

Monitoring the saguaro population in Saguaro National Park: continuing a 70-year tradition



Kara O'Brien and volunteers measuring saguaros on a plot in Saguaro National Park, Rincon Mountain District,
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Introduction

Studies of the saguaro cactus (*Carnegiea gigantea*) in Saguaro National Monument began soon after the monument was established in 1933 (the monument became Saguaro National Park in 1994). This was in part due to the close proximity of the University of Arizona, but mainly 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 (Swann and Ahnmark 2008).

In 1989-1990, as part of a study of epidermal browning, the NPS Air Quality Division established 45 plots that were also intended to provide baseline data for long-term monitoring (Duriscoe and Graban 1991). Due to the success of this program, park staff determined that this monitoring should take place every 10 years, and initiated a second survey that was completed in 2000 (Turner and Funicelli 2000). Because sampling in 1990 and 2000 coincided with the U.S. Census, this effort was named the “Saguaro Census.”

The major goal of the 2010 Census was to establish a stronger linkage between the 45 Duriscoe-Graban plots and historical analyses of the saguaro population by resurveying plots established in 1941, the 1970s and 1990. This approach enhances the continuity between the Census and historical saguaro demographic studies extending back 70 years. We also sought to ensure the integrity and compatibility of data collected in future surveys by formalizing sampling protocols. Additionally, we sought to remove a limitation of past surveys by establishing plots in high elevations to cover the entire geographic extent of the saguaro range. Previous studies have not examined the population outside of “prime” saguaro habitat. With interest in whether climate change will cause species to move upslope, we sought to add plots to the Census that would enable this question to be evaluated. Finally, we worked to engage the public in long-term monitoring of saguaros by restyling the Census as a Citizen Science program. Our new approach led to collaboration with a large number of volunteers equipped to discuss the importance of long-term monitoring of the saguaro population, and involved young people through the creation of educational and Service Learning programs.

Methods

Between August 2009 and October 2010 we conducted all preparation and field work related to the 2010 Saguaro Census. We developed a detailed survey protocol based on previous reports and interviews with authors (O’Brien et al. 2011). We relocated plot corners using GPS; flagged plot boundaries; and used 3-5 person teams to locate, measure, and flag all saguaros using a triple-count method. We measured all saguaros less than 4 m in height with a measuring stick and all saguaros greater than 4 m using a clinometer, measuring tape, and trigonometry. In addition we counted bird holes and the number of branches (arms) on each saguaro.

We relocated 11 “historic” plots, 5 that were established in 1941 by Gill and Lytle (1942) and 6 that were established in 1971 or 1975 by Steenbergh and Lowe (1983). Historic plots were surveyed using the Census protocol, and each saguaro was mapped using a Trimble GPS unit.

To better assess the response of saguaros to potential future climate change and to map the distribution of saguaros in RMD, we established 120 new, smaller (0.25 ha) plots in high-elevation areas of saguaro habitat. Using one-foot resolution aerial imagery in a GIS, we identified locations of saguaros by searching for their distinct shadows in the images (Figure 6). After recording saguaro shadows on south-facing slopes to nearly 5,500 ft (1,676 m; Figure 7), we stratified plots between 3,500 and 5,500 feet using three predictor variables: burn history, solar insolation, and elevation (Figure 8). We allocated 5 randomly-selected plots to each of the 24 strata, and sampled saguaros following our standardized Saguaro Census protocol.

For analysis of Census plot data, we followed the methods of Turner and Funicelli (2000) by placing saguaros into size classes of 50 cm (<2 m) or 1 m. We compared data from 1990 and 2010 by directly comparing the number observed on each plot, district, and habitat type. Because only 18 Census plots were surveyed in 2000, we could only examine changes between 1990, 2000, and 2010 on these 18 plots. We compared the number estimated for the entire park in 1990, 2000, 2010 using the methods of Turner and Funicelli (2000), which was based on extrapolation using the total area in each district of Saguaro National Park. To estimate the number of small saguaros not detected by our surveys, we used a detectability model based on the height of known saguaros when first observed (Orum et al., 2010). To estimate age distribution of saguaros in the park based on height, we used the Steenbergh-Lowe model (Steenbergh and Lowe 1983). To estimate potential for flower and fruit production, we divided the number of arms on saguaro stems ≥ 2 m by the number of saguaros ≥ 2 m for each district and habitat.

For the new high elevation saguaro plots, we used logistic regression to predict saguaro presence based on elevation, burn history, and solar radiation. The statistical results from this analysis were then utilized in ArcMap to create a map indicating the probability of saguaro presence throughout the RMD. Within the area that had at least a five percent probability of a saguaro being present we interpolated the saguaro density using the inverse distance weighting method in ArcGIS.

We hired student interns to recruit, train, and develop volunteer Citizen Scientists. We recruited primarily groups of 15-25 volunteers per survey from businesses, non-profit groups, and schools through a press release and Saguaro National Park's website. We created an area on the website for volunteers to be able to view photos of their work in the field and a graph comparing their results from with those from the same plot in 1990 and 2000.

Results

Census plots. We counted and measured a total of 20,372 saguaros on 37 Census plots and 8 sub-plots during 2010, 11,245 at TMD and 9,127 at RMD (Figure 1). This includes estimates based on a few plots we could not sample fully, and does not include 211 saguaros less than 10 cm in height. The number of saguaros observed 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 difference between the two districts was not statistically significant ($t_{43} = 1.76, p = 0.086$).

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. The number observed on 18 plots sampled during all three surveys in 1990, 2000, and 2010 increased by approximately 1,700 saguaros between 2000 and 2010. 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 479,411 in RMD. This represents a 65.5% increase in saguaros in the park since 1990, and a 16.7% increase since 2000.

The number of saguaros in the smallest size classes (< 1 m) greatly outnumbered saguaros in other size classes in both districts (Figure 2). 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 between 1990 and 2000, as well as between 2000 and 2010. We estimated that we failed to detect 4,082 saguaros less than 50 cm in height that were actually present on the 45 plots. The mean number of saguaro stems/plot ($x = 427$, $SE = 55.68$) and TMD ($x = 399.15$, $SE = 43.9$) was not significantly different ($t_{43} = 0.38$, $p = 0.708$) between the two districts or across habitats. More bird cavities were found in bajada habitats ($x = 58.1$, $SE = 6.86$), than on slopes ($x = 30.7$, $SE = 9.06$) or foothills ($x = 33.7$, $SE = 6.58$). Based on extrapolation, we estimate that there are 163,166 bird cavities in Saguaro National Park.

Historic plots. We observed 2,612 saguaros on the 11 2 ha plots surveyed by Steenbergh and Lowe (1986) and Funicelli and Turner (2002). We observed 747 saguaros on the 5 plots established in 1941 (all at RMD) and 1,865 on the 6 plots established in 1971 and 1975 (one plot at RMD, and 5 at TMD). In general, the RMD's saguaro population declined between 1941 and 1975, and has risen dramatically since 1975 (Figure 5), while the population at TMD has also risen, though less dramatically, since the 1970s.

High elevation plots. The saguaro occurs at higher elevations in Saguaro National Park than in the "saguaro habitat" previously described by Duriscoe and Graban (1992). Results from the logistic regression model indicate that while holding the other variables at their mean, increasing elevation by one meter decreases the odds of a saguaro being present by 1%; exposing an area to fire decreases the odds of a saguaro being present by 82%, and increasing solar radiation by 1000 WH/m^2 increases the odds of a saguaro being present by 2%. Figure 9 indicates the degree to which the probability of encountering a saguaro changes when burn history and solar insolation are held at the mean and only elevation changes. At 3,500 ft (1,067 m) there is an 87% probability of saguaros being present, which drops to 50% at 4,085 ft (1,245 m) and finally drops below 1% at 5,433 ft (1,656 m).

We also used the predicted probabilities to create cartographic products. Figure 10 displays the saguaro density in areas identified as having at least a five percent probability of a saguaro being present, which ranges from 0 to 477 saguaros per hectare. As Figure 11 indicates, we found a slight trend for younger saguaros at higher elevations in the RMD, but as the coefficient of determination indicates, elevation explains only a small percent of the variability in the data.

Discussion

Long-term monitoring in the Cactus Forest area of RMD (Turner 1992; Orum et al. 2010) indicates that the saguaro population declined from the 1940s through the 1960s. In the early 1970s, a surge of recruitment began, even as larger saguaros continued to decline. Data from our historic plots are consistent with these results, indicating that while nearly half the saguaros on the plots established in 1941 had died by 1975, by 2010 the numbers were again approaching those seen in 1941. 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 at RMD 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 and promote low elevation wildfires that may adversely impact saguaros, a species that is not fire-adapted (Stevens and Falk 2009).

Based on height-age models, we estimated when young saguaros would have entered the population during the past four decades. Our results indicate that saguaro recruitment was high during the 1970s and into the early 1990s throughout the park, but has declined during the past 10 to 15 years coinciding with recent drought conditions. 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.

Our data is not yet sufficient to evaluate whether saguaros are "moving upslope", as some climate models predict. Subsequent surveys of high elevation plots will reveal whether this trend is occurring. We did find that the saguaro's elevational range extends to nearly 5,500 feet in the RMD, especially on south-facing slopes. While their upper range is clearly related to solar radiation (as subtropical plants, saguaros can be damaged or killed by freezing temperatures), a much more significant factor influencing the saguaro distribution in the park appears to be fire. Our data indicate that the Box Canyon Fire in 1999 killed many saguaros at higher elevations, as did the 1989 Chiva Fire and 1994 Rincon Fire. Our data suggest that the benefit to saguaros at high elevations of warming winter temperatures during the past several decades (Weiss and Overpeck 2005) is probably offset by the increase in both non-native and native grasses, which carry fires that can kill saguaros (Stevens and Falk 2009).

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 (Swann et al. 2011). 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.

More complete results from all Saguaro Census activities in 2009-2010 are reported in separate reports for demographics (O'Brien et al. 2011), vegetation subplots (Springer et al. 2011a), historic plots (MacEwen et al., *in prep.*), and ecotone plots (Springer et al. 2011b). In addition, we have published an article on the saguaro census in Park Science (Swann et al. 2011) and are developing two peer-reviewed scientific papers.

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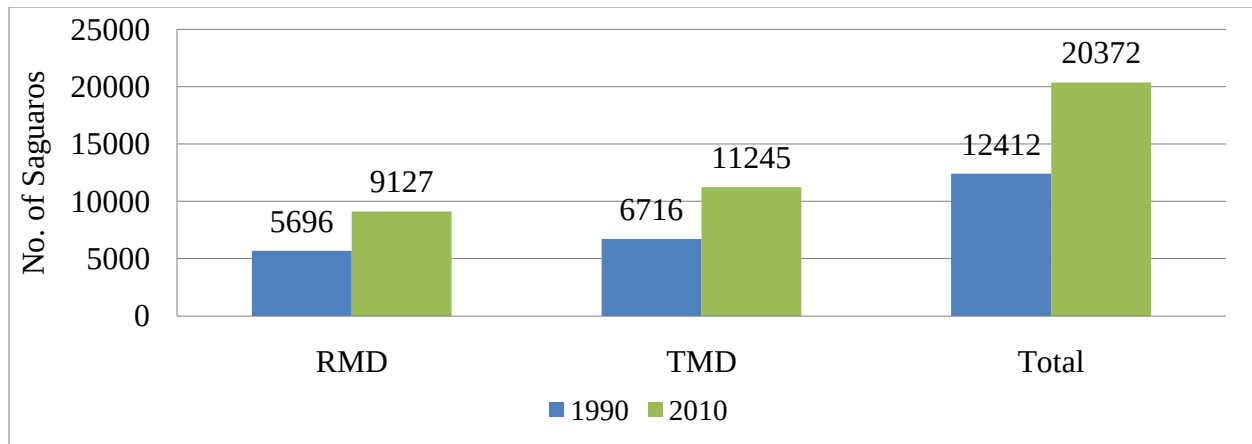


Figure 1. Number of saguaros observed on 45 plots sampled or sub-sampled in 1990 and 2010 (number of saguaros ≥ 2 m on each plot estimated based on sub-sample in 1990; number of total saguaros estimated on 8 plots based on sub-sample in 2010).

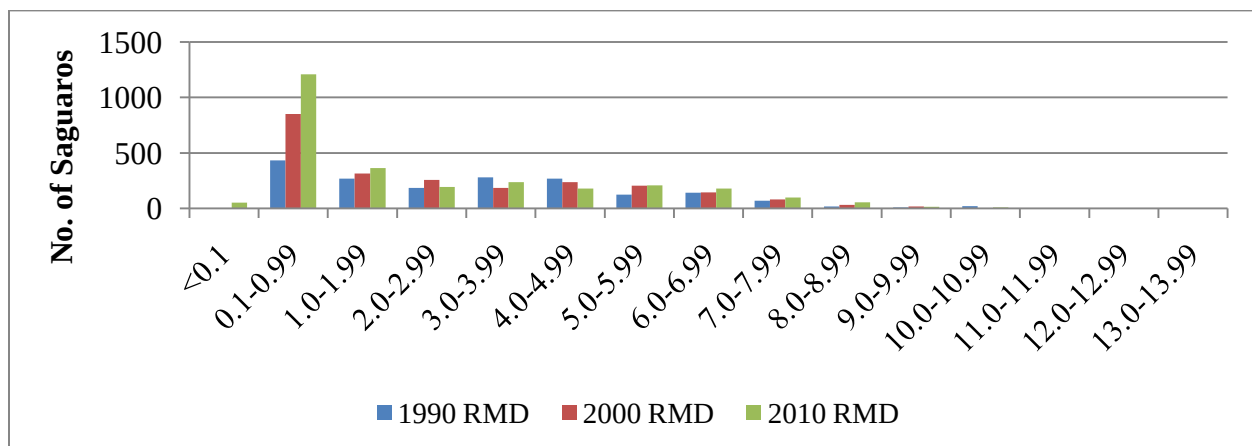


Figure 2. Saguaro size distribution in the Rincon Mountain District of Saguaro National Park for all 18 plots surveyed in 1990, 2000, and 2010. Note that saguaros <0.1 m were not recorded in 1990 or 2000.

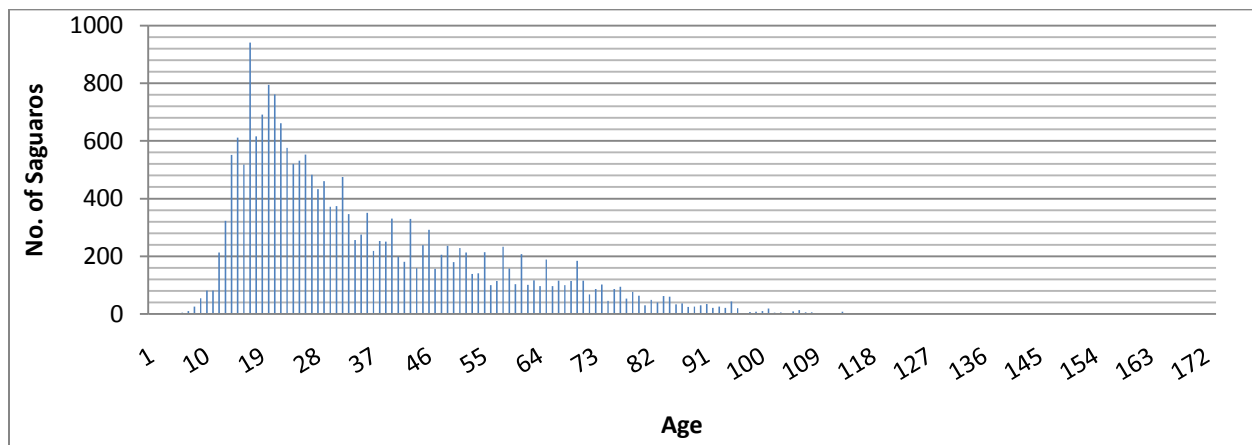


Figure 3. Age structure for all saguaros observed on 45 plots during the 2010 Saguaro Census. Age estimates are based on the Steenbergh-Lowe age-height model for RMD.



Photo 3. Southwest Conservation Corps members working on a Saguaro Census plot in the Rincon Mountain District, April 2010. **Figure 4** (right). Locations of saguaros on historic plot 41C, originally established in 1941. In 1975, 310 saguaros (including dead saguaros) were mapped on the plot; in 2010, 248 live and 24 dead saguaros were mapped.

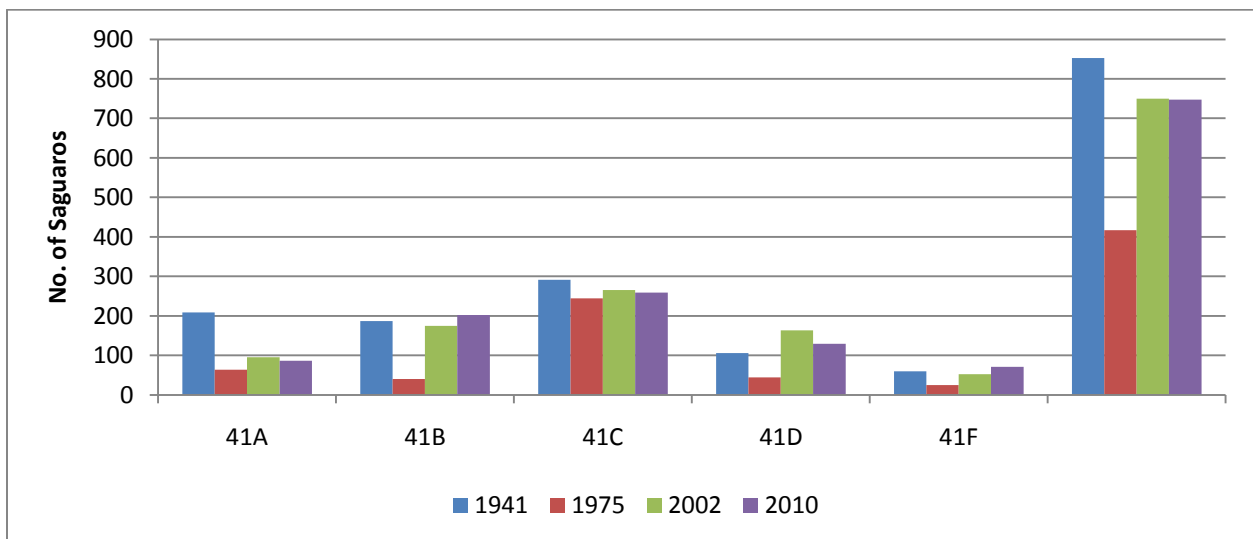
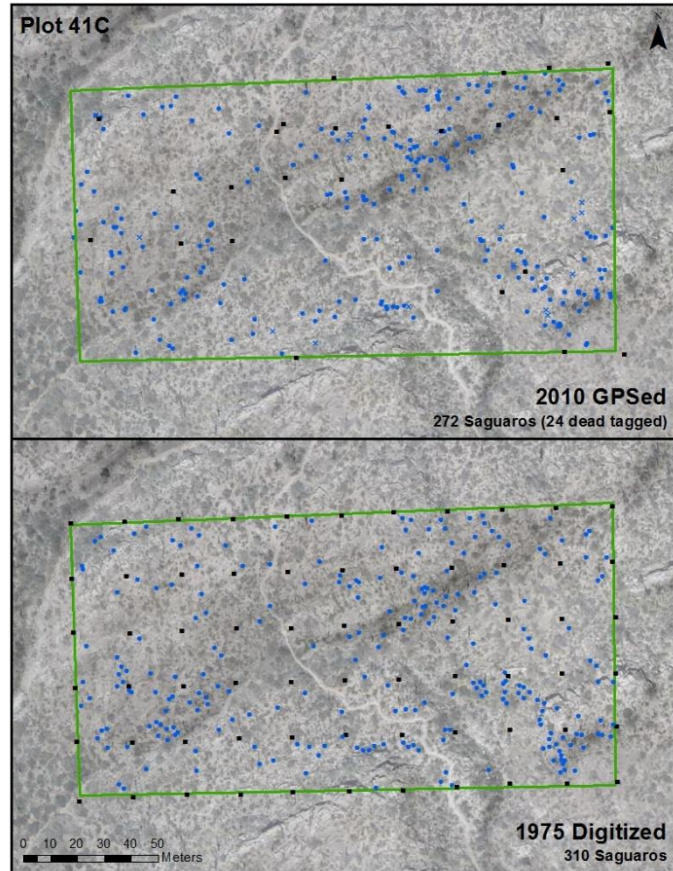


Figure 5. Number of live saguaros on 4 plots surveyed in the Rincon Mountain District in 1941, 1975, 2001-2002, and 2010 (with total on far right). Saguaros declined on all plots in the bajada from 1941 to 1975, then rebounded. The number of saguaros on plot 41C, on a rocky slope, has been relatively stable since 1941.



Figure 6. Saguaros in the ecotone identified from aerial imagery by their shadows (circled).

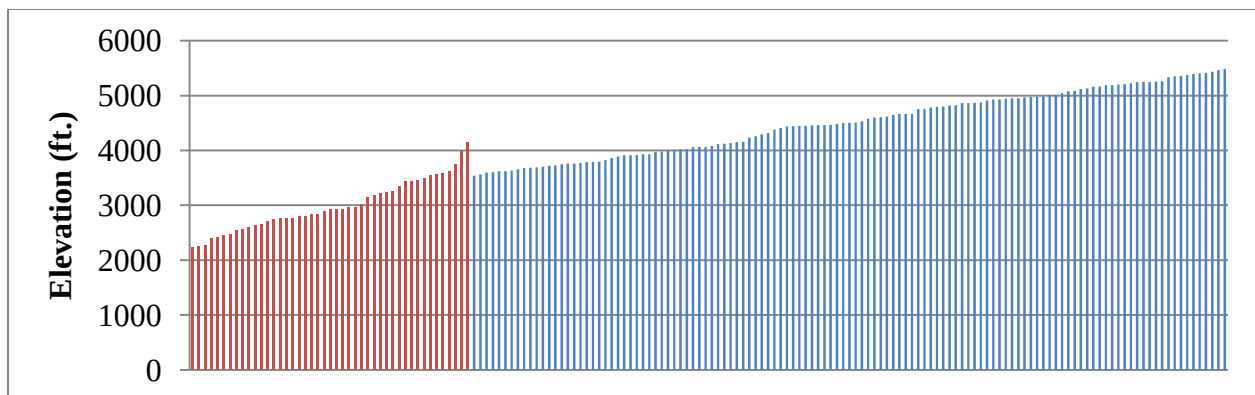


Figure 7. Elevation of historic saguaro plots (red; n=45) and newly established ecotone plots (blue; n=120) at the Rincon Mountain District of Saguaro National Park.

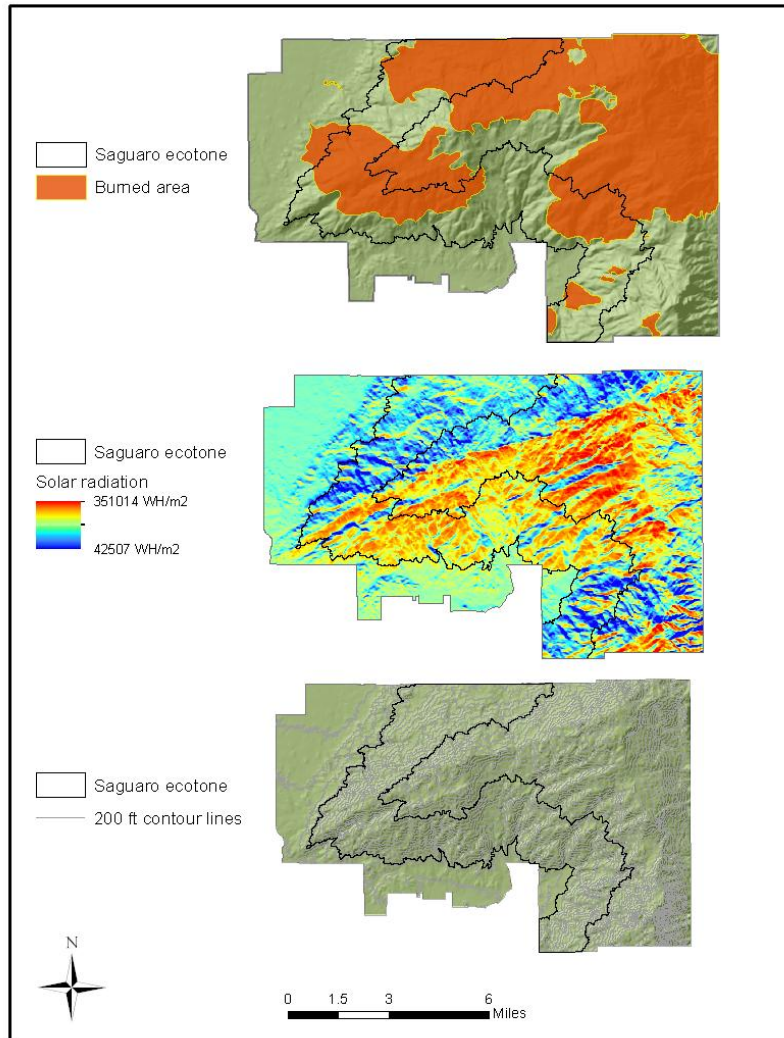


Figure 8. Historic fire locations (top), solar insolation (middle), and elevation gradient (bottom) at the Rincon Mountain District of Saguaro National Park.

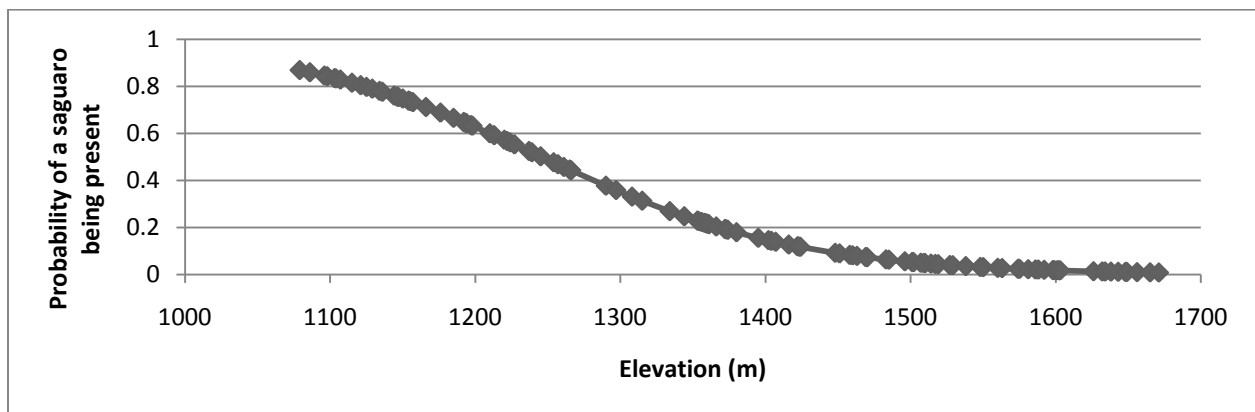


Figure 9. Predicted probability of a saguaro being present at the Rincon Mountain District at Saguaro National Park as elevation changes.

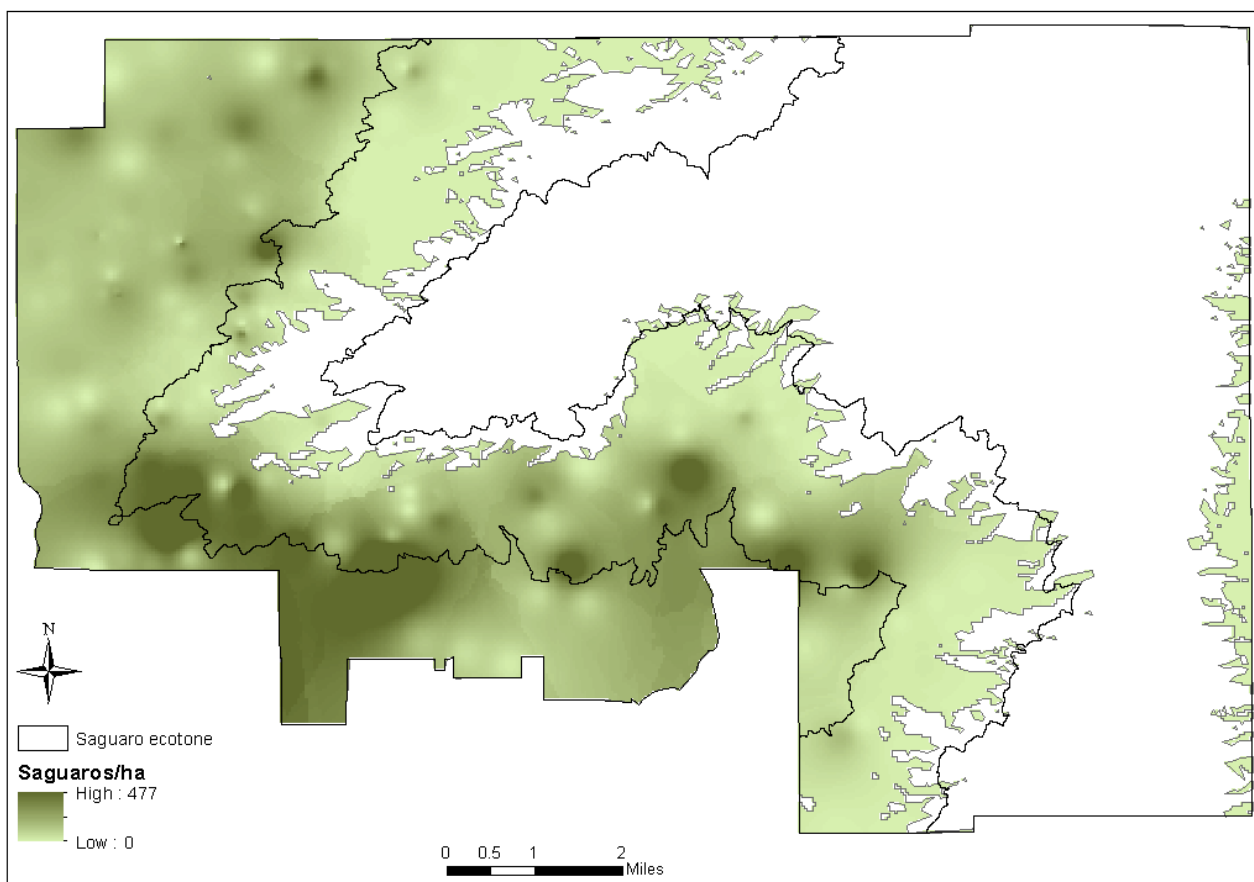


Figure 10. Saguaros per hectare at the Rincon Mountain District of Saguaro National Park. Saguaro density is indicated where the probability of a saguaro being present is at least 5%.

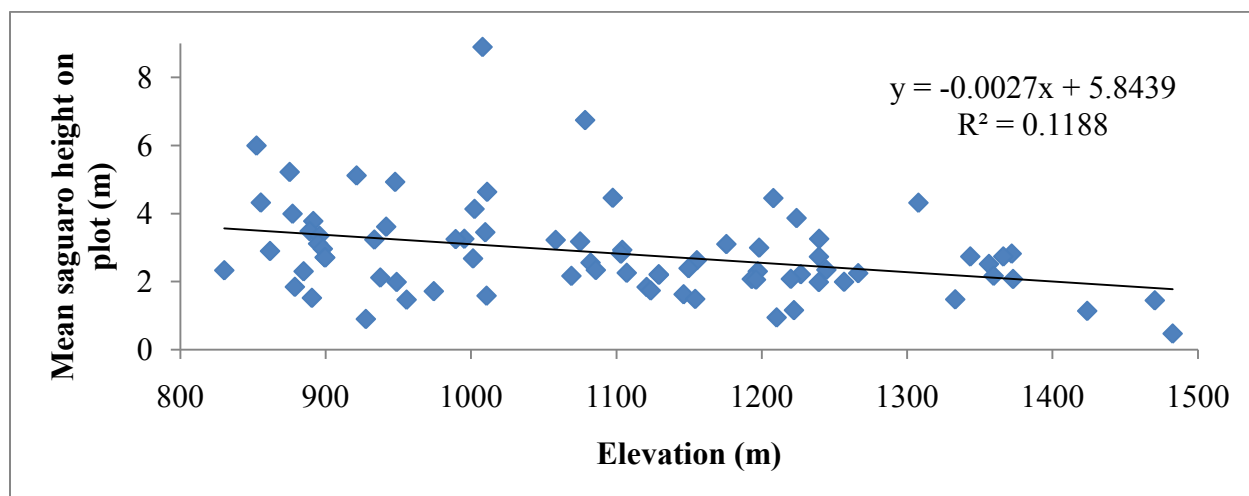


Figure 11. Mean plant height by elevation within the saguaro ecotone.