

Saguaro Census: 2009 Demography Data and Change Analysis (1975-2009) for Plot 75J

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Saguaro Demography—Stand Age Structure

Demography is the study of population dynamics and the success or fate of populations over time. According to Measuring and Monitoring Plant Populations (1998), there are three primary types of general demographic study. The first, population modeling and viability analysis, usually involves marking or mapping populations over time and constructing models that assess the future viability of the species. Single age/stage class investigation is another form of demographic study, where specific life periods or ages are measured across populations (i.e. reproductive stages, seedling stages, etc.). The final general type, demographic structure is the demography type utilized in this study. Demographic structure quantifies the distribution of individuals in age or stage classes and is used to assess changes in community structure over time. In this study we have attempted to investigate the stand age (as a function of height) structure of a small population of saguaro cacti (*Carnegiea gigantea*). The resulting data suggested information about both the life history of the species, as well as historic environmental influences at the study site.

Saguaro Natural History

Saguaro cacti (*Carnegiea gigantea*) are an iconic southwestern species, renowned for their stature and longevity. Their range is largely restricted to southern Arizona and northern Sonora, with some scattered individuals in southeastern California and northern Sinaloa. Across their range, communities vary widely in density, age structure, and

growth rates, coincident to microhabitat preferences. Saguaros grow in greatest abundance in the Arizona Upland community, also known as the saguaro palo verde community (occurring 0-1200 m) where frequent, short-duration hard frosts seem to limit most other large columnar cacti (Dimmit, 2000).

Saguaros are the largest and longest lived of several columnar cacti native to the United States. In this species, age has been shown to correlate with height, and so often both attributes are grouped when describing life history. Their impressive height commonly reaches 12 meters, but heights up to 24 meters have been documented. They grow inordinately slowly, especially when very young and very old. On average, it takes about 10 years to reach 1.5 inches in height, and 30 years to reach 2 feet. Generally, they are thought to flower at about 55 years of age (approximately 8 ft tall). Arms emerge and grow between 50 to 100 years of age, if they grow at all, and may be as abundant as 50 members on a single individual. It is thought that the number of arms and overall size of the plant correlates to soil conditions and precipitation rates. On gentle-sloped desert bajadas where finer particulate soils allow increased water retention, saguaros grow larger and more rapidly than on rocky, steep hillsides.

Saguaros are episodically recruited, germinating when conditions are most favorable. They require abundant moisture for multiple consecutive years in order to germinate and establish themselves. Mortality is high in plants less than 40 years old, or 3 ft tall, due to the atypical conditions required for successful establishment and to the vulnerability of young plants. Young plants grow extremely slowly and require the shelter and protection of an adult shrub or tree (nurse plant). A nurse plant provides a buffer from extreme heat and cold, helps conceal young, fleshy seedlings from herbivory,

and provides a more ambient microclimate against desiccation and frost. Saguaro survival into adulthood depends on multiple factors, including intensity and seasonality of rainfall, prolonged freezing events, and land-use issues—namely grazing, woodcutting, and rock removal. The uncommon conditions required to germinate and successfully establish a saguaro into adulthood are highly periodic, and thus consecutive years where conditions are favorable will produce more individuals. Therefore, when analyzing regional age structure, like-aged cohorts are often grouped into generations, and several cohorts may be missing where establishment was near impossible due to challenging environmental conditions.

Field Methods

In 1975, researchers identified and surveyed a 2,000m² plot in the southwestern corner of what is currently the Tucson Mountain District of Saguaro National Park. At this time, plot corners were identified manually, using a compass and pacing, and were permanently marked with rebar and aluminum identification tags. Saguaros located by the researchers were marked with a numbered aluminum tag, and a rough map was created with estimated saguaro positions, relative to the plot corners. The survey area was named plot 75J (Steenburgh 1986).

On November 11th 2009, research plot 75J was resurveyed in an effort to estimate saguaro demography changes since the original 1975 survey. Seven UA students and 2 park service personnel were involved in locating and documenting every visible saguaro in the 2,000m² area. Three teams were formed: Team A walked transects and located saguaros, Team B followed Team A and recorded data for all saguaros greater than 3 meters in height, and Team C followed Team A and B, recording data for all saguaros

less than 3 meters in height. Three meters was the Team B/C cut-off not because it marked anything significant about the saguaro, but rather because that was the height that at which it became difficult to measure a saguaro with our 3 meter measuring stick.

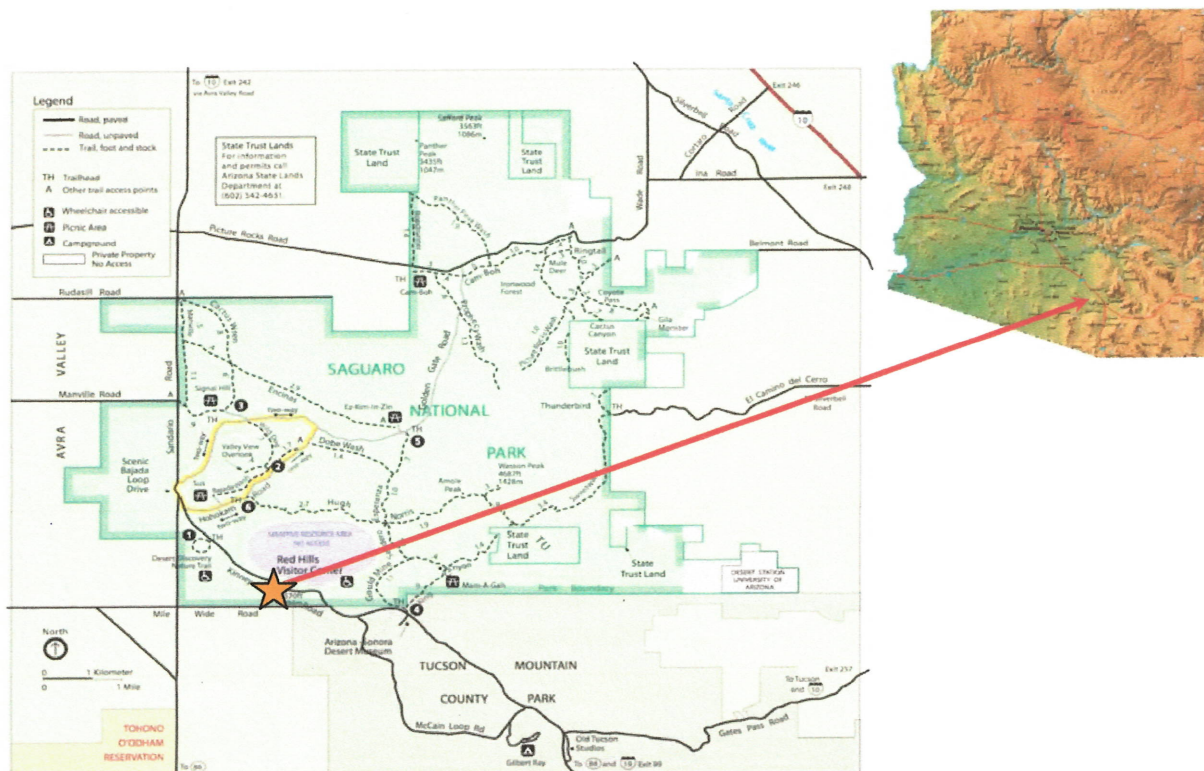


Figure 1. The above graphic shows a map of the Tucson Mountain District of Saguaro National Park (from: http://www.nps.gov/sagu/planyourvisit/upload/SAGUwestmap_SavedAs_pdf.pdf), and where the National Park is in relation to the state of Arizona (from <http://www.arizona-map.org/arizona-map.jpg>). The orange star denotes research plot 75J.

Finding Saguaros

Saguaro surveys were performed by using Garmin GPSMAP 76 hand-held GPS units (datum NAD83) and a compass (not declinated). Starting at the northwest corner, Team A participants lined up 5 meters apart (spacing initially calibrated by using a measuring tape) and followed a navigator. The navigator used a compass to find a general bearing, and then proceeded to walk due south, maintaining a precise UTM easting. Surveyors stayed 5 meters apart, walking slowly in line with the navigator and diverting

only to walk around large trees/shrubs and to inspect possible saguaros a reasonable distance from their transect line. Saguaros that were located by Team A were marked with a consecutively numbered piece of surveyors flagging. Transects were conducted in this manner, walking north or south until reaching the end of the plot, then moving east to the appropriate number of meters and reversing direction until surveyors reached the southeastern plot corner [see Figure 2 below]. Each time the transect bearing was changed (between north and south), the color of flagging was changed to indicate to Teams B and C the presence of newly located saguaros.

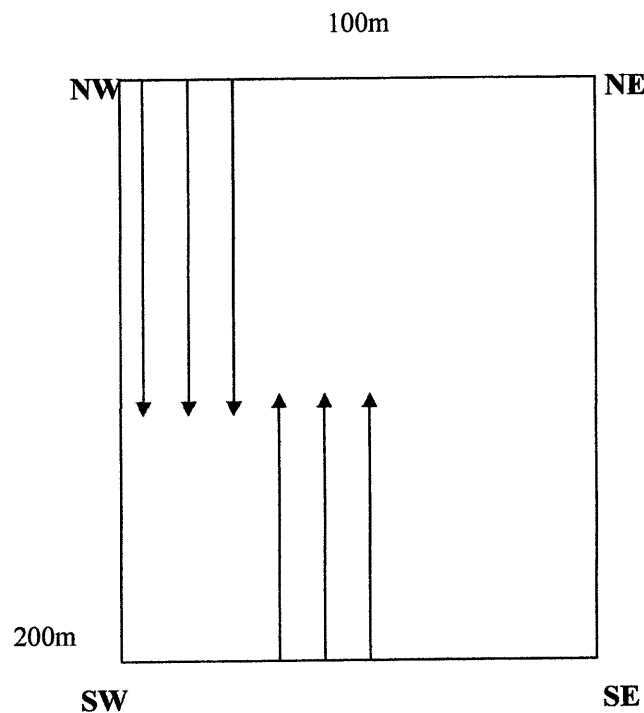


Figure 2. Above diagram is a rough, not to scale, representation of the survey methodology. The plot is depict with corners marked. Lines capped with arrows symbolize surveyors walking transects 5m apart.

Documenting Saguaros

Following Team A, Teams B and C recorded information about each located saguaro. Five saguaro attributes were recorded for each plant: location (in UTM's), height (in centimeters), number of arms, number of holes usable by birds, and if the plant appeared to be tagged from the 1975 survey. Both living and dead plants relocated from the 1975 survey were documented. UTM locations were recorded to sub-meter precision using a GeoXT handheld Trimble unit. Team B measured the taller saguaros using Suunto Clino Master, model ES 1298 clinometers and a measuring tape.

A distance of 10 meters was measured from a saguaro, and an angle from observer to top of saguaro was determined using the clinometer. Angle measurements from this tool were used with trigonometry to calculate plant heights. To correctly use the clinometer, we measured ten meters from the base of the saguaro. This is the reference point where the group uses the clinometer to measure the height. Ten meters was chosen for two reasons. The first reason being that ten meters is an uncomplicated even number to calculate the percentages. The second reason applies to the clinometer operation itself. If the height measurement is more than forty-five degree, the reading is not accurate. Once the ten meter distance was determined with a measuring tape, a mark was made on the ground with a boot or shoe. This was the reference point for sighting the clinometer at the base of the saguaro.

An angle measurement was determined by holding the clinometer vertically and looking through the sight. The sight has a (x10) magnification system that allows a person to see the percentage scale on the right and the degree scale on the left. The dial inside the clinometer floats like the dial of a compass, except it is vertical (Figure 3). We

were only concerned with the percentage scale on the right. With both eyes open, we sighted the base of the saguaro. This created an optical illusion since the clinometer does not have a direct line of sight magnification. This illusion enhances the horizontal index line that can be used to sight the base and top of the saguaro, and calculate the percent difference. At the base of the saguaro, it is important remember the percentage at the right. Next, our group sighted the top and calculated the percentage from the right side of the scale. If, at the base we had a reading of 15% and at the top we had a reading of 65%. The documented height of the saguaro would be $15\% + 65\% = 80\% \times 10$ meters, which equals 8.0 meters in height. The percentages were multiplied by the 10 meter distance we measured from each saguaro. To further increase the accuracy, two different researchers would take a reading and compare the two numbers. If the two researchers did not obtain the same results, an average of the two measurements was recorded.

Teams A, B, and C completed the survey in an all day field effort; park personnel returned later to remove flagging.

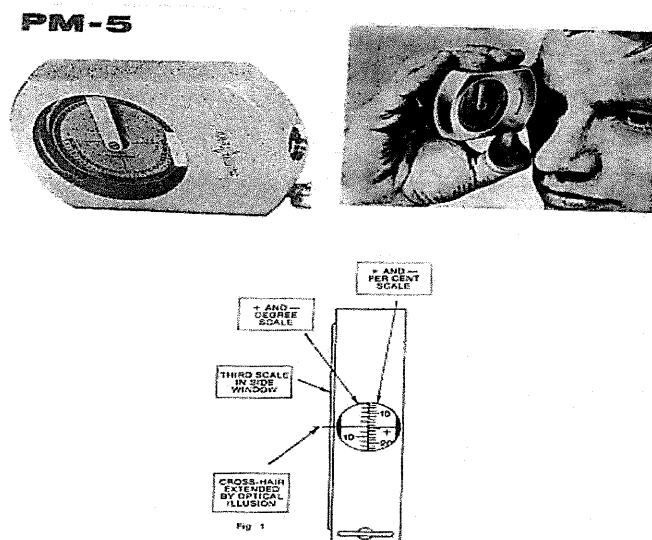


Figure 3: Clinometer (Source: Suunto Clinometer manual)

Research Questions

With the spatial, temporal, and attribute data collected on the saguaros in plot 75J at Saguaro National Park West, we were able to address several questions pertaining to saguaro biology and ecology:

- (1) What patterns can we observe in population dynamics, specifically the addition of new individuals to the population and the loss of individuals through mortality?
- (2) What patterns of saguaro growth can be observed since they were measured in 1975?
- (3) What spatial patterns can we see in how saguaros are distributed throughout the study plot? Are they randomly distributed, aggregated in certain areas, or more regularly spaced? Do areas of saguaro concentration persist through time? Are smaller saguaros found in close association with large ones?

Preprocessing and cartographic methods

After gathering the data from the survey, the information was entered into an Excel spreadsheet. The spreadsheet was returned to the National Park Service (NPS) for verification and for any final adjustments. The NPS returned to the plot to confirm some of the data and see if any saguaros were missed. The spreadsheet with additional and corrected information was then returned to the group along with prior census data from 1975 and 2001. With adjustments made to the current census spreadsheet, we began analyses and the creation of cartographic files. The NPS provided initial georeferenced shape files for the outline and corner stakes for Plot 75J and a scanned JPEG image of the

1975 plot map (see Figure 4).

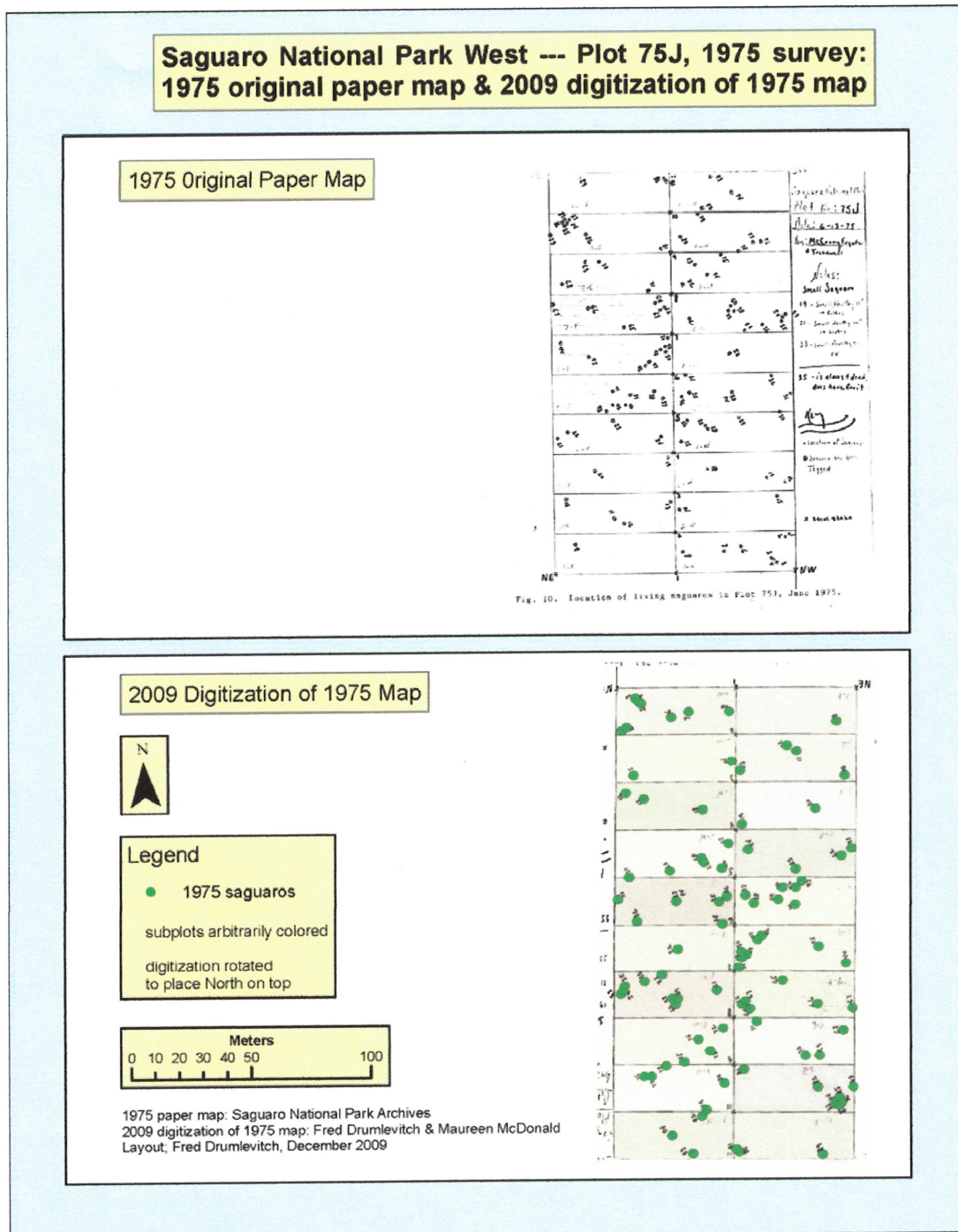


Figure 4: 1975 Map

Our first step was to create layouts for the 2009 census. We created separate files in Excel with the coordinate data for the total number of saguaros, living and dead. We then utilized the add XY data tool to display the points in ArcMap and then exported the data into feature class shape files. Once we had the shapefiles, we were able to create layouts to visually display our 2009 survey (Figure 5).

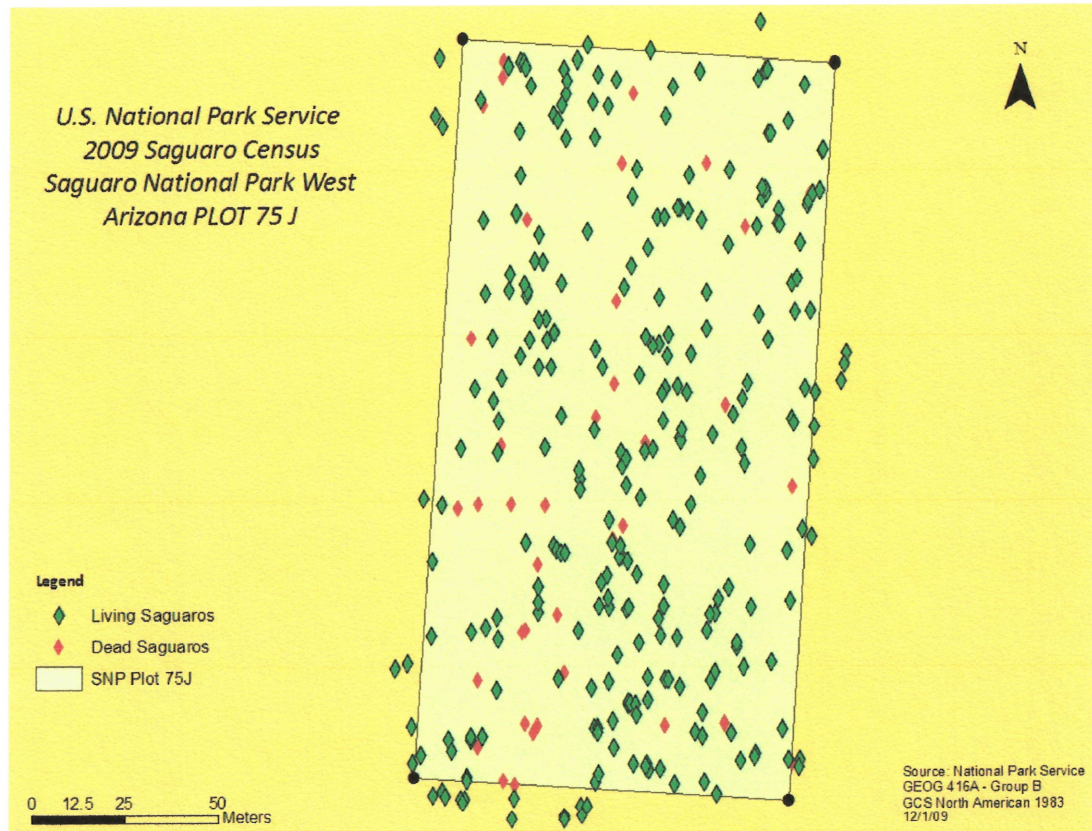


Figure 5: Map of Data Collected in 2009

For part of the Z score analysis, using the 2009 data table imported into Arc Map, we utilized the table select tool in analysis tools to create two new tables using an SQL expression to define the query by height. One selected saguaros with heights equal or above 4 m and the other selected saguaros below 4 m. These tables were then used to display XY data and which was transformed into new shape files for both height classes.

In order to include the 1975 data in our analysis, we needed to import the 1975 plot map with saguaro point locations as a JPEG. We added this raster file to an .mxd map that already had the shape files for Plot 75J and its corner points and coordinates. Using the georeferencing tool bar, we were able to create control points from the 2009 shape files and match them to our 1975 data. The updated georeferenced 1975 image now had geographic coordinates. We then used the 1975 data to create new shape files. Polylines were drawn over the existing grid of the plot and subplots and points were created where saguaros were located in the 1975. We then used the new line shape file to overlay on the 2009 data to analyze the subplot distribution for the Z score and for the growth rate analysis.

To help in visually portraying our data, we created layouts in ArcGlobe and ArcScene. ArcGlobe allowed us to import our shape files for the plot and locations points and look at our data in a three dimensional environment. In ArcScene we imported a DEM for reference and the growth rate data for the 1975, 2001 and 2009 censuses. This data allowed us to view the growth of the saguaros over time in a semi-animated three-dimensional environment. (See Appendix A for images for stills of semi-animated 3D growth created in ArcGlobe; See Appendix B for ArcScene Growth Display Images)

Analysis Methods

We received two Excel files from the rangers at Saguaros National Park. The first named "Saguaro data_plot75J" contained data from 1975 and 2001. This file provided information for living Saguaros in 1975, and their height. This file also included the living and dead saguaros in 2001 with their height. The second file named "SNP census

75J2009” included all information for living and dead Saguaros in 2009. This was the data that we had collected with the Rangers.

Table 1: Saguaros from 1975 to 2009

	1975	2001	2009
Living Saguaros	94	194	285
Dead Saguaros	0	42	40

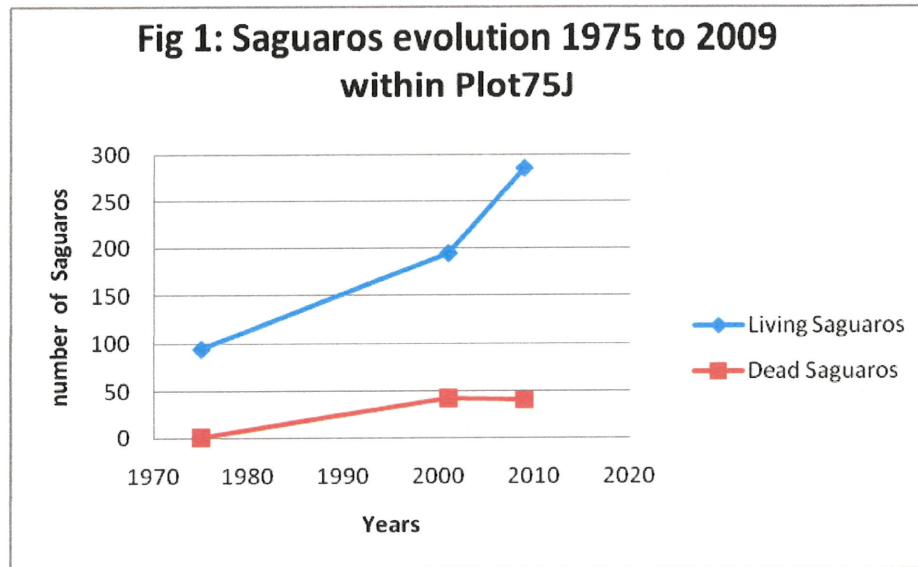


Figure 6: Summary of Dead and Living Saguaros, 1975-2009

We constructed height-frequency graphs for the three census periods (1975, 2001, and 2009) to examine patterns of size (and age) at the census periods. These graphs were helpful in discerning episodic recruitment of new individuals to the population. Because saguaros had been individually measured and tagged during the 1975 census, we were able to plot growth patterns of these saguaros through time. In order to maximize the sample size for the growth rate plots, we used data from tagged saguaros from 1975 and 2001.

We determined cactus abundance for each of the 20 subplots within survey plot 75J for (a) total saguaro counts in 1975 and 2009, and (b) for small saguaros (less than 4 m in height) and large saguaros (4 m or greater in height) for the 2009 data. We standardized the abundance data using z-scores, to determine the relative distribution of each category of saguaros in the subplots, and then we calculated z-score anomalies (the difference between z-scores) for each subplot for (a) 1975 vs. 2009 total saguaro abundance and (b) for large vs. small saguaro abundance in 2009. The chi-square statistic was used to compare the 2009 saguaro distribution among subplots with a Poisson distribution to test for randomness (Hampton and Havel 2006).

Analysis and Results

Population Dynamics

The height-frequency plots for the three census periods (1975, 2001, and 2009) show significant differences (Figure 7).

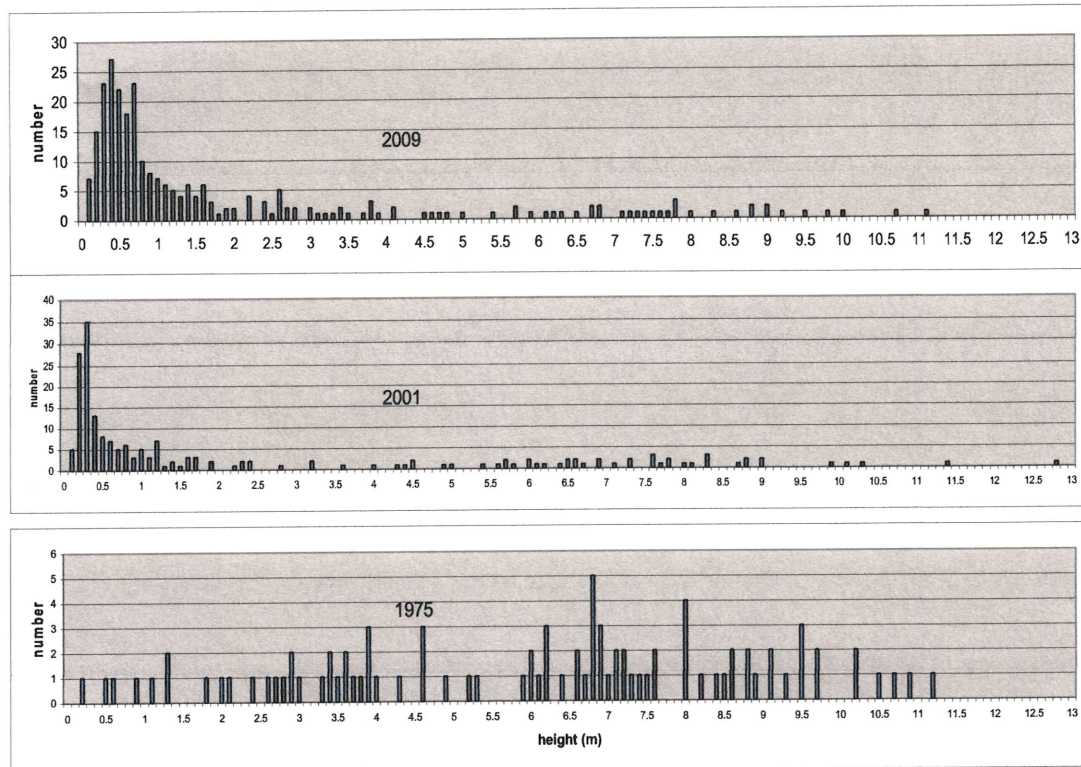


Figure 7: Saguaro length-frequency plots for three census periods, 1975, 2001, and 2009.

In particular, the later plots have large numbers of small saguaros (2 m or less in height), while very few saguaros in this size range were measured in 1975. Assuming that the 1975 census was as thorough as those in 2001 and 2009, these data indicate that there were one or more significant episodes of successful seed deposition, germination, and young plant growth between the time of the 1975 census and that of 2001. There may also have been additional recruitment between 2001 and 2009. The diminishing numbers of saguaros with increasing height is an indication of mortality rates with age. Mortality

was verified by the presence of the remains of several dead saguaros in 2009, which had been living in 1975.

Growth and Death

When studying patterns in saguaro death, we started by began by inspecting the 1975 data. The lack of documented mortality in 1975 indicates that no data available for this year because the researchers did not record dead saguaros; in subsequent years, and in our survey, deaths were noted. Saguaro germination increased after 2001 with a decrease in the death toll. We don't have enough information to explain this change, but climate conditions changes are likely involved.

The second analysis we performed was to plot the growth rate between 1975-2001 and 2001-2009. We used the same 33 living saguaros from 1975-2009 and performed the difference in height during the two time periods. The mean height difference for each period was divided by the period duration, in order to calculate an annual growing rate. Table 2 and Figure 8 show the evolution of the growth rate.

Table 2: Saguaro growth rate evolution

	Annual growing rate	Period duration (years)
1975 - 2001	0.108724942	26 years
2001 - 2009	0.084659091	8 years

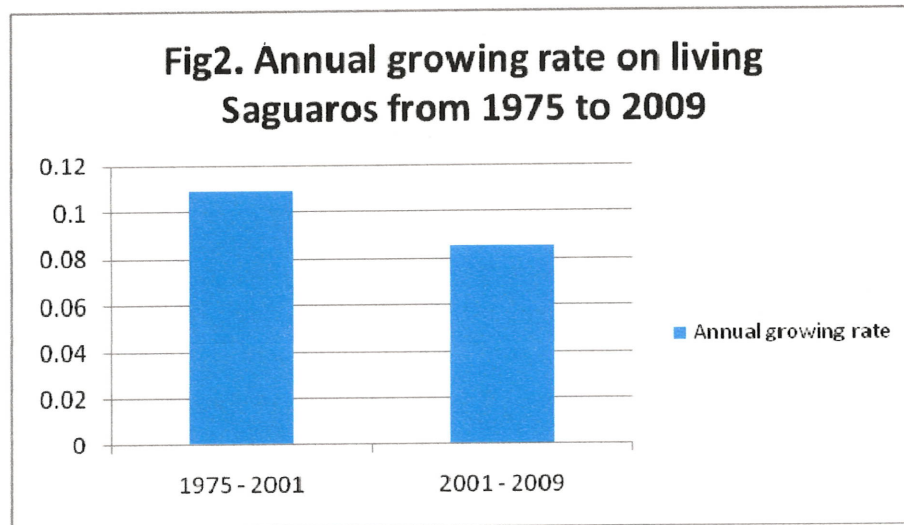


Figure 8: Annual growth rate, 1975-2009

Table 3: T test analysis

Parameters	1975-2001	2001-2009
σ^2	0.79448357	0.168920455
Number Saguaros	33	33
μ_1	2.826848485	
μ_2		0.677272727
Ho: $\mu_1 = \mu_2$		
$\Gamma_{d.f.} = 45.01893513$	P value <<0.0005	
$T\gamma = 12.58072002$		

We performed a T test in order to know if the difference in growing rate between the two periods was important. The result in Table 3 showed a huge difference.

Growth of saguaros tagged in 1975 also shows a pattern of decreasing rates of growth with increasing size. When measured in growth increments, this decrease is linear; when measured as growth as a proportion of initial size, the rate of growth appears to decline logarithmically with initial size (Figure 9).

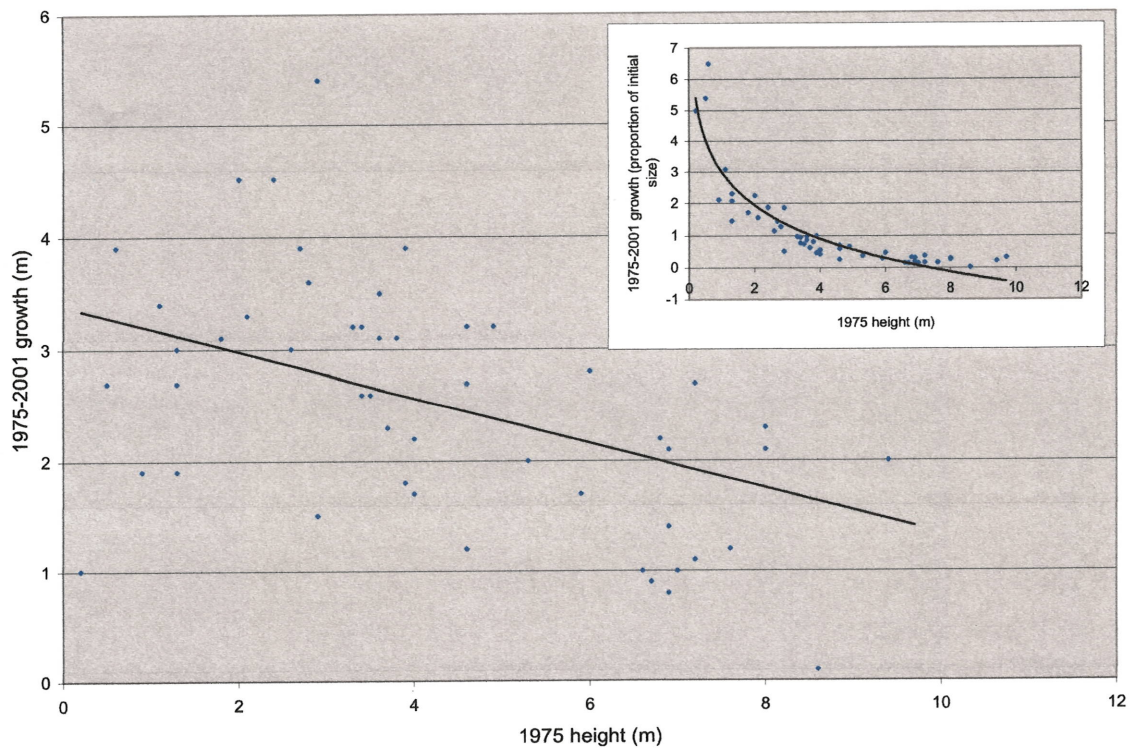


Figure 9: Saguaro growth curve – main plot: growth in increments; inset: proportional growth.

Spatial Patterns

When saguaro abundance among subplots was compared to a random Poisson distribution, there was no significant departure from randomness (Figure 10).

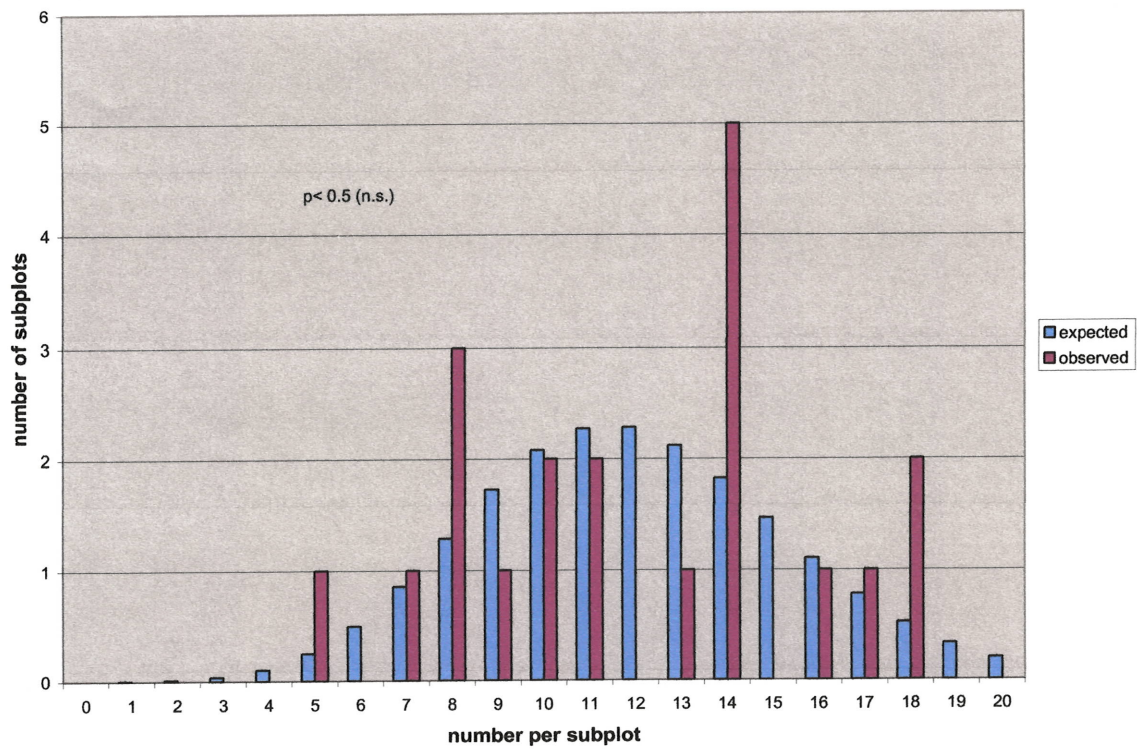


Figure 10: Saguaro distribution among subplots (observed) compared to Poisson distribution (expected) for 2009.

Z-score anomaly maps tended to be consistent with this result: Z-score anomalies between the 1975 and 2009 surveys (Figure 11) range from small (-2.24) to large (3.02) with numerous intermediate values, suggesting that there is not a clear-cut pattern of distribution that is consistent over the 34-year period.

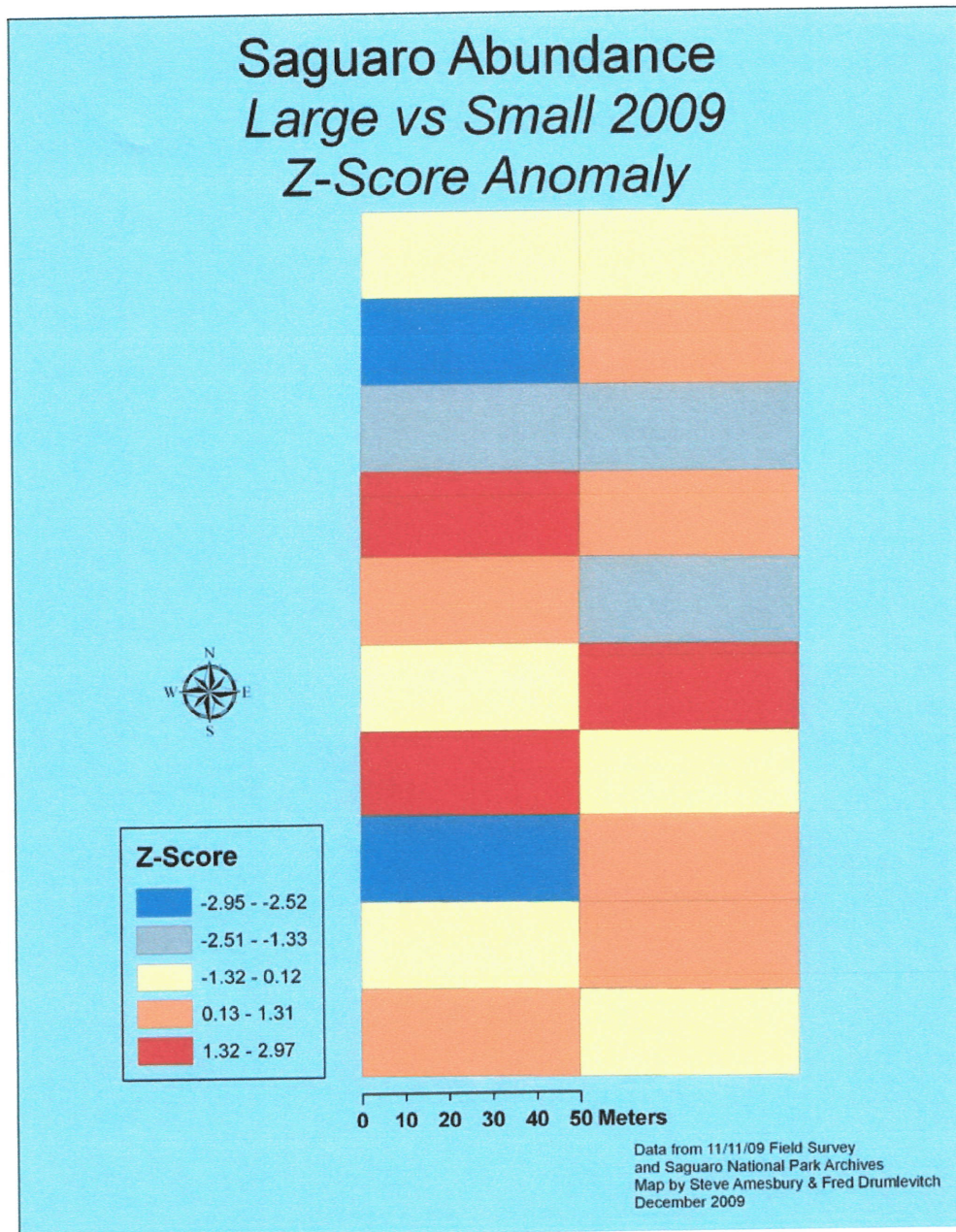


Figure 11: Map of Z-score anomalies comparing subplot abundances, 1975 – 2009.

Similarly, Z-score anomalies for large vs. small saguaros in 2009 (Figure 12) show a range of values from -2.95 to 2.97 with many intermediate scores, suggesting that there is no consistent relationship between the distribution of large saguaros and small ones.

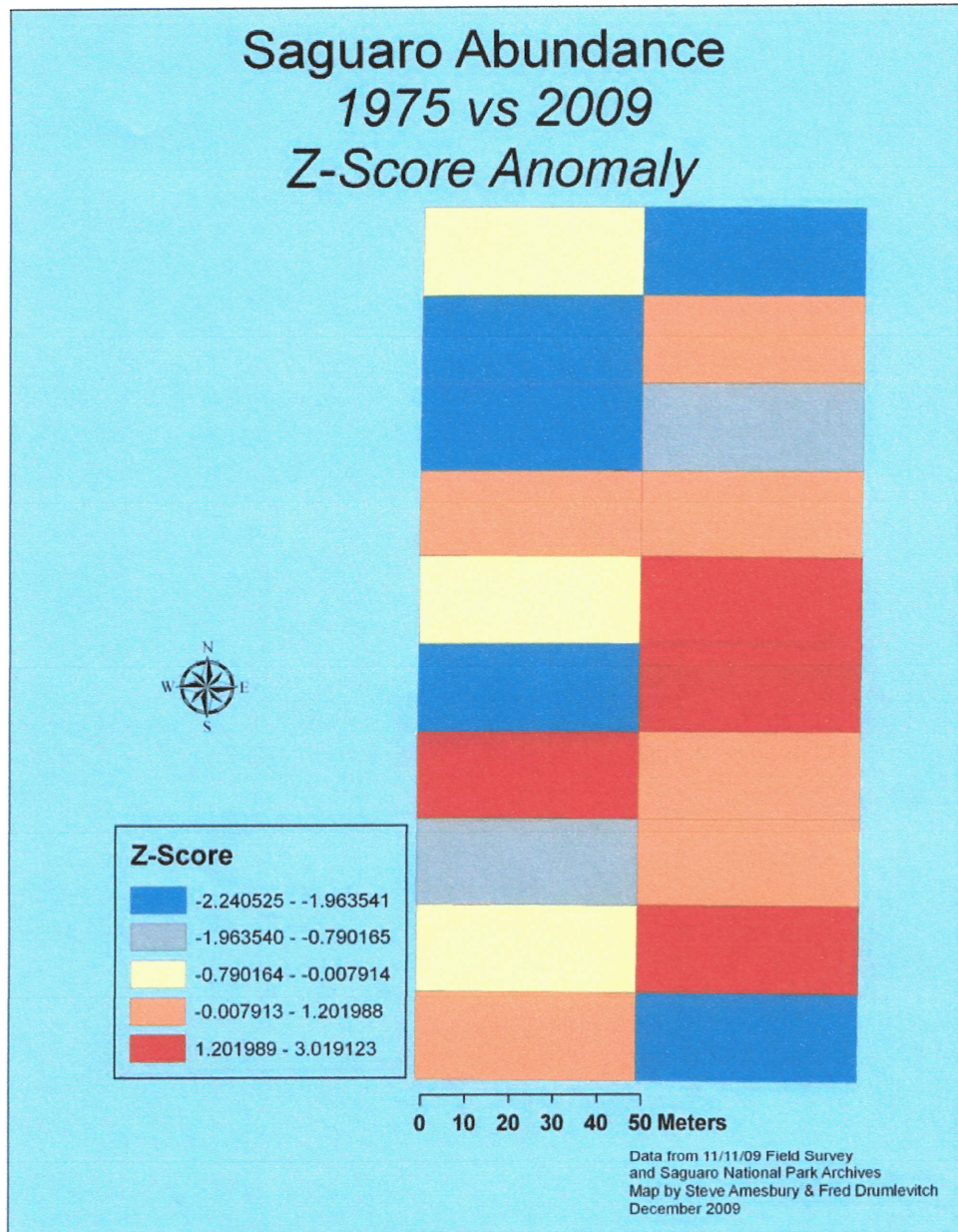


Figure 12: Map of Z-score anomalies comparing subplot abundances of large and small saguaros, 2009.

Conclusions

Our finding of episodic recruitment within the saguaro population in our study area was consistent with the results of Pierson and Turner's (1998) analysis of long-term demographic trends in saguaro populations on Tumamoc Hill near Tucson. They noted

that "saguaro seedling establishment responds to seasonal rainfall patterns . . . and pulses in seedling establishment and survivorship depend on availability of suitable niches and a sequence of favorable years for regeneration." Further analysis of the Saguaro National Park census data should include comparisons with local rainfall data.

Our growth analysis was also consistent with the growth studies carried out by Pierson and Turner (1998). They found an increase in annual growth increment in saguaros as they grew from 0 to 3 m in height, then a decline in growth rate thereafter.

Recommendations

Saguaro National Park is an ideal location for studies of saguaro biology and population ecology and has a valuable history of demographic studies ranging back to 1941. The census program of the Park is an implementation of these studies. We recommend the following modifications to the saguaro census program:

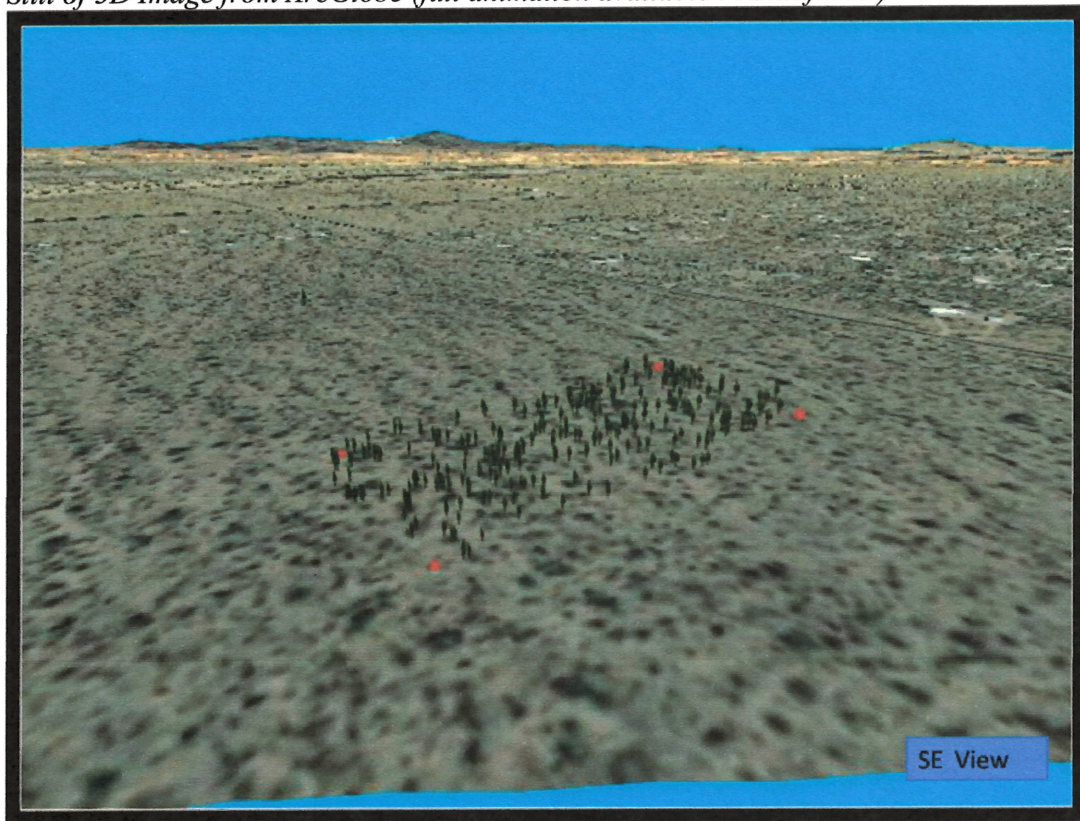
- 1) census timing be standardized to 5-year intervals;
 - 2) all saguaros in the plots be found, measured, and individually tagged at each census date;
 - 3) a better tagging method be developed to minimize cactus damage and tag loss
 - 4) use of remote sensing technology for annual assessment of the plots for overall health.
 - 5) continue and expand volunteer programs for the public to assist in saguaro census.
- Efficient use of limited park funds and provides valuable opportunity for public education.

Acknowledgements:

Special thanks to Saguaro National Park Rangers Don Swann and Becky MacEwan for their assistance with historic data and helping us conduct our field data collection.

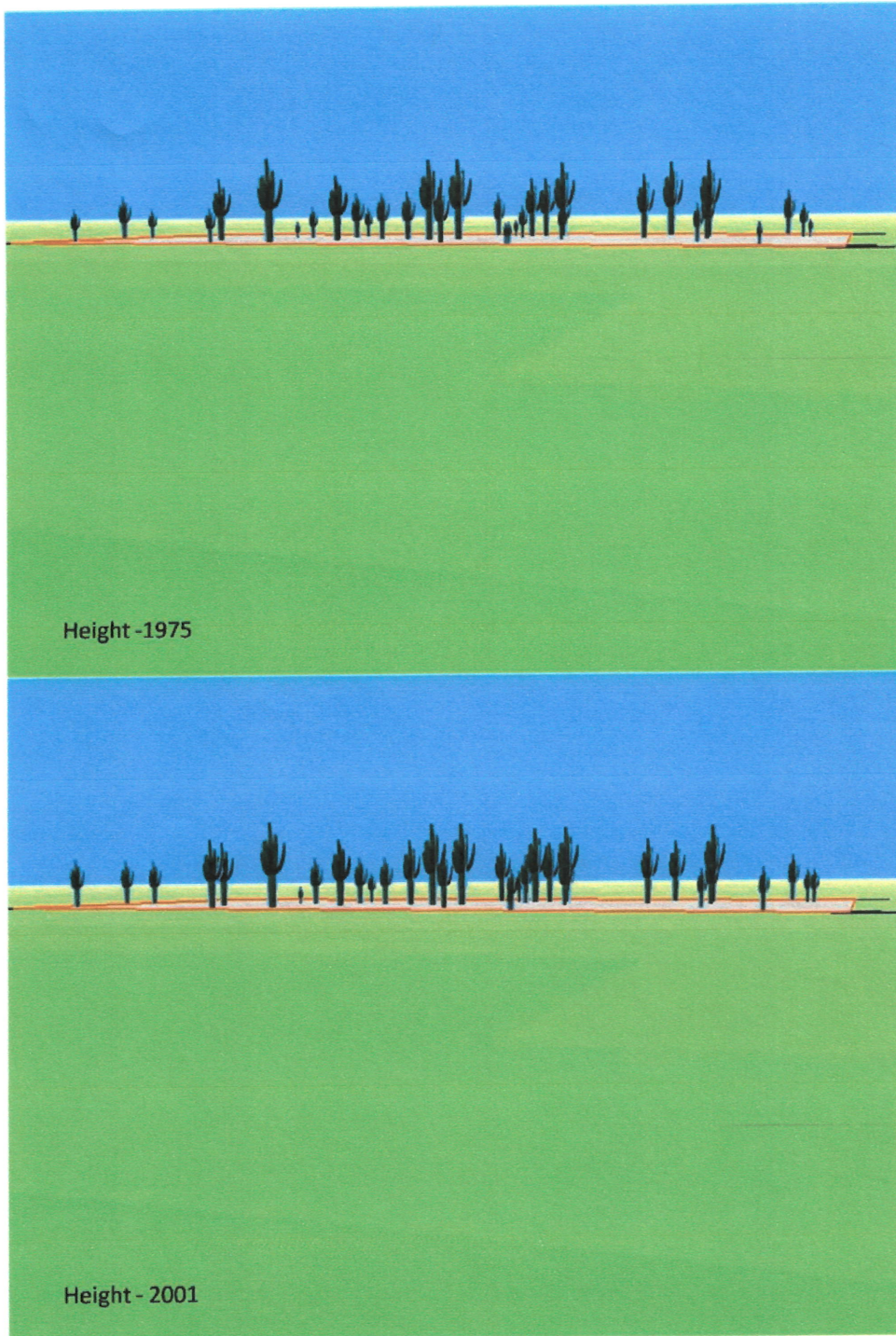
Appendix A

Still of 3D Image from ArcGlobe (full animation available in SAL folder)

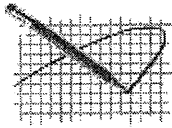


Appendix B:

ArcScene Screen Capture Images







Esther Rivera/SAGU/NPS
12/18/2009 10:20 AM

To Don Swann/SAGU/NPS@NPS, Becky
MacEwen/SAGU/NPS@NPS

cc

bcc

Subject Saguaro Census Paper

Hi Don and Becky,

Here is the written paper that accompanied our Saguaro Census GIS Project in case you were interested in the kind of analysis we did. I'll create a folder on the P Drive soon with all of the data and shape files (digitized 1975 data, 2009 data/maps, etc.) in case you ever need them for future projects. Thanks so much for all of your help with the project! Also, I'll be working with Gary Christopherson next semester to do the TMD cultural resources map as part of my GIS Practicum requirement, so you'll be hearing more from me when the new semester kicks off.

Happy holidays,



Estee Rivera SaguaroCensus516A.pdf