Results of the 2010 Saguaro Census
Saguaro National Park

Draft final 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 2011

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Saguaro National Park

Contents

List of Figures and Tables

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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 during the past four decades. 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 Districts' "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 added 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 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 (Pierson and Turner 1998).

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 ≥ 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)

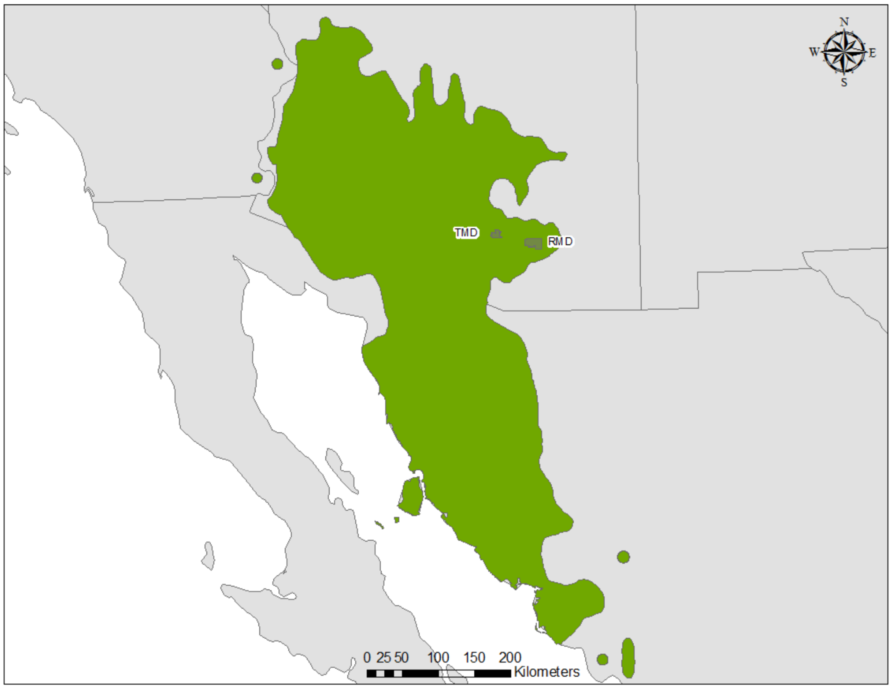

Figure 1. Range of the saguaro cactus, showing location of Saguaro National Park. Spatial data from Little (1976).

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.

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.

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

Table 1. Summary of Saguaro Census activities in 1990, 2000, and 2010. [1]In 2000, complete Census conduced on only 18 plots. [2]In 2010, complete Census conducted on 37 plots, 8 plots were sub-sampled. [3]Historic plots were re-located and re-sampled in 2001; reported separately by Funicelli and Turner (2002).

Monitoring Component	**1990**	**2000**	**2010**
Census – count and measure all saguaros on 45 plots	Yes	Yes[1]	Yes[2]
Intensive surveys of 30 selected saguaros on each of 45 plots (epidermal browning, # arms, etc.)	Yes	Yes	No
Detailed vegetation map (10 m^2 on all 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 each of 45 plots	No	Yes	No
Re-survey of 11 historic plots established in 1941 and 1975	No	Yes[3]	Yes
Survey of saguaro plots established outside of prime saguaro habitat	No	No	Yes

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. 2011), historic plots (MacEwen et al., *in prep*.), and new "ecotone" plots (Pruden et al., *in prep*.).

Long-term monitoring at Saguaro National Park (Pierson and Turner 1998, 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 it 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, correlated with global climate change, may favor 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 RMD (Figure 2) and 20 in the TMD (Figure 3). The plots within TMD are distributed randomly (using an aerially stratified 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, and plots were distributed using an areally stratified random method (Duriscoe and Graban 1991).

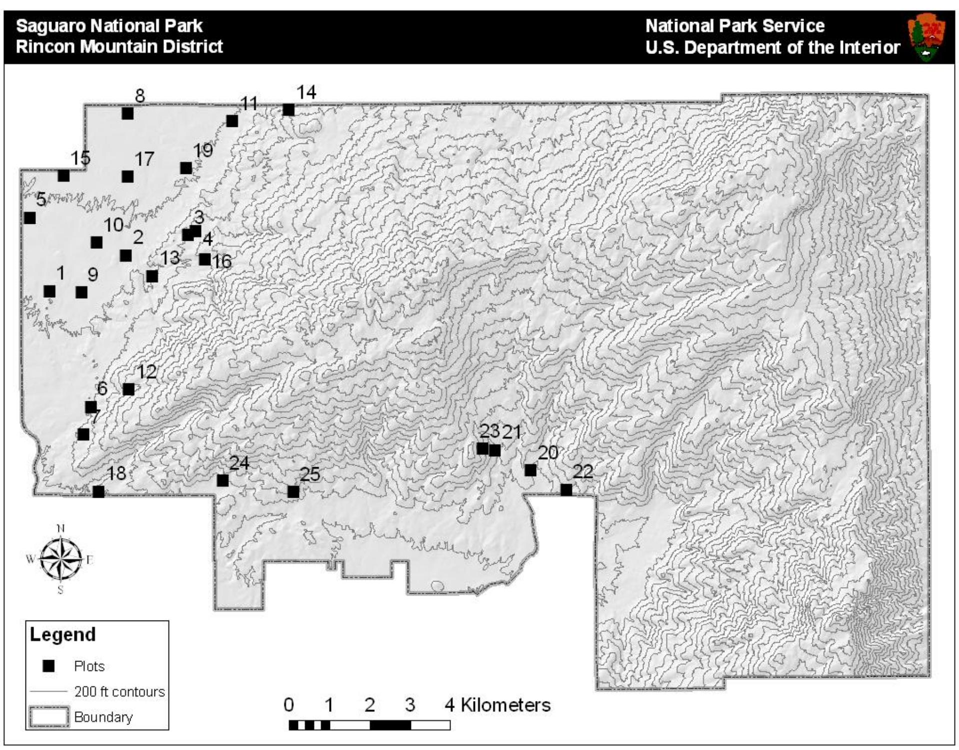

Figure 2. Plot locations in the Rincon Mountain District of Saguaro National Park.

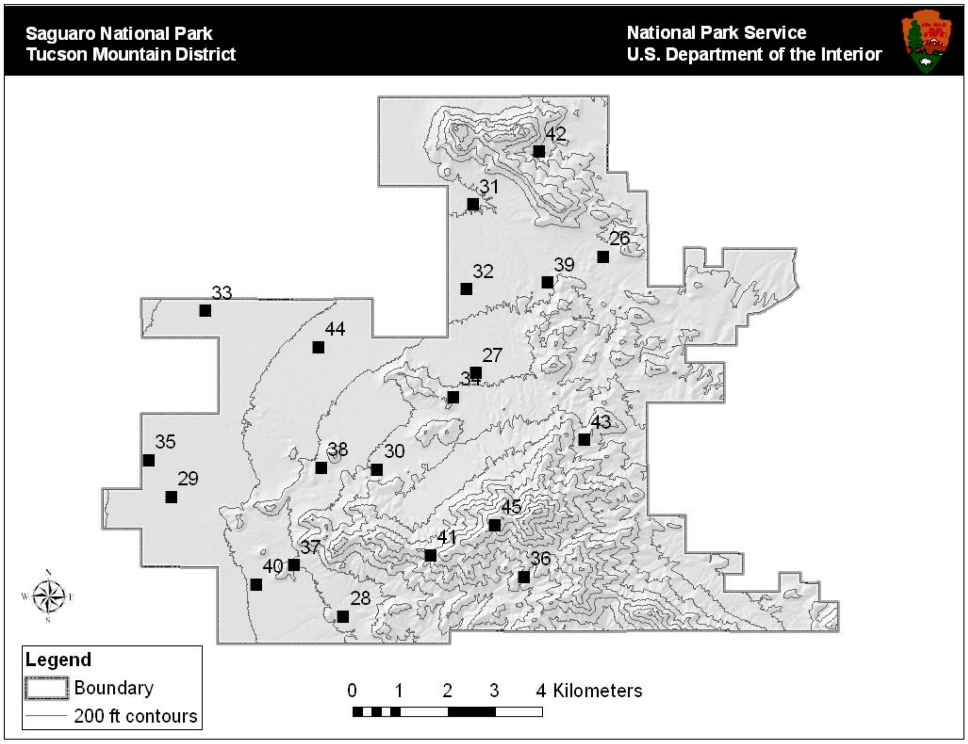

Figure 3. Plot locations in the Tucson Mountain District of Saguaro National Park.

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 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 (Turner and Funicelli 2000). 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. For plot locations, see Appendix A.

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 (Figures 4-5). 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).

Figure 4 (left). SCA intern Kim Diamond and volunteer Lindsey Sloat flag small saguaros in the Rincon Mountain District, bajada habitat. Figure 5 (right). Volunteer intern Tarah Bigger measures a saguaro in the Rincon Mountain District, rocky foothills habitat.

In addition, we counted the number of bird holes (round holes that showed evidence of an inner chamber) and arms (including all sizes of arms, ranging from "buttons" to fully developed arms). We recorded data on paper data sheets (Appendix D). 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 sub-sampled 8 plots (4, 12, 23, 25, 36, 41, 42, and 43). For sub-sampled 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 (note: we also surveyed historic plots twice and plan to include these data in final draft).

Data analysis. All data were entered into an Excel spreadsheet by one technician, 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 (see Appendix C). 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 compared 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 compare detectability among the fall/winter (when little green vegetation was present) and spring (where many annual plants were present) seasons, we compared the number detected on the two plots that were searched in both seasons. To estimate the number of small saguaros not detected by our surveys, we used a detectability model based on data from four study plots in the RMD that are sampled annually (Orum et al., *in review*). This model estimates mean detectability 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 Fergusen 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 Fergusen 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 (Steenbergh and Lowe 1983). They developed separate age-height models for each district because saguaro growth depends on precipitation (Steenbegh and Lowe 1977, 1983) and mean precipitation is different between TMD and RMD. However, in our analysis we used the RMD model for both districtsbecause we were primarily interested in the age of very young saguaros, 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 number of saguaro stems ≥ 2 m tall with the number of their arms and divided this number by the number of saguaros ≥ 2 m in each district and habitat. We also compared the number of stems/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

Population size. 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 6). 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 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 B.

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 7).

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

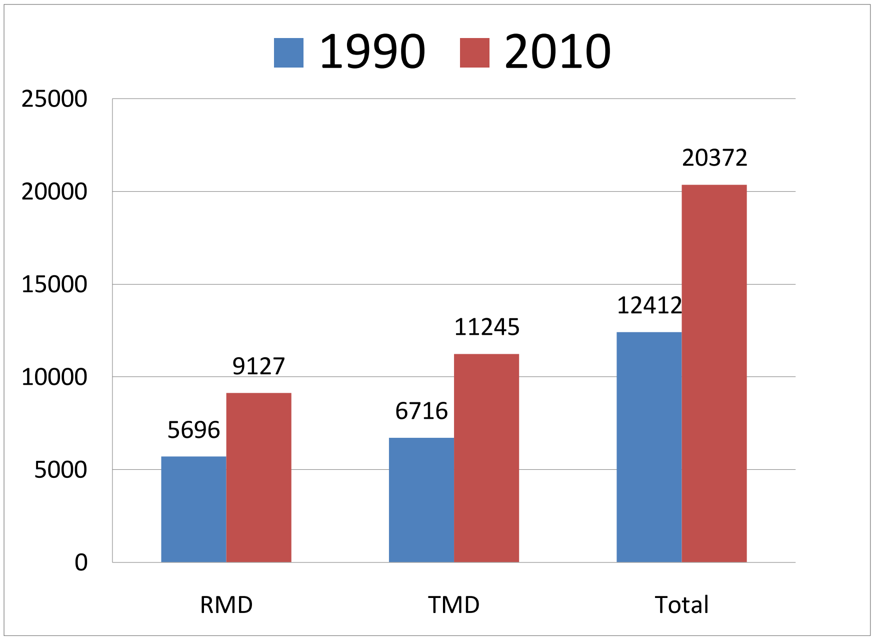

Figure 6. Number of saguaros observed on 45 plots sampled or sub-sampled in 1990 and 2010. Number of saguaros > 2 m on each plot estimated based on sub-sample in 1990; number of total saguaros estimated on 8 plots based on sub-sample in 2010.

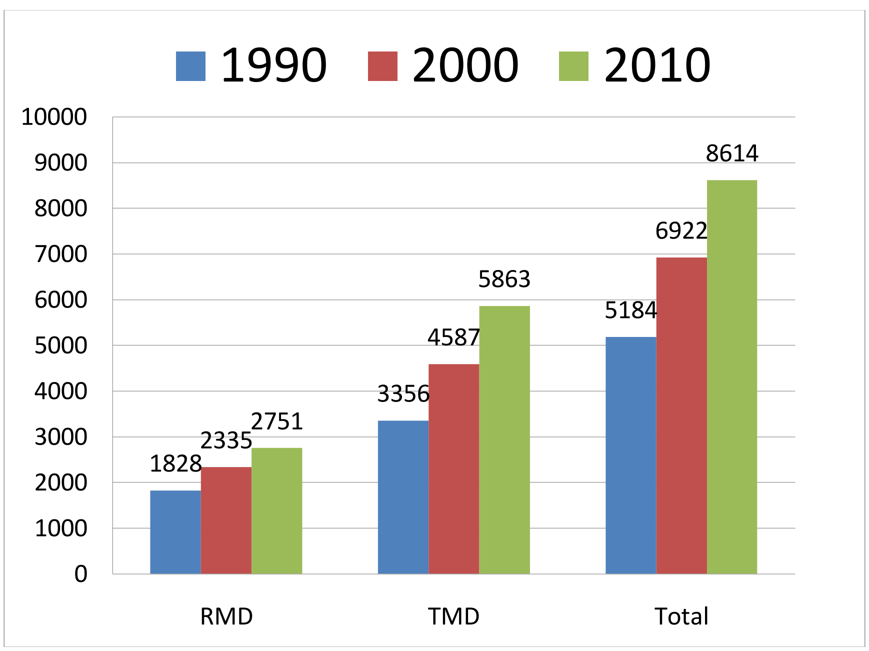

Figure 7. Number of saguaros observed on the 18 plots sampled or sub-sampled during all 3 Saguaro Census surveys, 1990, 2000, and 2010. Number of saguaros ≥ 2 m on each plot estimated based on sub-sample in 1990; all others are actual counts.

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

Year	District	No. Observed	# Plots	Total ha Surveyed	Mean Density (saguaros/ha)	Mean Density Standard Error	Population Estimate (saguaros)	Population Estimate Standard Error
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

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.

Increased numbers of saguaros observed occurred in all habitats over both the 20-year and 10-year periods (Figure 8); 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 fewer saguaros in bajada than in foothill and slope habitats combined (t_{43} = 2.89, p = 0.006). In general, saguaros were

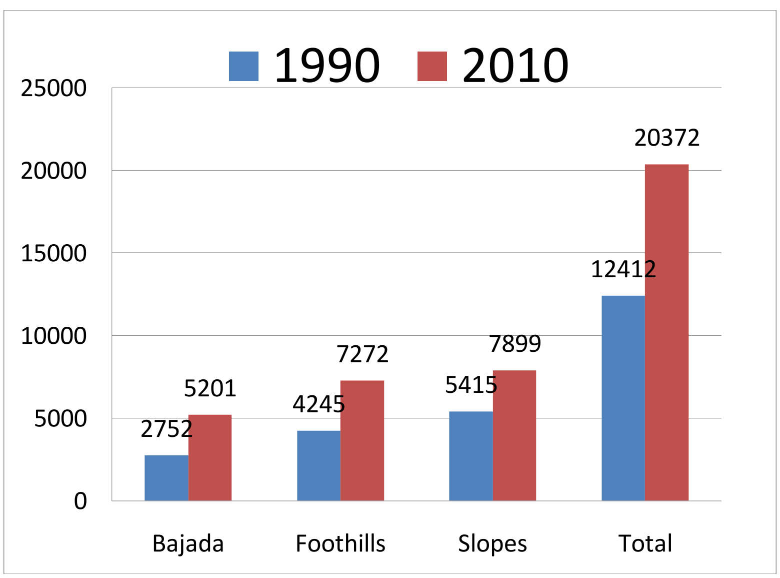

Figure 8. Number of saguaros counted on 45 plots, showing distribution across major habitat classifications (bajada, foothills and slopes).

most abundant in foothills in TMD and least abundant in bajada in RMD, but considerable variability occurred within habitats.

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 9-10). 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 $\geq$ 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 9-10).

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 11). The largest spike is for individuals17-24 years old, which would have germinated in the late 1980s and early 1990s.

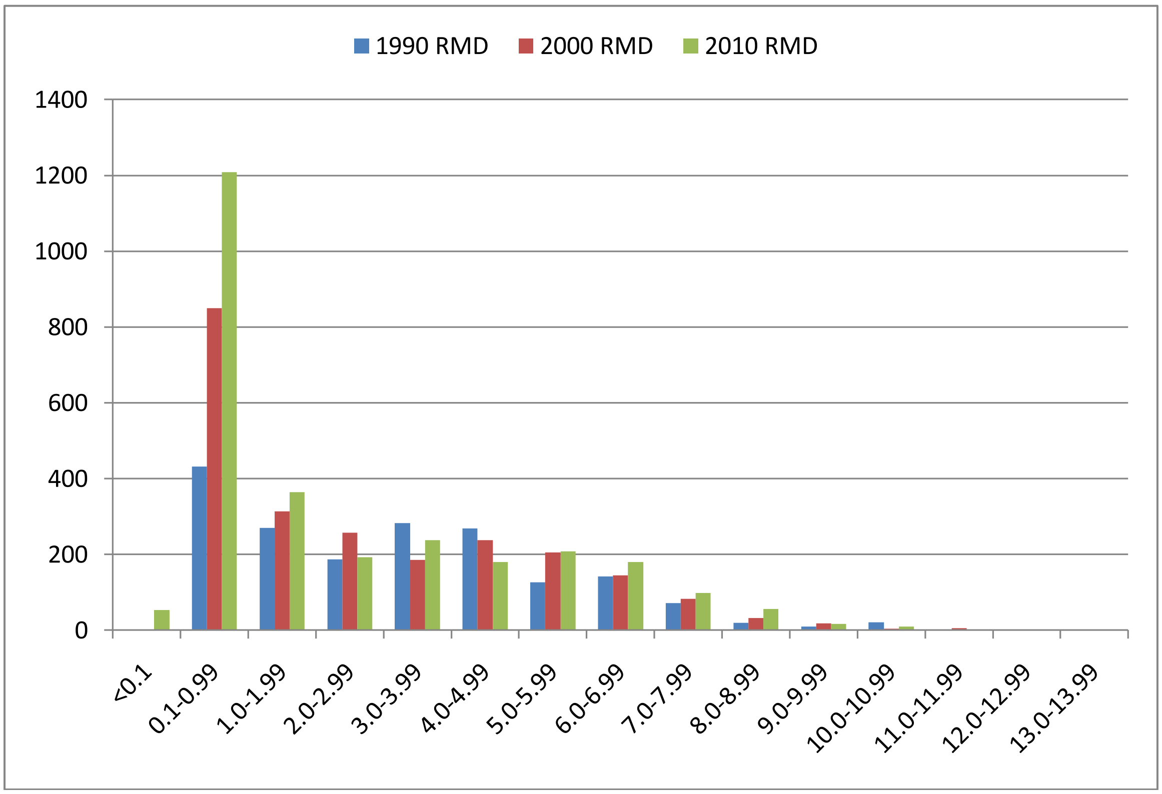

Figure 9. Saguaro size distribution in Rincon Mountain District for all 18 plots surveyed in 1990, 2000, and 2010. Note that saguaros <0.1 m were not recorded in 1990 or 2000.

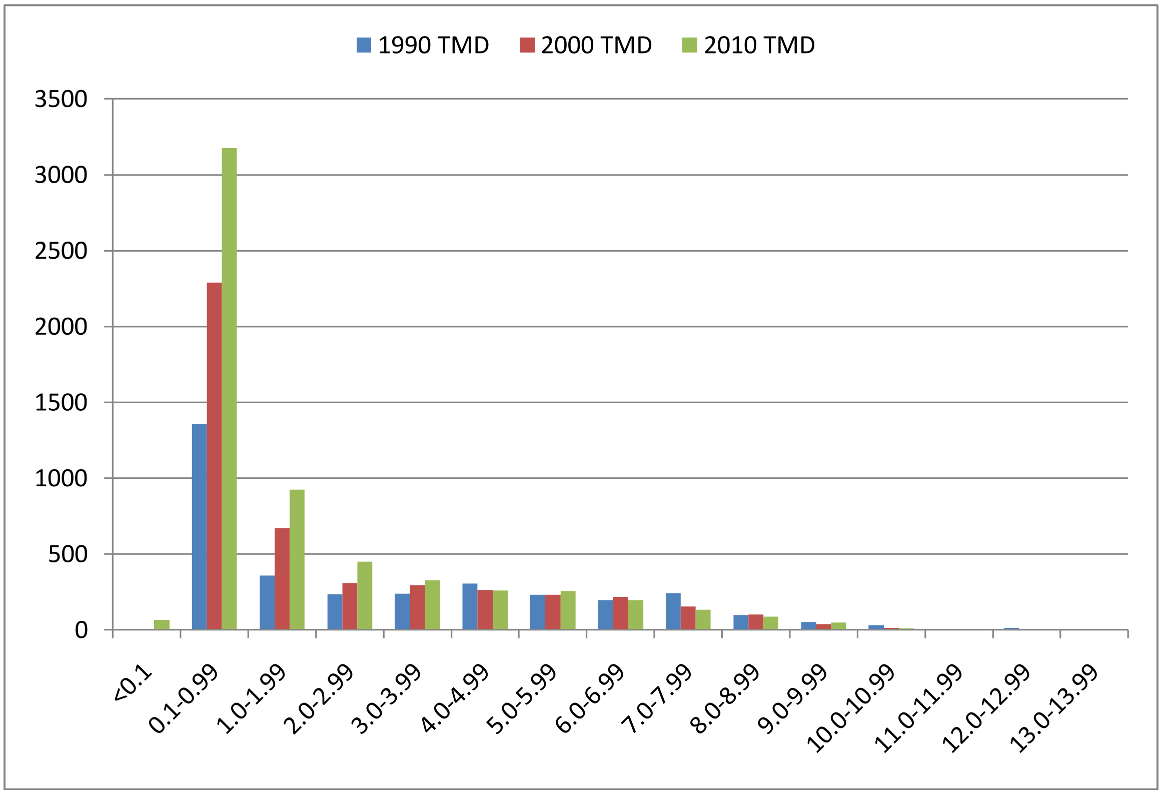

Figure 10. Saguaro size distribution in Tucson Mountain District for all 18 plots surveyed in 1990, 2000, and 2010. Note that saguaros < 0.1 m were not recorded in 1990 or 2000.

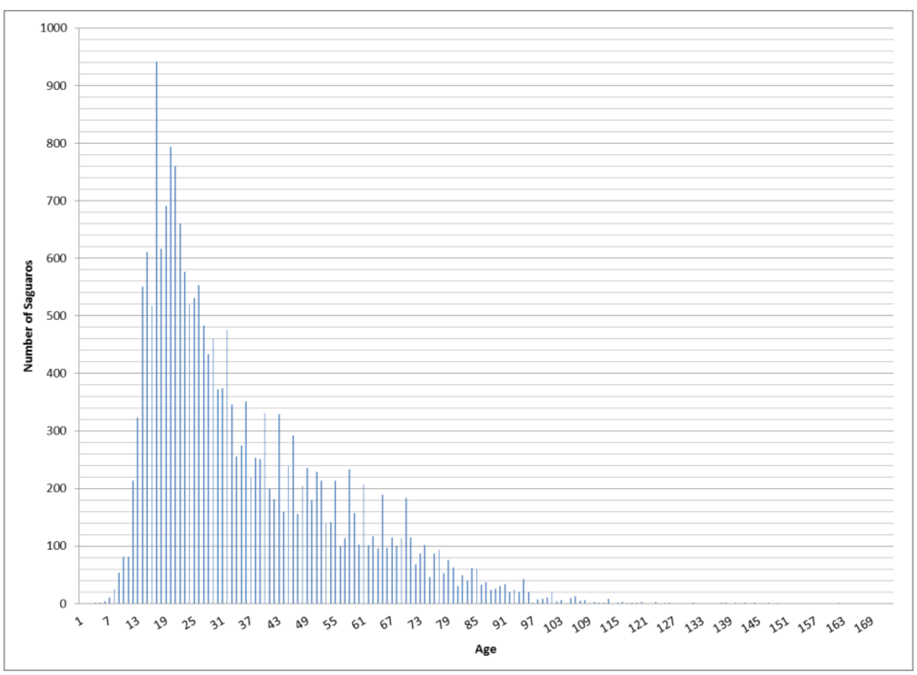

Figure 11. Age structure for all saguaros observed on 45 plots during the Saguaro Census. Age estimates are based on the Steenbergh-Lowe age-height model for RMD.

Detectability. Using the Orum-Fergusen detectability model, we estimated that we failed to detect 4,082 saguaros that were actually present on the 45 plots (Table 3, Figure 12). Among 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 0-112, 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.

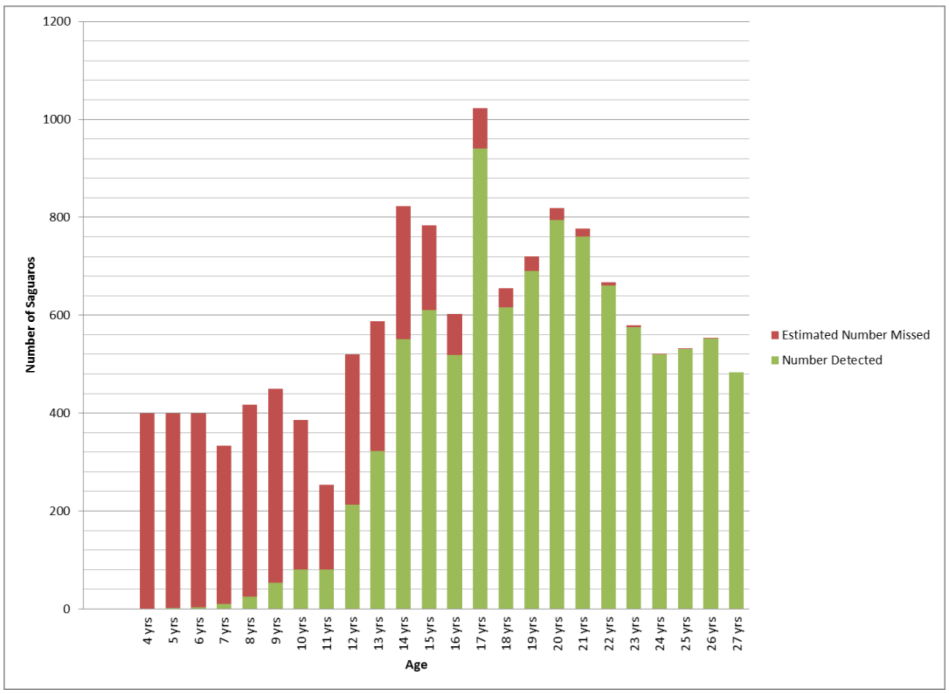

Figure 12. Estimated number of saguaros for each year class <27 yr on 45 Census plots. Estimates based on Orum-Fergusen detectability model for RMD; ages based on the Steenbergh-Lowe model for RMD, as in Figure 11.

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.

Table 3. Number of small saguaros estimated to be present but not detected during the 2010 Saguaro Census, based on Orum-Fergusen detectability model (Tom Orum, pers. comm.).

Combined RMD & TMD					
Age	Height	Number Detected	Detectability	Estimated Count	Estimated Number 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

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

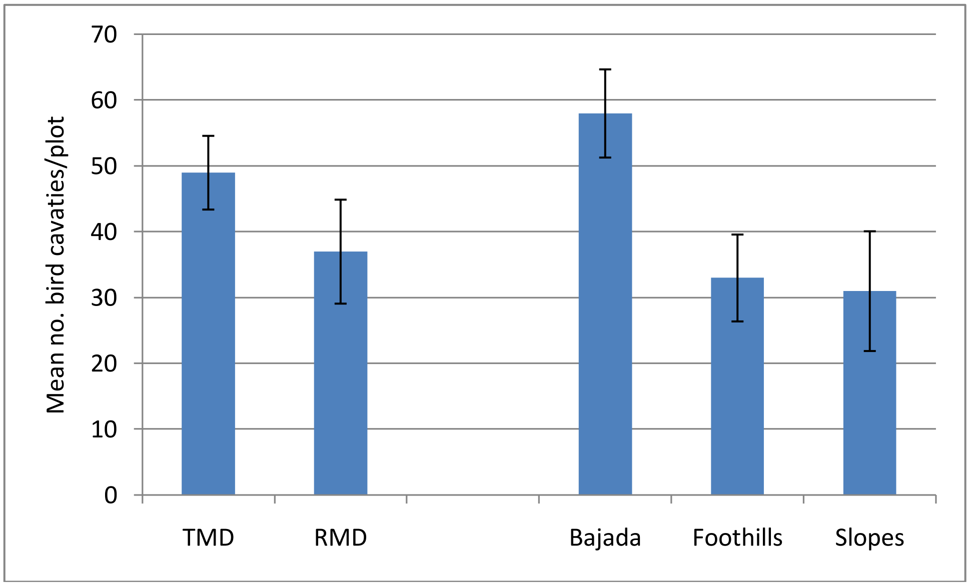

Figure 13. Mean number of bird cavities/plot (+1 SE) by district and habitat, 2010 Saguaro Census.

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.

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. Pierson and Turner 1998, Orum et al., *in review*) 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 (Pierson and Turner 1998).

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 9-10 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 arms.

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., *in review*) 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 11), and what has caused the apparent recent decline? The Census data bolster other studies (e.g., Pierson and Turner 1998, Orum et al., *in review*) 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 (March 2011) 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 spines 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 among habitats or between the 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. We have no idea why the number of cavities might be higher at TMD or in bajada areas, but we suspect that it is related to the distribution of Gila Woodpeckers and Gilded Flickers, which 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.

Methodology. 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 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

Figure 13. Group of Southwest Conservation Corps members working on a Saguaro Census plot in the Rincon Mountain District, April 2010.

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 (see Appendix C). Kim's work made it possible to effectively mobilize large numbers of excellent volunteers.

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 C), 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 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.

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 visitor fee funds 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.

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Appendix A
UTM Coordinates of Plot Locations (NAD 1983)

Insert regular plot coordinates
Insert subsampled plot coordinates

Appendix B
Data summary table

Appendix C
Educational and web site products

Appendix D
Educational and web site products

Appendix E
Locations and naming conventions for all associated files

Raw data is located at:
1990:
N:\Resources\Long-term Plant Monitoring\Saguaro_Perennial Veg Monitoring Plots\Final 1991 Saguaro Population Report\Table 1

2000:
P:\Resources\Saguaro 2010\Maps and data\2000_RawData_Census Saguaros.