (2.09)	0.33 (1.01)	0.03 (0.17)
42 (subsample)	1	58 (58)	2.12 (2.66)	0.69 (1.61)	0.07 (0.32)
43 (subsample)	0.5	39 (78)	1.57 (1.61)	0.31 (0.83)	0 (0)
44	4	378 (94.5)	1.67 (2.22)	0.48 (1.44)	0.31 (1.65)
45	4	894 (223.5)	1.59 (1.64)	0.14 (0.63)	0.01 (0.13)

50 Meter Plots and High Elevation Plots

Plot	Sample area (ha)	Total saguaros (saguaros per ha)	Mean height (Std. Dev.)	Mean branches (Std. Dev.)	Mean bird holes (Std. Dev.)
100	0.25	5 (20)	2.72 (3.18)	2 (4.47)	0 (0)
101	0.25	11 (44)	1.52 (0.77)	0.09 (0.3)	0 (0)
102	0.25	7 (28)	3.78 (2.65)	1.86 (2.67)	1.14 (1.35)
103	0	0 (0)	0 (0)	0 (0)	0 (0)
104	0.25	12 (48)	5.12 (2.87)	3.33 (2.96)	0.58 (1)
105	0.25	12 (48)	0.9 (0.78)	0 (0)	0 (0)
106	0	0 (0)	0 (0)	0 (0)	0 (0)
108	0.25	13 (52)	4 (2.88)	2.85 (3.93)	0.31 (0.75)
109	0.25	18 (72)	4.93 (2.43)	2.78 (2.69)	0.17 (0.38)
110	0.25	7 (28)	1.85 (2.18)	1.43 (2.7)	0 (0)
111	0.25	3 (12)	3.35 (3.61)	1.67 (2.89)	0.33 (0.58)
112	0	0 (0)	0 (0)	0 (0)	0 (0)
113	0.25	15 (60)	3.12 (2.84)	1.93 (4.04)	1 (3.36)
114	0.25	17 (68)	2.71 (2.29)	0.76 (1.75)	0.59 (1.97)
115	0.25	24 (96)	2.97 (2.61)	1.71 (2.96)	0.21 (0.66)
116	0.25	2 (8)	6 (2.12)	2.5 (3.54)	0 (0)
117	0.25	12 (48)	2.9 (3.67)	2 (4.07)	0.5 (1.45)
118	0.25	18 (72)	3.62 (3.27)	1.78 (2.56)	0 (0)
119	0.25	8 (32)	3.18 (2.23)	1.38 (2)	0 (0)
120	0.25	9 (36)	2.33 (2.59)	0.67 (2)	0.11 (0.33)
121	0.25	38 (152)	3 (1.79)	0.29 (0.8)	0 (0)
122	0.25	3 (12)	1.65 (1.62)	0 (0)	0 (0)
123	0.25	79 (316)	1.72 (2.09)	0.15 (0.53)	0 (0)
124	0.25	4 (16)	2.12 (2.62)	2.25 (3.3)	0 (0)
126	0.25	32 (128)	2.3 (2.23)	0.78 (2.03)	0.03 (0.18)
127	0.25	2 (8)	3.26 (1.64)	3 (4.24)	0 (0)
128	0.25	9 (36)	3.25 (2.14)	1.56 (2.35)	0 (0)

129	0.25	2 (8)	3.26 (1.64)	3 (4.24)	0 (0)
130	0.25	4 (16)	2.94 (2.22)	0 (0)	0 (0)
131	0.25	10 (40)	4.33 (3.41)	2.2 (2.39)	0 (0)
132	0.25	47 (188)	1.99 (2.2)	0.66 (1.54)	0 (0)
133	0	0 (0)	0 (0)	0 (0)	0 (0)
134	0.25	37 (148)	2.06 (1.84)	0.41 (1.21)	0 (0)
135	0	0 (0)	0 (0)	0 (0)	0 (0)
136	0.25	13 (52)	5.22 (1.52)	2.69 (3.35)	0.08 (0.28)
137	0	0 (0)	0 (0)	0 (0)	0 (0)
138	0	0 (0)	0 (0)	0 (0)	0 (0)
140	0	0 (0)	0 (0)	0 (0)	0 (0)
141	0.25	35 (140)	3.49 (2.11)	0.77 (1.35)	0.2 (0.72)
142	0.25	5 (20)	0.47 (0.54)	0 (0)	0 (0)
143	0	0 (0)	0 (0)	0 (0)	0 (0)
144	0	0 (0)	0 (0)	0 (0)	0 (0)
145	0	0 (0)	0 (0)	0 (0)	0 (0)
146	0.25	11 (44)	2.2 (1.56)	0.18 (0.6)	0 (0)
147	0.25	13 (52)	3.24 (2.56)	0.46 (1.39)	0.31 (0.85)
148	0	0 (0)	0 (0)	0 (0)	0 (0)
151	0	0 (0)	0 (0)	0 (0)	0 (0)
152	0.25	46 (184)	2.63 (1.66)	0.22 (0.79)	0 (0)
153	0	0 (0)	0 (0)	0 (0)	0 (0)
154	0	0 (0)	0 (0)	0 (0)	0 (0)
156	0	0 (0)	0 (0)	0 (0)	0 (0)
157	0	0 (0)	0 (0)	0 (0)	0 (0)
158	0.25	10 (40)	2.68 (2.07)	0.1 (0.32)	0 (0)
159	0	0 (0)	0 (0)	0 (0)	0 (0)
160	0.25	30 (120)	2.08 (1.48)	0.2 (0.81)	0 (0)
162	0	0 (0)	0 (0)	0 (0)	0 (0)
163	0.25	4 (16)	1.99 (0.73)	0 (0)	0 (0)
164	0	0 (0)	0 (0)	0 (0)	0 (0)
165	0	0 (0)	0 (0)	0 (0)	0 (0)
166	0	0 (0)	0 (0)	0 (0)	0 (0)
167	0.25	1 (4)	1.47 (0)	0 (0)	0 (0)
168	0	0 (0)	0 (0)	0 (0)	0 (0)
169	0	0 (0)	0 (0)	0 (0)	0 (0)
170	0.25	5 (20)	4.64 (2.18)	2.4 (1.14)	0.2 (0.45)
171	0	0 (0)	0 (0)	0 (0)	0 (0)
172	0	0 (0)	0 (0)	0 (0)	0 (0)
173	0.25	6 (24)	2.35 (1.81)	0 (0)	0 (0)
174	0.25	6 (24)	2.08 (1.96)	0 (0)	0 (0)
175	0	0 (0)	0 (0)	0 (0)	0 (0)
176	0.25	48 (192)	2.26 (2)	0.44 (1.24)	0 (0)

177	0	0 (0)	0 (0)	0 (0)	0 (0)
178	0.25	6 (24)	4.14 (3.38)	3.67 (5.13)	0.67 (1.03)
179	0	0 (0)	0 (0)	0 (0)	0 (0)
180	0.25	22 (88)	4.46 (2.14)	1.86 (1.83)	0.18 (0.5)
182	0	0 (0)	0 (0)	0 (0)	0 (0)
183	0	0 (0)	0 (0)	0 (0)	0 (0)
184	0.25	1 (4)	1.48 (0)	0 (0)	0 (0)
185	0.25	1 (4)	2.74 (0)	0 (0)	0 (0)
186	0.25	55 (220)	2.74 (2.87)	1.56 (3.72)	0.05 (0.3)
187	0	0 (0)	0 (0)	0 (0)	0 (0)
188	0	0 (0)	0 (0)	0 (0)	0 (0)
191	0.25	13 (52)	2.74 (2.66)	1.15 (2.3)	0 (0)
193	0.25	5 (20)	2.17 (2.48)	0.8 (1.79)	0 (0)
194	0	0 (0)	0 (0)	0 (0)	0 (0)
195	0	0 (0)	0 (0)	0 (0)	0 (0)
196	0	0 (0)	0 (0)	0 (0)	0 (0)
197	0	0 (0)	0 (0)	0 (0)	0 (0)
198	0.25	45 (180)	2.17 (2.95)	1.22 (2.47)	0 (0)
199	0.25	1 (4)	8.9 (0)	8 (0)	6 (0)
201	0.25	3 (12)	3.45 (4.46)	1 (1.73)	0.33 (0.58)
203	0	0 (0)	0 (0)	0 (0)	0 (0)
204	0.25	12 (48)	2.82 (2.86)	1.92 (2.57)	0.17 (0.39)
205	0.25	8 (32)	3.23 (2.05)	0.75 (1.75)	0 (0)
206	0.25	39 (156)	0.95 (1.39)	0.26 (0.94)	0 (0)
207	0	0 (0)	0 (0)	0 (0)	0 (0)
208	0	0 (0)	0 (0)	0 (0)	0 (0)
210	0.25	2 (8)	4.32 (3.96)	1.5 (2.12)	0 (0)
211	0	0 (0)	0 (0)	0 (0)	0 (0)
213	0	0 (0)	0 (0)	0 (0)	0 (0)
214	0	0 (0)	0 (0)	0 (0)	0 (0)
300	0	0 (0)	0 (0)	0 (0)	0 (0)
301	0	0 (0)	0 (0)	0 (0)	0 (0)
302	0	0 (0)	0 (0)	0 (0)	0 (0)
303	0	0 (0)	0 (0)	0 (0)	0 (0)
304	0.25	1 (4)	3.87 (0)	0 (0)	0 (0)
305	0	0 (0)	0 (0)	0 (0)	0 (0)
306	0	0 (0)	0 (0)	0 (0)	0 (0)
307	0	0 (0)	0 (0)	0 (0)	0 (0)
309	0.25	11 (44)	2.22 (1.83)	0.09 (0.3)	0 (0)
310	0.25	32 (128)	1.84 (1.99)	0.41 (1.13)	0 (0)
311	0.25	14 (56)	2.52 (2.63)	0.71 (1.64)	0 (0)
312	0.25	27 (108)	2.25 (2.37)	0.44 (1.63)	0 (0)
313	0.25	10 (40)	2.82 (3.13)	1.1 (1.97)	0.2 (0.63)

314	0.25	51 (204)	2.39 (2.06)	0.71 (1.64)	0.04 (0.28)
315	0.25	4 (16)	1.99 (2.12)	1 (1.15)	0 (0)
316	0.25	19 (76)	2.08 (1.79)	0.74 (1.91)	0 (0)
318	0	0 (0)	0 (0)	0 (0)	0 (0)
319	0	0 (0)	0 (0)	0 (0)	0 (0)
320	0	0 (0)	0 (0)	0 (0)	0 (0)
321	0	0 (0)	0 (0)	0 (0)	0 (0)
322	0	0 (0)	0 (0)	0 (0)	0 (0)
323	0.25	1 (4)	1.14 (0)	0 (0)	0 (0)
324	0.25	2 (8)	1.45 (0.64)	0 (0)	0 (0)
325	0	0 (0)	0 (0)	0 (0)	0 (0)
326	0	0 (0)	0 (0)	0 (0)	0 (0)
327	0	0 (0)	0 (0)	0 (0)	0 (0)
328	0	0 (0)	0 (0)	0 (0)	0 (0)
329	0.25	1 (4)	6.75 (0)	0 (0)	0 (0)
331	0	0 (0)	0 (0)	0 (0)	0 (0)
335	0.25	29 (116)	1.63 (2.2)	0.45 (1.57)	0 (0)
336	0.25	9 (36)	2.31 (1.6)	0.33 (1)	0 (0)
337	0.25	5 (20)	1.16 (1.14)	0 (0)	0 (0)
338	0	0 (0)	0 (0)	0 (0)	0 (0)
339	0	0 (0)	0 (0)	0 (0)	0 (0)
340	0	0 (0)	0 (0)	0 (0)	0 (0)
341	0	0 (0)	0 (0)	0 (0)	0 (0)
342	0.25	18 (72)	1.49 (2.4)	0.56 (1.34)	0.17 (0.71)
343	0	0 (0)	0 (0)	0 (0)	0 (0)
344	0.25	4 (16)	2.34 (3.13)	1.25 (2.5)	0.25 (0.5)
348	0	0 (0)	0 (0)	0 (0)	0 (0)
349	0	0 (0)	0 (0)	0 (0)	0 (0)
350	0	0 (0)	0 (0)	0 (0)	0 (0)
351	0	0 (0)	0 (0)	0 (0)	0 (0)
352	0	0 (0)	0 (0)	0 (0)	0 (0)
353	0	0 (0)	0 (0)	0 (0)	0 (0)
354	0	0 (0)	0 (0)	0 (0)	0 (0)
355	0.25	5 (20)	1.74 (1.83)	0 (0)	0 (0)
356	0	0 (0)	0 (0)	0 (0)	0 (0)
357	0	0 (0)	0 (0)	0 (0)	0 (0)
358	0	0 (0)	0 (0)	0 (0)	0 (0)
359	0.25	16 (64)	3.11 (2.02)	0.06 (0.25)	0.06 (0.25)
360	0	0 (0)	0 (0)	0 (0)	0 (0)

Historic Plots

Plot	Sample area (ha)	Total saguaros (saguaros per ha)	Mean height (Std. Dev.)	Mean branches (Std. Dev.)	Mean bird holes (Std. Dev.)
41A	2	86 (43)	2.01 (2)	0.76 (2.31)	0.12 (0.54)
41A (GPS)	2	87 (43.5)	2.08 (2.28)	0.94 (3.27)	0.06 (0.38)
41B	2	202 (101)	1.3 (1.33)	0.12 (0.72)	0.06 (0.78)
41B (GPS)	2	197 (98.5)	1.27 (1.15)	0.08 (0.57)	0.01 (0.07)
41C	2	259 (129.5)	2.4 (1.86)	0.43 (1.36)	0 (0)
41C (GPS)	2	248 (124)	2.64 (2.06)	0.65 (3.39)	0.06 (0.38)
41D	2	129 (64.5)	1.22 (1.69)	0.5 (2.06)	0 (0)
41D (GPS)	2	124 (62)	1.42 (1.93)	0.59 (2.11)	0.2 (1.74)
41F	2	71 (35.5)	1.05 (1.59)	0.3 (1.49)	0 (0)
41F (GPS)	2	76 (38)	1.09 (1.52)	0.28 (1.44)	0.16 (0.78)
75G (GPS)	2	279 (139.5)	2.27 (2.25)	0.52 (1.52)	0.07 (0.58)
75H (GPS)	2	390 (195)	3.15 (2.45)	0.37 (1.09)	0.01 (0.07)
75J	2	270 (135)	1.9 (2.46)	0.7 (2.03)	0.24 (2.12)
75J (GPS)	2	32 (16)	6.77 (2.28)	3.91 (2.93)	1.06 (2.15)
75K (GPS)	2	210 (105)	2.29 (2.41)	0.34 (1.01)	0.13 (0.82)
75L (GPS)	2	372 (186)	2.48 (2.35)	0.34 (1.02)	0.02 (0.15)
75M (GPS)	2	344 (172)	3.09 (2.54)	1.53 (4.06)	0.03 (0.3)

Appendix D. Survey Protocol. Field Guidelines for the Saguaro Census at Saguaro National Park (January 8, 2011)

Supplies and Equipment

- Park radio
- Digital camera for recording field data and volunteer photos

- 1-2 extra park radio batteries
- Emergency contact sheet (radio, phone numbers)
- Large crew first aid kit
- GPS Garmin unit
- Clipboards with volunteer forms
- Plot maps with UTMs of corners
- Leader's binder with safety topics to cover, extra volunteer forms and data sheets, list of UTM plot coordinates, census calendar, and *How to use a clinometer* worksheet
- Orientation poster (for interpreting why we do the Census to volunteers)
- Pin flags to mark saguaros – up to 200, numbered (e.g., A-1, A-2…Z-99)
- Pink and blue boundary flagging
- Gatorade and extra water
- Complete census equipment bags (see below) – one for each 3-4 person group

Census Bag Equipment

- 1-2 clinometers
- 2 wooden stick measures
- 1 metal tape measure
- 1 20-m roll tape
- Clipboard with plenty of data sheets, map and coordinates of plot
- 1 two-way radio
- Extra batteries for two-way radio
- Writing implements

Figure 1. Metal tape measure (left), clinometer (center) and folding rule (right)

Safety

Please refer to two documents from the 2010 Saguaro Census: the Safety Plan and the Green-Amber-Red review, which is an attachment to the Safety Plan. These lay out many of the safety concerns that are relevant to the Census and working with volunteers. The Saguaro Census has some inherent safety concerns that must be addressed – take them seriously!

Recruiting Volunteers and Selecting Plots

In 2010, when contacting new volunteers or volunteer groups, we explained how difficult the Census work was. We requested that they describe their physical ability and experience hiking in the desert (see Safety Plan for more information). We explained in detail what is involved in the Census, including safety, the difficulty of the terrain, need for the right clothing – hats, good boots, and long pants required! For individual volunteers, we invited them to join an easy plot first and monitor how well they do. Then, if they were interested in more challenging plots, we would progressively take them to more difficult plots. When receiving RSVP's for Census dates, we established a cut off point for each plot, typically about 15 volunteers for "public" plots, or about 5 more for groups (beyond this number, confusion begins to reign!). In 2010, we had a single intern, Kimberly Diamond, in charge of recruitment, volunteer organization, documentation, and logistics with the project manager (Don Swann). Kim usually went out with volunteers, accompanied by other park staff (Don Swann, student employees, or other experienced staff).

Groups ranged in ability, but nearly all were recruited because of their outdoor experience. We used groups from local hiking societies, the Friends of Saguaro National Park, the Summit Hut, the Sky Island Alliance, the University of Arizona, and many others.

Each month in 2010 we surveyed a variety of plots, ranging from easy to difficult, in both districts of the Park. In 2010, the last Saturday of each month was considered a 'public plot' for individual volunteers – for this, we selected one of the plots at RMD that was easy enough for all levels of physical ability. At the beginning of the month an email was sent to all census participants that described the plots in terms of whether they were easy, intermediate, or difficult. Based on this email, volunteers could determine if they were capable of participating in the plot surveys. Very difficult plots were left off the

mass email, but we would invite individual volunteers that we believed, based on our experience in working with them, and were fully capable of the physical work. Plot difficulty assessments were based on distance from road, slope, vegetation, and number of saguaros during last survey.

Flagging the Plot

Pre-flagging is important so that the plot can be scouted out in advance. Pre-flagging helps make the day of the Census go much faster and smoother. Pre-flagging also provides an opportunity to determine where parking should occur, the easiest route to hike to the plot, and what type of terrain to expect. We recommend pre-flagging the plot before the day of the Census, but no more than a week in advance. We also made a point to let the rangers know that we had flagged a plot, in case a question about it came up.

If the plot is off-trail, flag a route to the plot using flagging other than pink or blue. Take a radio, extra battery, plot map, pink and blue flagging and other flagging color if necessary. One of the appendices of the Saguaro Safety plan is a data sheet for flagging the plot.

To flag the plot, we recommend the following steps:

1. Locate one corner of the plot using GPS. Ideally, locate the corner stake.
2. Flag the corner with pink and blue flagging.
3. Using the view on the GPS unit that shows the coordinates, follow the north-south coordinate to the next corner (200 meters). Every twenty meters or so, tie a pink flag on a shrub (consider using Velcro or other easy-to-remove tape in future). In brushy areas, flag more frequently than every 20 meters.
4. We recommend a knot that can be easily removed with one hand. Put the flag high enough so that it can be seen, but not so high that it cannot be easily removed. Avoid flagging cholla.
5. There will be some drift in the GPS coordinate. Follow it anyway, and adjust the flags slightly if one is way off. GPS drift is random and there is no need to create an absolutely straight line.
6. When you arrive at the next corner, find the corner stake. Flag the corner with pink and blue flags.
7. Follow the east-west coordinate to the next corner, flagging in pink every 20 meters.
8. Continue until the entire plot is flagged.

Before the Volunteers Arrive

Check RSVPs and prepare a list of the volunteers that are attending. Once the list reaches 15, do not allow more volunteers to sign up. Sign out a park vehicle for the census date. Gather all equipment the day before, and load the park vehicle the morning of the census. Send an email to law enforcement rangers notifying them of the date,

location and contact persons for the census for that day. In addition, provide law enforcement and a fees or visitor center employee a copy of the plot map and emergency contact info, and post this in the Resource Management office. The plot maps can be found under *P:/Resources/Saguaro 2010/Maps and data*, and are in a PowerPoint document titled *Plot finder maps*.

For each public saguaro census, there should be at least two park staff members/interns, or one park staff/intern, and one very experienced volunteer to lead the volunteer group. The Census seemed to work best with about 5 groups of 4 people each, with one experienced person in each group and one "roving supervisor," usually one of the leaders, who roamed around the plot to check in with groups, take photos, check data quality, make sure the groups stay on track and don't get too separated, and answer questions.

Orientation to Volunteers

Staff members/interns should arrive early in the park vehicle to meet the volunteers at the visitor center. Once everyone has arrived (in 2009-2010, we usually started at 7 AM until December, then 8 AM until April), have one of the park staff or interns provide an orientation about the census. Orientation should include a greeting/introduction, brief history, how the survey is conducted, a safety message, and a check to ensure that everyone has enough water and food. We used a stiff poster board with repeat photos of the Cactus Forest and simple data graphs of previous results to interpret changes in the saguaro population in the park over time during the orientation, and this is also a good time to show pictures of small saguaros and demo equipment.

Drive to the plot – we usually carpooled, with several of the volunteers driving, and with one park vehicle. At the parking spot, we divide the gear to carry to the plot. One staff member/intern should lead the group (preferably the person who flagged the plot) to the plot. The other staff member/intern should remain at the back of the group to make sure no one gets lost, or lags too far behind.

Surveying the plot

1. *Training*. Once the plot is reached, a detailed training is essential. It is easiest if this is done in groups of about 4, with an experienced leader in each group explaining the procedures. If this is not possible, it is best to do an orientation with the larger group. The orientation should cover:
    a. How to identify a small saguaro compared to other cacti
    b. How to measure a saguaro using a tape measure
    c. How to measure a saguaro using a clinometer
    d. How to record data
    e. Other important "census rules" (see below)

2. *Moving through the plot*. Once the groups are trained, the leader will spread them out along a boundary line, approximately 20 meters apart. The groups

will walk together in their designated swaths, and count and measure each saguaro within their group's boundary (see figure 2). How wide the swaths are will depend on how dense the saguaros are, and very dense plots will go better if the swaths are less than 20 m wide.

As an example: One group will start in the northwest corner and follow the boundary flags 200 m east to the northeast corner. The next group will start 20 meters south, and follow a 20 m wide swath 200 m east to the eastern boundary line. The next 2-3 groups will do the same. *An experienced person in the most southern group will follow a GPS coordinate designed by the leader and flag the bottom line of the section of the plot that being sampled.* This line (southern line in this case) will form the northern boundary of the second half of the plot in a "typical" plot where the plot can be covered in two sessions; plots with many saguaros will need to be broken into 3-4 sections.

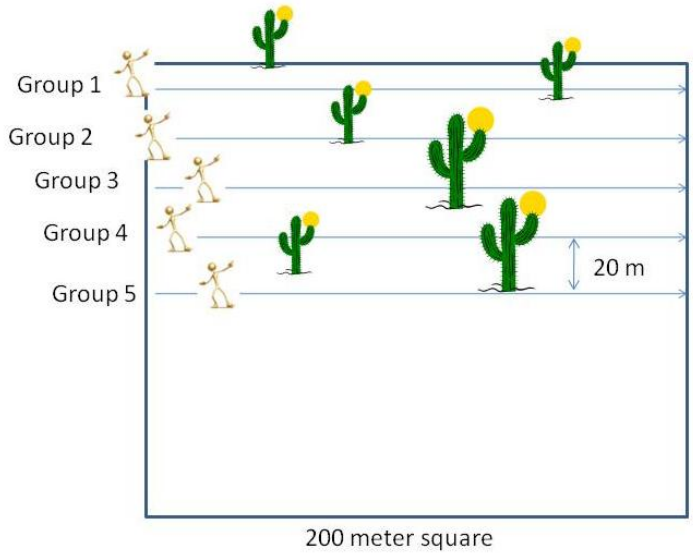

Figure 2. Illustration of a Saguaro Census plot, showing how 5 survey groups of 3-4 people move across the plot. Typically, the top group will follow the northern flag line from the northwest corner to the northeast corner, a distance of 200 meters. They will measure and flag all saguaros as they go. Group 2 would measure and flag all saguaros in a swatch about 20 meters wide, working parallel to Group 1. Group 3 would work a 20 meter swatch parallel to and just south of Group 2. Group 4 would work south of Group 3, and Group 5 would work south of Group 4. A person in Group 5, or the roving leader, will flag a temporary southern boundary of the plot. Often the temporary southern boundary would be 100 meters south of the northern boundary and through the middle of the 200 x 200 m plot, but this will vary depending on how dense the saguaro population is on the plot.

3. *Sampling*. In a group of four, there is typically a recorder, two people estimating saguaro heights using a clinometers, and one person looking for, and measuring, small saguaros. Once a saguaro is encountered, it is flagged with a numbered pin flag and measured, and the arms and holes are counted. All of this data, including the pin flag number (flags are numbered to avoid double-counting saguaros; numbers are recorded so that we do not forget to flag any saguaro), is recorded by the recorder. Saguaros can be directly measured using a tape measure, and the only trick is to make sure they are measured in meters, *not* inches or centimeters. Even very small saguaros should be measured in meters. See "Census rules" for measuring.

   For estimating the height of taller ones, clinometers were used in 2000 and 2010 (and presumably 1990 as well). Two people should always be used to independently estimate the height. See the Census rules.

4. *Checking the work*. Walking a 20 meter wide swatch that is 200 meters long, measuring every saguaro, will often take a couple of hours. This is usually a good time to take a break if one has not been taken. When the groups reach the end, we then switch them. For example, the 5th group could walk down to where the 1st group was, and then everyone else can bump up 20 meters. The main point is that the groups will all walk back through a different area than the one they sampled, looking for any saguaros the first group missed. And yes, it is a contest! The goal is to look hard and find new saguaros (or cacti that are not saguaros and must be removed from the first group's data); walking back, we have more time, new lighting, and a new perspective.

   If any new saguaros are found, they are flagged and measured as before. The recorder makes a note that they were found on the second pass, such as by marking them with an asterisk and a line. Then, a line should be put below this section also before starting another transect. The second pass does not usually take more than 20 minutes.

5. *The third pass to pick up all the flags*. This usually takes only about 10 minutes. On the third pass we do not look for new saguaros, and do not measure one if we find it unless we are ABSOLUTELY convinced that someone before us has not removed the flag. On the third pass all the side and corner flags are picked up as well except, of course, the side that will become the new boundary of the rest of the plot. If we thought we might have a hard time finding our way back to the start, we might leave those flags up too.

6. *The second half of the plot*. This proceeds similarly to the first half. On plots with many saguaros, of course there may be thirds, or quarters, or other

divisions. On the most difficult plots in 2010, we used a large crew (more than 20) for 3 or more days.

7. *Closing out*. At the end of the day, all flags should be removed from the plot unless the plot is not yet done. We generally provided cold Gatorade to all volunteers when we returned to the vehicles. We took a group photo and thanked everyone! Additional information on closing out is in the Safety Plan.

8. *Data entry*. Data should be entered as soon as possible when the field work is completed – preferably the same day. All data was entered into an Excel spreadsheet and then checked by a second person.

Census "rules"that everyone should know

* Measure to the top of a saguaro's spines, not the green fleshy part (see photo above).
* A saguaro is considered a double or triple if two or more saguaros appear to be connected, or are sharing the same base. (In the case of a double saguaro, measure the stem of the tallest "saguaro", count the other stems as arms, and make the note "double" in the notes).
* A bird hole is defined as a very dark, circular hole in a saguaro that an animal/bird may live or nest in. A bird hole looks different than a scar or irregular hole.
* If the main stem of a saguaro is missing/broken-off, but has arms that exceed the height of the main stem, measure to the top of the broken-off stem and note "broken stem" in the notes.
* Make sure to count every saguaro arm, no matter its location or size. Small nubs where the arms are just emerging from the stem or other arms are still considered arms.
* Some saguaros have arms growing on other arms. Each arm should be counted separately.
* The flags that form the sides of the Census plot create an imaginary line that outlines the plot. These lines will be slightly erratic because of natural "drift" in the GPS unit, but the drift is random. To determine if a saguaro is "in" or "out" of the plot, site from one flag down to the next one in a straight line. If the saguaro is inside the line, or on it, count it. If the saguaro is outside the imaginary line, it is not counted.
* Do not count dead saguaros. However, count any saguaro that still has green on it and is still standing (note green saguaros lying on the ground). If you see a live or dead saguaro that has a tag with a number, however, record the number and indicate if dead.
* ALWAYS have two people use the clinometers to estimate height. The proper procedure is to have one person measure the saguaro, calculate the height, and keep the result to him or herself while the next person measures. Then, the two share their results. If the estimates are within 0.1 m (or 0.2 m for a very tall

saguaro), they split the difference. If they are further away, they re-take the measurements until there is agreement.

Issues to be on the look-out for

Recording data: It is important that the data recorder write legibly and that they fill out all columns. To ensure data quality, the folks measuring saguaros usually call out the height, and the recorder calls it back as he/she enters it – very important for ensuring accuracy.

It is VERY important that the date and plot number be recorded on every data sheet (leaders could record the date and plot prior to sampling if desired). It is also important that the data recorder fill in the names of all of the workers and follows the other instructions on the data sheet. The roving supervisor should periodically check the data for each group to make sure that the form is being filled out correctly and is legible. At the end of the day, the leader should ensure that the data forms are intact and properly stored.

Estimating height: It is *very* important the person who teaches the others in the group be very experienced in how to estimate height using a clinometer. The roving leader must check in at least once with each group and measure a saguaro or two with them to make sure the group is doing it correctly. Early in the season in 2010 we did not ensure this and we found a few differences in people's opinions about how it should be done.

There are detailed instructions on how to use the clinometers on the instruction sheet. The most common mistakes are:

a. Adding the two numbers incorrectly.
b. Reading the wrong (left) side of the clinometer.
c. Measuring 10 feet instead of 10 meters from the saguaro.
d. Standing on a slope, so that the base of the saguaro is above the measurer's eye, or the top of the saguaro is below the eye (this can be accounted for, but requires subtraction rather than addition and can be confusing to staff and volunteers).

Some of our measuring devices have both metric and English units, and ensuring that metric units are used is an important part of the orientation.

Figure 3. Using a tape measure and clinometer to measure a saguaro. It's easiest if you are on same contour as the saguaro, and not looking into the sun. Always have two people measure independently!

Figure 4. Using a folding rule to measure a saguaro. You can usually measure up to a 4 meter saguaro this way, especially if someone else lets you know when the stick is at the top.

Saguaro Identification

It's important to do a bit of training on this starting out and to make sure volunteers know to ask questions when they find what they think is a small saguaro. Develop and visuals before the season if possible, and use them. The most important things to note are the following:

1. Saguaros always have straight spines (barrel and pincushions have curved spines).
2. A small saguaro (less than a foot or two) is rounded at the top, narrows at the bottom, and resembles the shape of a thin hot air balloon.
3. A very small saguaro (less than an inch) may look different than a small one; it is more globular.
4. Saguaro spines are almost always white. Hedgehog cacti usually grow in clumps, are shaped like a cylinder (not narrow at the base), and have brown or golden-brown spines.
5. Very small hedgehogs can have single stems, and distinguishing them from saguaros can be tricky. Fortunately, this is rarely an issue, but it is occasionally. Look for the shape and spine color. In the rare occasion where confusion persists, take a good photo and record the pin flag number, and submit to an expert back at the office. Don't guess!

It is always a good idea to bring everyone over to inspect the first very small saguaro you find, and the first single stem hedgehog. This helps in the training.

Appendix E. Educational information from the 2010 Saguaro Census on Saguaro National Park's website.

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Saguaro Census 2010

NPS

Every 10 years, Saguaro National Park leads a "Saguaro Census" of the park's namesake cactus. This effort helps us keep track of the health of the park's saguaro population and coincides with the U.S. Census. As the United States counts its citizens, we count our saguaros! The 2010 Saguaro Census took place between October 2009 and October 2010 with the help of over 300 volunteers.

You can take a look back at specific survey dates and plots for the 2010 Saguaro Census using our **Saguaro Census Calendar**. Click on the highlighted dates on each calendar to view the results and photos from past volunteer groups.

Look at the current results of the Saguaro Census

Find out more about long-term saguaro monitoring

Find out more about saguaros

Look at the final results of the Saguaro Cactus Census

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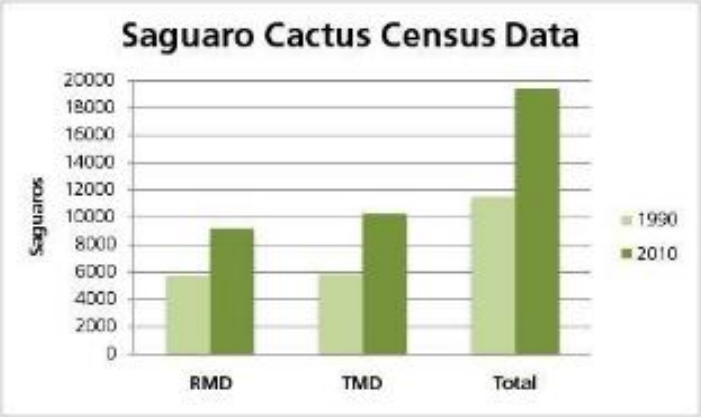
2010 Saguaro Census Final Results

NPS

Saguaro Census

Thanks to more than 300 volunteers who helped with the 2010 Saguaro Census, the Census is now complete - with more than 17,000 saguaros counted and measured!

The results from 2010 are very encouraging. While data analysis has not been completed, it is clear (see below) that the of the number of saguaros in booth districts of the park has continued to surge since the Census was last conducted in 2000. In some areas, the number of saguaros has more than doubled since 1990. We are hoping to post the final report of the Saguaro Census, by the end of January 2011.



NPS