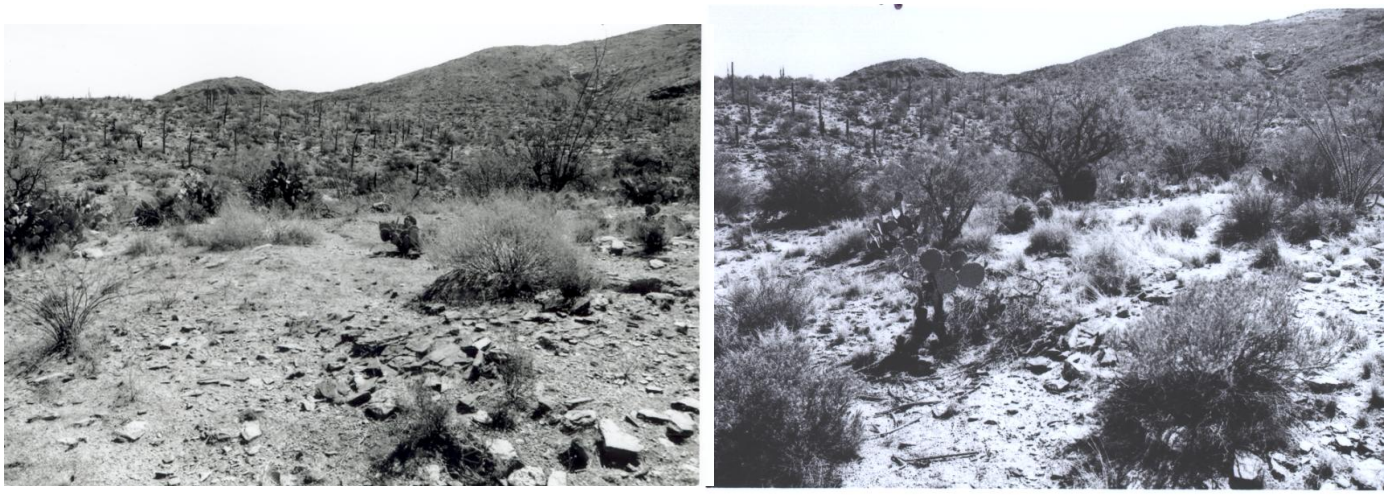
A Repeat Survey of Vegetation Plots Established to Evaluate Grazing Effects at Saguaro National Park, 1976 and 2007



Plot 1 (ungrazed control plot) in photos taken in 1976 (L) and 2007 (R).

Final Report

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This report is dedicated to the memory of Paul Fugate, who was a member of the original survey team in 1976. Paul disappeared in 1980 while on duty as a ranger at Chiricahua National Monument. His body has never been recovered and he is believed to be deceased.

Executive Summary
Domestic livestock grazing has occurred in southern Arizona for several centuries, and in what is now the Rincon Mountain District of Saguaro National Park for most of the period from the 1870s to the 1970s. In 1976, shortly after the rescission of the grazing permit in the Tanque Verde allotment, NPS ecologist Warren Steenbergh initiated a long-term study, with both treatment (recently grazed) and control (historically grazed) plots, to examine the long-term implications of grazing on vegetative communities within this protected area. Initial results of this study were never published, but photos and data from the project were re-discovered at Saguaro National Park in 2005. In 2007 park staff relocated the original points and repeated the study. This report details an analysis from surveys of ten plots in 1976 and 2007. Our results indicate that during the past three decades, vegetation change has been significant on both the treatment and control plots. Overall, most plant lifeforms (grasses, sub-shrubs, vines, succulents including cacti) have increased in cover and density, but trees have decreased. The results suggest that the effect of removing cattle from the park has not been as great on vegetation as the effect of other environmental changes such as increased precipitation and warming temperatures during the 30-year period between 1976 and 2007.

Introduction
The presence of domestic cattle in southern Arizona was documented as early as the late 17th century (Allen 1989) and has persisted with varying degrees of intensity to the present day. The area that is now the Rincon Mountain District (RMD) of Saguaro National Park was grazed with varying degrees of intensity starting in the 1870s and extending for the next 100 years (Clemensen 1987; R. Pinto, University of Arizona, pers. comm.).

In 1935, shortly after the passage of the Taylor Grazing Act of 1934, Saguaro National Monument formalized grazing agreements by establishing three allotments. These three allotments were called the Rincon Allotment (23,000 acres), the Pantano Allotment (6,700 acres), and the Tanque Verde Allotment (16,000 acres). The Happy Valley Allotment was added in the 1960s and included 6,700 acres of monument land. These allotments were operated for several decades, changing hands numerous times. In the coming years, however, grazing was

gradually reduced. It was eliminated in the Cactus Forest area in 1956, and throughout the entire monument in 1976 (Clemensen 1987).

By the 1970s, cattle grazing and its impact on saguaros and native Sonoran Desert vegetation, especially in a national monument that was created to protect this vegetation, had become highly controversial. Scientists identified the detrimental impact of livestock on saguaros (Niering et al. 1963) and called for the removal of livestock from the monument (Niering and Whittaker 1965; Steenbergh 1976a). In 1976, a study of the effect of grazing on saguaros in the park by several prominent ecologists was published in National Parks magazine, and this paper was a factor in cattle grazing finally being phased out (R. Pinto, pers. comm.).

Shortly after the rescission of the grazing permit in the Tanque Verde allotment, NPS research scientist Warren Steenbergh initiated a long-term study to examine the implications of grazing on the vegetative communities within this protected area. Steenbergh, who had studied the saguaro for more than 20 years later co-authored a highly-regarded three-volume study of this plant (Steenbergh and Lowe, 1976, 1977, and 1983). Steenbergh was an outspoken critic of cattle grazing in the park (Steenbergh 1976a) and in 1976 set out to show the effects of cattle grazing on the vegetation of the monument.

In the 1976 study, Steenbergh established ten (0.1 ha) plots. Eight of these plots were paired with grazed and ungrazed treatments (Appendix A), and two additional plots were established in grazed areas. This method of comparing the effects of livestock grazing on adjacent grazed and ungrazed areas has long been utilized as a means to assess the impact of livestock on the landscape (Clements, 1934).

After Steenbergh's death in the early 1980s, the study was forgotten until 2005, when park staff found three boxes of data and photographs during a reorganization of the Saguaro National Park library. Thirty years after the initiation of Steenbergh's initial study, the plots were relocated and surveyed to examine long-term differences in vegetation communities between grazed and ungrazed areas over the three decades that had elapsed.

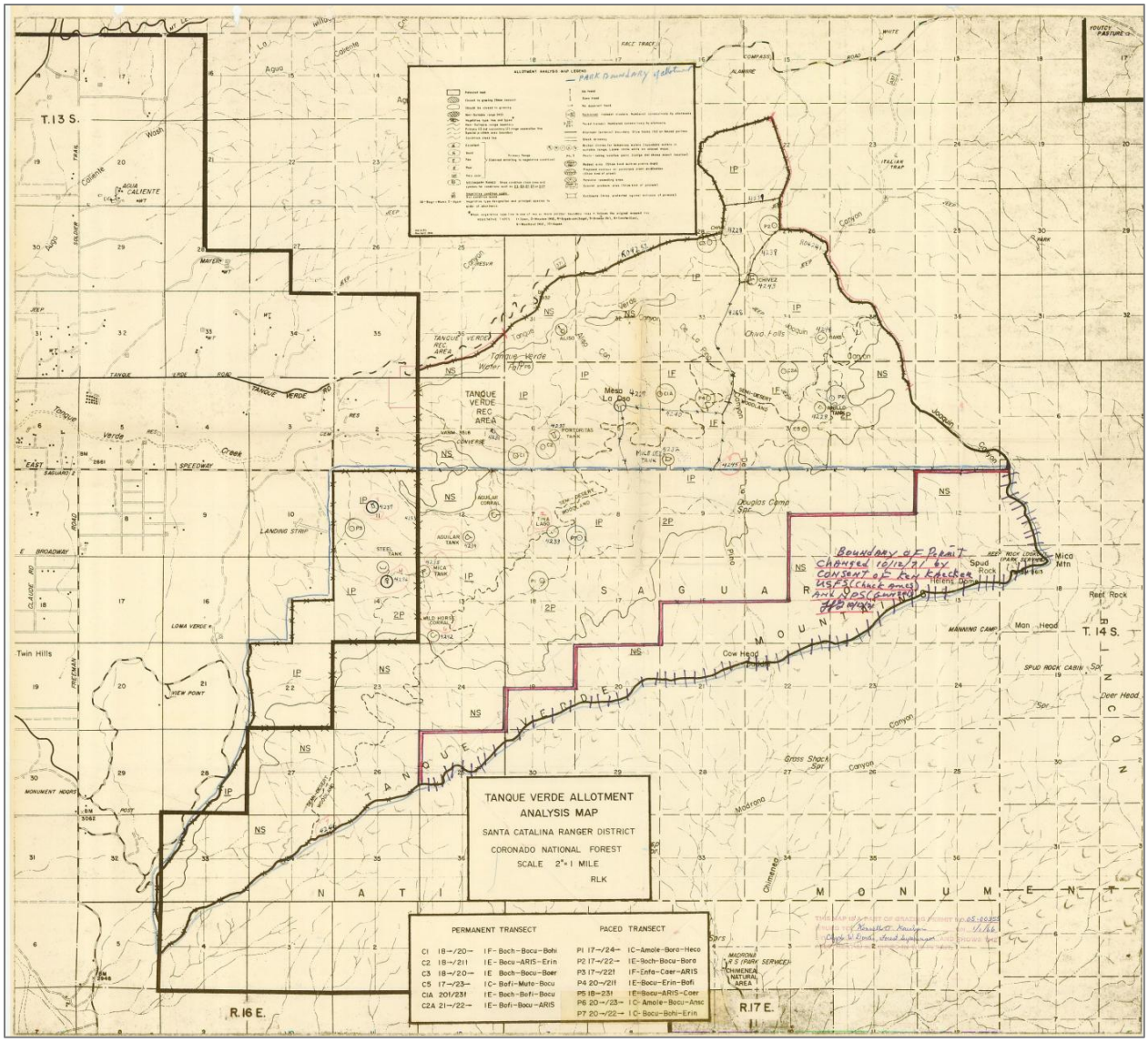


Figure 1 Tanque Verde Allotment Map at the Rincon Mountain District of Saguaro National Park

Study Site and Climatic Conditions during 1976-2007

Saguaro National Park's Rincon Mountain District is located in Pima County, Arizona, on the east side of the city of Tucson. The district includes a large portion of the Rincon Mountains, is 67,307 A (27,238 ha) in area, and ranges in elevation from 2,670 ft (814 m) to 8,666 ft (2,641 m). The district includes both low elevation desert areas and high elevation forests. The 10 plots in this study range in elevation from 3,248 ft (990 m) to 4,692 ft (1,430 m) and are located in the northwestern portion of the park. Vegetation communities in this area include Arizona Upland and Semi-desert Grassland.

The years preceding the 1976 survey were generally characterized by below average precipitation regionally with dry conditions again prior to the 2007 survey[1] (Figure 1). Climatic

[1] On July 31, 2006 the Tucson area received one of the highest amounts of precipitation on record (Perger 2008).

conditions were abnormally wet during the 1980s and tapered off into a series of abnormally dry years by the 2000s. Additionally, it appears that nearly all plots were exposed to fire during the 30 year period (Figure 2). The Chiva Fire burned the northern portion of the area in 1988, and the Mother's Day Fire burned the southern portion in 1994.

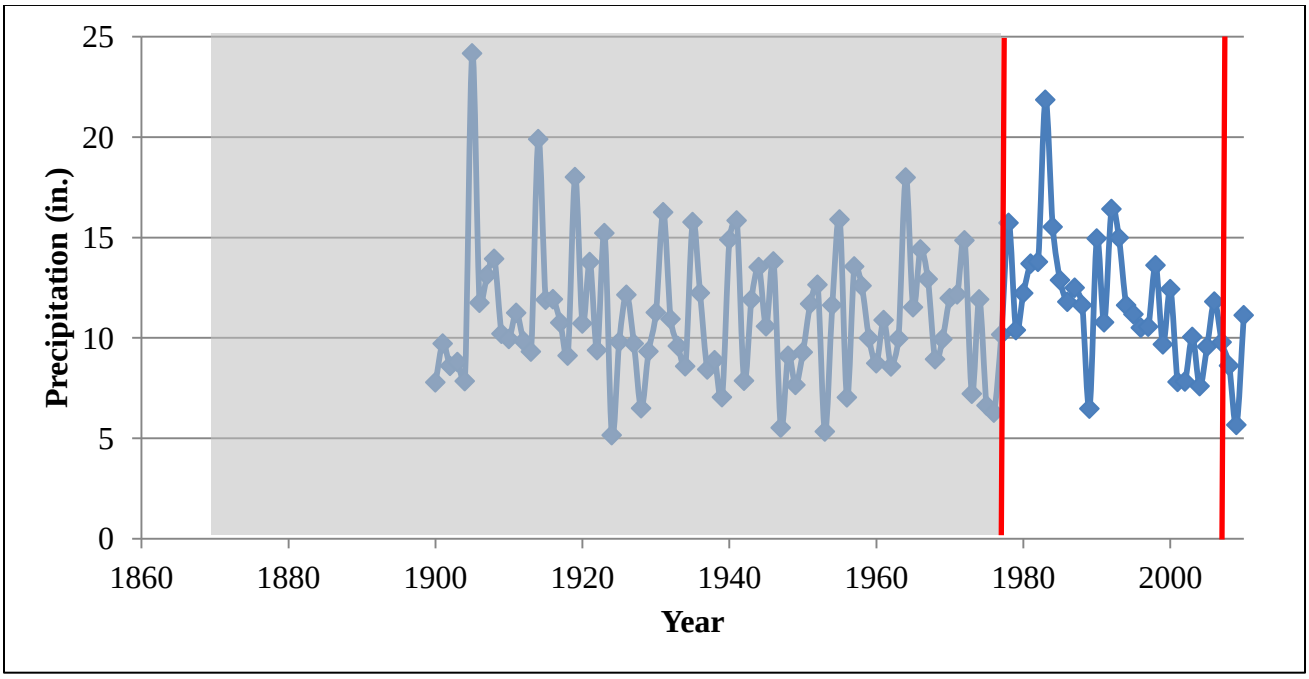
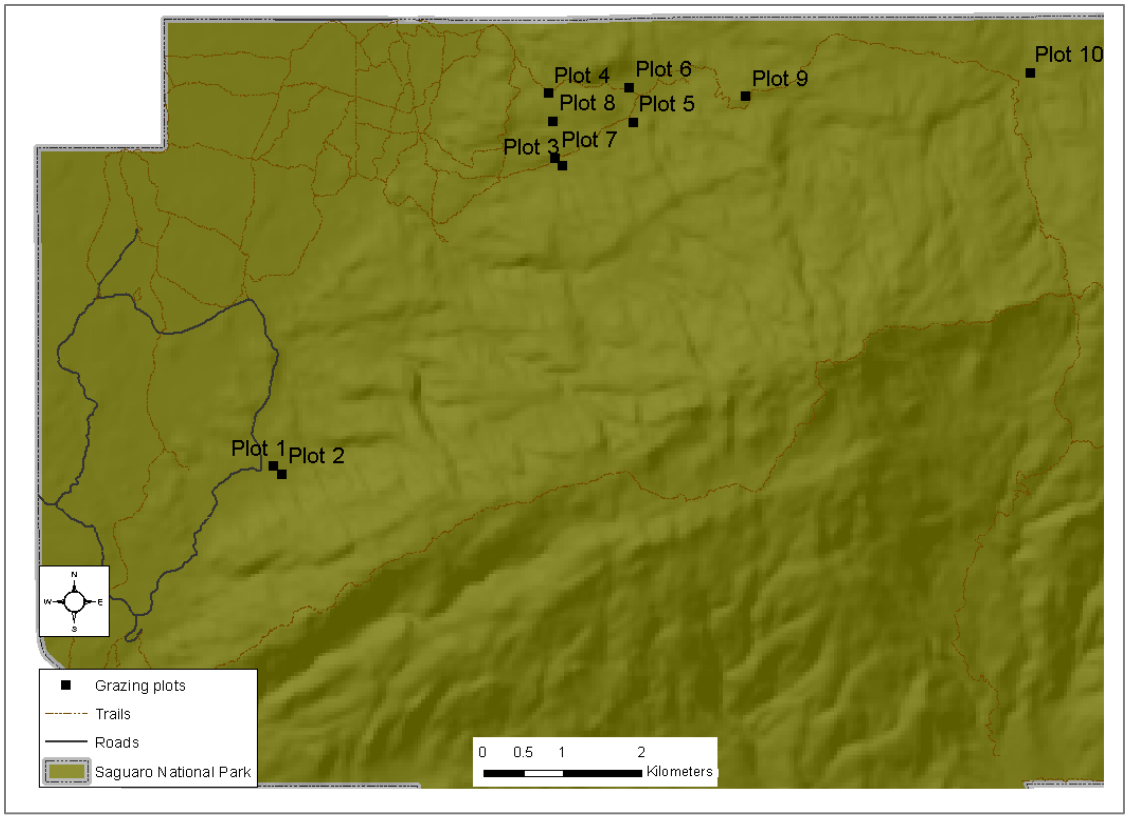


Figure 2. Regional annual precipitation record and grazing history in the Rincon Mountain District of Saguaro National Monument. Grazing period extended from the 1870s and continued to 1976 (indicated by shaded area). Vegetation surveys were conducted in 1976 and 2007 (indicated by vertical red lines).

Methods

Plot Selection

Plots were selected in 1976 to identify differences between adjacent grazed and ungrazed areas. Plots 1 and 2, 3 and 4, 5 and 6, 7 and 8 are all paired plots. Plots 9 and 10 are unpaired and located in a grazed area. Steenbergh (1976) does not appear to select paired plots randomly, but selected representative plots based on similarity in exposure, elevation, and dominant vegetation type.



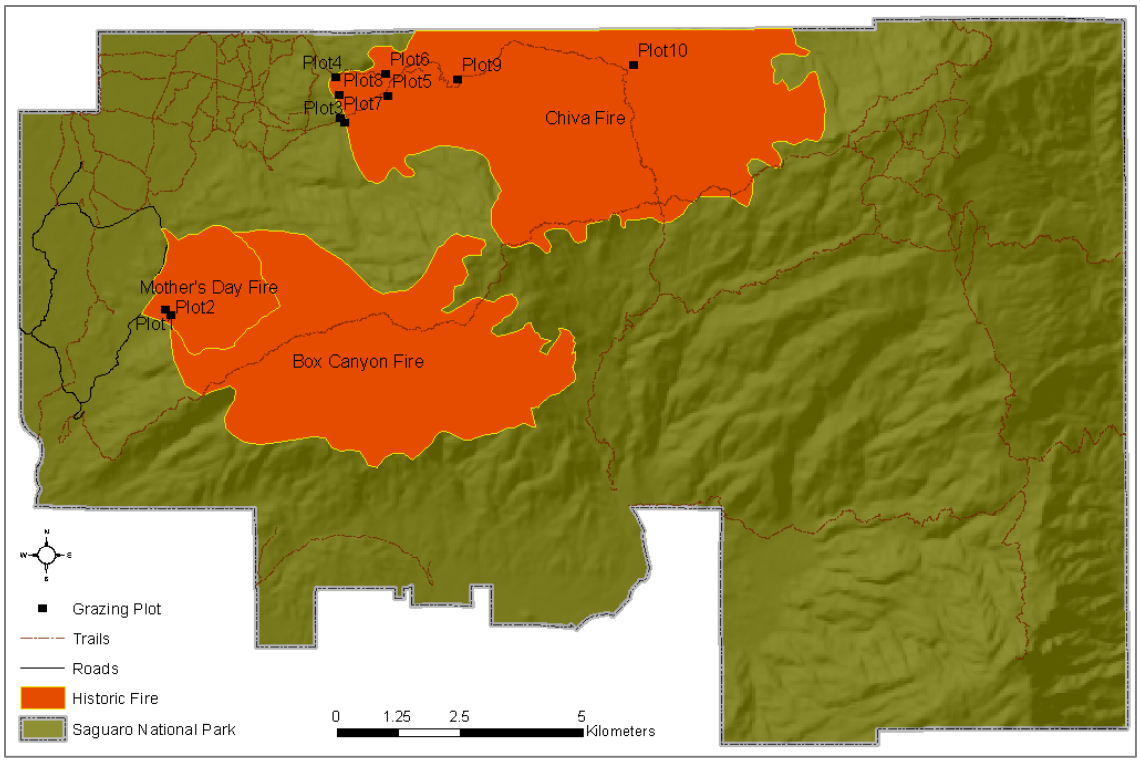


Figure 3. Location of grazing plots surveyed in 1976 and 2007 (top) and their exposure to the Chiva (1989), Mother's Day (1994), and Box Canyon (1999) fires at the Rincon Mountain District of Saguaro National Park (bottom). It seems likely that all or most plots burned once between 1976 and the present.

Survey methodology
Canfield's (1941) line intercept method was used to record all living perennial plants, rocks, and trail crossings in both survey years. This method was applied to determine cover on 21, 20-meter transects spaced every 2.5 m within each plot (Figure 3). The height of each individual plant was measured to the nearest 0.5 cm. The maximum height of the entire plant was recorded, regardless of whether the tallest portion fell on the line. Maximum height was measured with a meter stick. Cover measurements were determined by recording the locations along the 20m tape at which a plant first intercepts ("crown in"), and then exits, ("crown out") the line. A meter stick was used to determine a perpendicular line from the edge of the crown to the line. The "in" and "out" intercept were recorded to the nearest 0.5 cm.

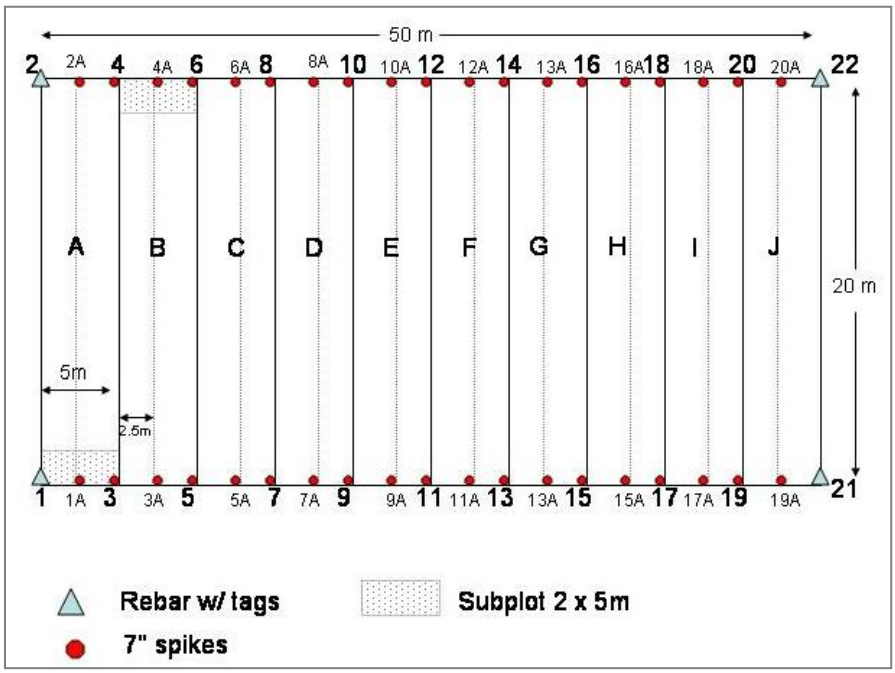


Figure 4. General plot layout

In addition to the original research design intended to examine the effects of livestock grazing through plant surveying and repeat photography, new elements were added to the study in 2006-2007. Biological soil crusts were surveyed and an analysis of soil structure was also conducted. Need to decide if we are going to include repeat photos and soil crusts as part of paper; if so we need some detail on the methods here. We could say, "we re-located and photographed the original 1976, photos, but did not analyze vegetation changed based on the photos."

Statistical analysis
Descriptive statistics are provided in this report for changes in the cover (m^2) by lifeform. We used t-tests to examine the significance of changes in cover between grazed and ungrazed plots and survey years. The statistical testing of the data was separated by grazing effect and survey year effect. Additionally, we utilized multi-dimensional scaling to isolate the impacts of grazing from a time effect. Finally, we calculated descriptive statistics for biological soil crusts and soil structure on the plots. Appendix E provides the full survey protocol and results from this component of the project.

Repeat photography
Steenbergh (1976) established four photo points for each plot and an additional 20 photo points in the near vicinity of the study. Rebar stakes with attached metal identification tags were placed in 1976 to establish repeatable photo points. These photo points were revisited again in 2007, with photos archived at the park.

Results
No significant differences were found between grazed and ungrazed plant communities in either 1976 or 2007. There was, however a significant change in overall vegetation composition over time. In the 2007 survey intensive exploiters, such as grasses, had increased significantly from 1976 levels across all plots while extensive exploiters, such as shrubs and trees, showed a marked decrease in abundance.

Table 1. Mean cover area (m^2) for plant lifeforms observed in paired grazing plots in 1976 and 2007. Standard deviations are provided in parenthesis.

Lifeform	1976 Ungrazed	1976 Grazed	2007 Ungrazed	2007 Grazed
Fern	0.01 (0.00)	0.00 (0.00)	0.09 (0.05)	0.10 (0.04)
Forb	0.03 (0.01)	0.04 (0.01)	0.05 (0.03)	0.09 (0.03)
Graminoid	0.34 (0.10)	0.37 (0.12)	0.53 (0.16)	0.71 (0.18)
Shrub	2.55 (0.96)	2.24 (0.79)	1.83 (0.55)	1.67 (0.48)
Subshrub	0.25 (0.11)	0.22 (0.07)	1.91 (0.74)	2.01 (0.88)
Succulent	4.34 (1.96)	3.32 (1.37)	2.62 (1.04)	2.14 (0.71)
Tree	7.41 (2.74)	7.21 (2.76)	3.38 (1.42)	5.62 (2.51)
Vine	0.89 (0.58)	0.11 (0.06)	1.50 (1.04)	0.57 (0.36)
All lifeforms	1.65 (0.36)	1.43 (0.30)	1.29 (0.21)	1.35 (0.22)

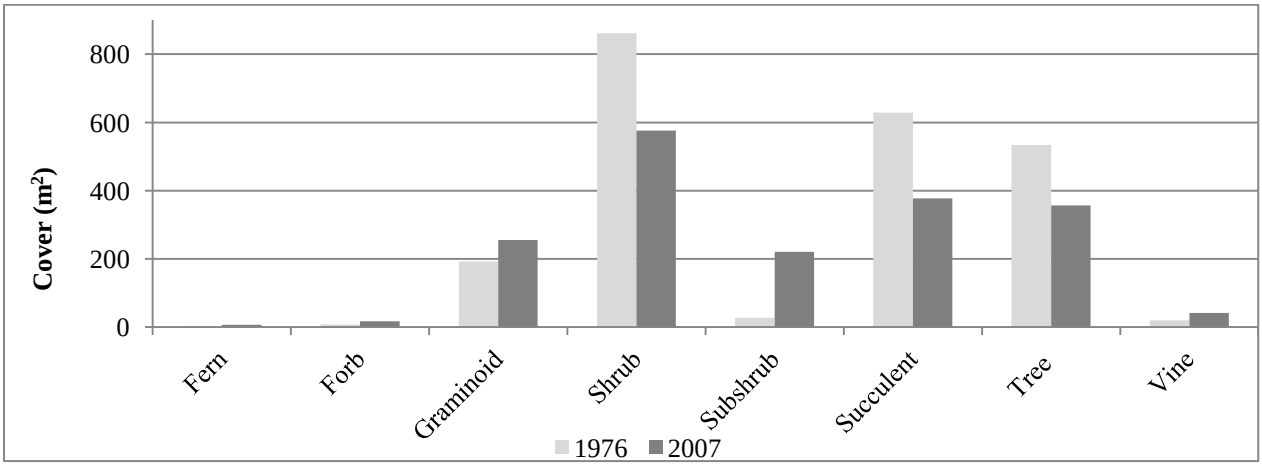


Figure 5. Cover area (m^2) for plant lifeforms in 1976 and 2007 on study plots at the Rincon Mountain District of Saguaro National Park.

Differences between treatment and control - 1976
Grazing had a moderate influence over cover values in 1976, but the results were not significant. Overall, cover on treatment plots was 128.1 m^2 less than on control plots. The greatest difference between treatment and control was in shrubs and succulents, which had 44.5 m^2 and 65.3 m^2 less cover, respectively. Six of the eight life form categories had less cover on treatment than on control plots; only graminoid (grass) and forbs had higher cover on grazed plots.

Differences between treatment and control - 2007
In 2007, previous grazing continued to have a moderate but non-significant effect (t-test statistics here). Overall, grazed plots showed a net gain of 66.6 m^2 from 1976 to 2007. Six of of the eight life form categories saw some type of ground cover addition when the plot had been previously grazed, with only succulents and shrubs decreasing. Trees gained 71.6 m^2 over all of the plots.

Differences between 1976 and 2007 – all plots combined
Regardless of previous grazing status, survey year had a significant influence on cover values overall. For both ungrazed and grazed plots combined, there was an overall vegetation cover increase of 1263.7 m^2 from 1976 to 2007. For ungrazed plots alone the increase in cover was 534.5 m^2. For grazed plots the increase was 729.2 m^2.

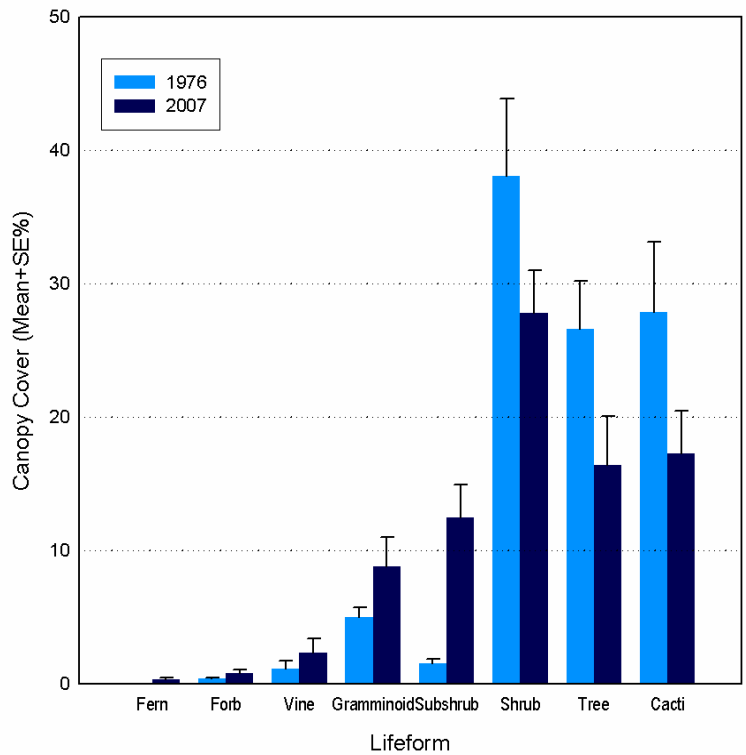


Figure 6. Effect of year (1976 vs. 2007) on vegetation lifeform abundance.

In addition, survey year had a significant influence on cover values for several life forms that increased over the 30-year period, including ferns, subshurbs, and vines. Vine ground cover alone increased 1538.7 m^2 on both treatment and controls from 1976 to 2007. For three life

forms, shrubs and succulents, cover decreased significantly over the 30-year period. Shrubs lost 181.1 m^2 and succulents lost 186.4 and trees lost 179.6 m2.

Fourteen individual species showed significant changes at the 95% confidence level (Table 2), with 9 species increasing in cover and 5 species decreasing.

Table 2. Species exhibiting significant cover change at the 95% confidence level from 1976 to 2007 on grazing plots at the Rincon Mountain District of Saguaro National Park.

Species	Common name	Percent change
Abutilon incanum	Sweet pelotazo	2.56
Acacia greggii	Catclaw acacia	3.16
Calliandra eriophylla	Fairyduster	4.61
Celtis ehrenbergiana	Spiny hackberry	-2.83
Dalea pulchra	Santa Catalina prairie clover	3.12
Encelia farinosa	Brittlebush	4.25
Ericameria laricifolia	Turpentine bush	-9.39
Fouquieria splendens	Ocotillo	-6.47
Janusia gracilis	Slender janusia	2.64
Jatropha cardiophylla	Sangre de cristo	3.13
Mimosa aculeaticarpa v. biuncifera	Catclaw mimosa	2.06
Opuntia phaeacantha	Pricklypear	2.87
Parkinsonia microphylla	Yellow paloverde	-5.96
Prosopis velutina	Velvet mesquite	-3.76

Biological soil crust data collected in 2007 indicated the presence of six species. While distinct differences exist in frequency data for individual soil crusts between grazed and ungrazed plots, there is not a detectable trend across biological soil crusts generally.

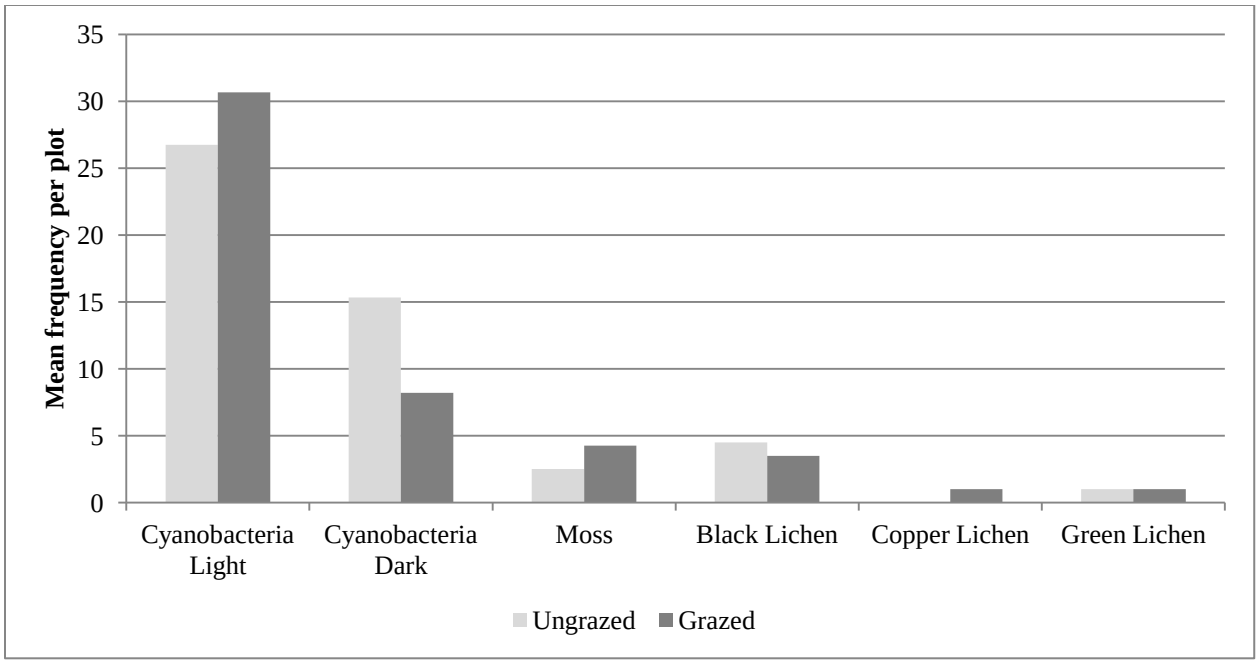


Figure 7. Mean frequency of biological soil crust observations per plot by ungrazed and grazed plots at the Rincon Mountain District at Saguaro National Park.

Multidimensional scaling

Multi-dimensional scaling (MDS) of grazed versus ungrazed plots for both 1976 and 2007 do not indicate a likely grazing effect for this observational study. This is further supported by 2-way analysis of similarities (ANOSIM), which indicates that graze effect is not significant (Global R=-0.208%, P=96.4%). MDS of all plots by year indicates strong differentiation along axis 2, with no obvious pairing by plot number. ANOSIM again backs this effect (Global R=0.344, P=0.3%). A similarity percentage (SIMPER) analysis indicates that the species in Table 2 contributed the most to the dissimilarity.

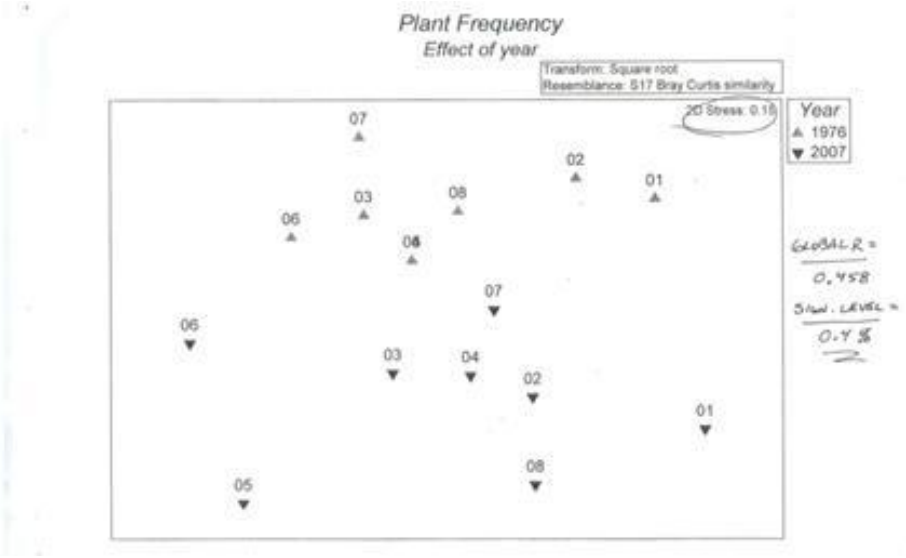


Figure 8. Multi-dimensional scaling showing grazing effects on ten plots at the Rincon Mountain District of Saguaro National Park sampled in 1976 and 2007.

Soil stability

Differences in soil stability were minimal, with grazed plots having a mean stability class of 4.07 and ungrazed plots having a mean of 3.98. This difference is slight and the opposite of the hypothesis that grazing would have negative implications for soil stability. Stability codes are located in Appendix D.

Table 3. Soil stability results from a 2007 survey of long-term grazing plots located at the Rincon Mountain District of Saguaro National Park.

Treatment	Plot	Mean stability class	Most frequent cover	Most frequent basal
ungrazed	1	4.53	No cover	Gravel (<64mm)
grazed	2	4.50	No cover	Gravel (<64mm)
grazed	3	4.30	No cover	Gravel (<64mm)
ungrazed	4	4.07	No cover	B
grazed	5	4.33	No cover	B
ungrazed	6	4.03	Forb	Gravel (<64mm)
grazed	7	3.63	No cover	Gravel (<64mm)
ungrazed	8	3.30	No cover	Gravel (<64mm)
grazed	9	3.30	No cover	L
grazed	10	4.33	No cover	Gravel (<64mm)

Finally, repeat photos from 60 photo points were collected again in 2007. These photos provide visual evidence of the statically significant changes across the three decades of the study.

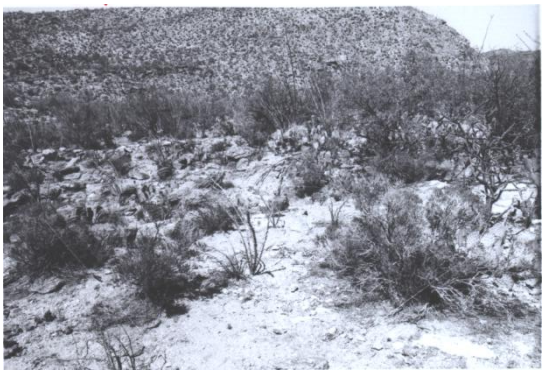
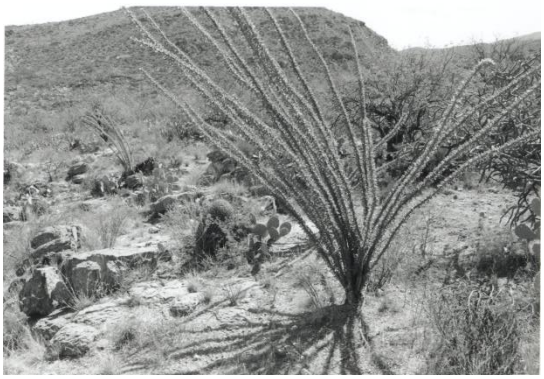
	1976	2006
Plot 4 (ungrazed)		
Plot 7 (grazed)		

Figure 9. Repeat photos from paired plots 1 & 2 from the Steenbergh Grazing Plots at the Rincon Mountain District of Saguaro National Park.

Discussion

Steenbergh (1976) notes in the opening remarks of his report that,

> "The condition of natural vegetation in the Rincon Mountains has been substantially altered by decades of domestic livestock grazing. The removal of domestic livestock from these lands will allow natural regeneration of native vegetation to occur."

While this was and continues to be a widely-held hypothesis, our statistical analysis of the 1976 and 2007 data fails to support it. Grazing had no effect on functional groups, lifeforms, species or communities in either 1976 or 30 years later, in 2007. It is likely that grazing pressures in the mid- to late 20th century were relatively minor compared to late 19th and early 20th centuries and relative to other factors, or that the control plots in 1976 were still influenced by grazing that had occurred 20 years previously (Clemensen 1987).

Year of observation had great effects, such that intensive exploiters (grasses and subshrubs) dramatically increased, and extensive exploiters (shrubs and trees) and water storers (cacti, but NOT saguaros) greatly decreased between 1976 and 2007. This pattern is reflected in the species and community analyses. Collectively, these data are compelling evidence of a major plant community shift that reflects responses to climate, demography, long-term succession or an unknown perturbation.

Management implications

The findings of this study in 1976 and 2007 are contrary to what has been found in similar studies elsewhere in arid grasslands. We find no significant difference between grazed and ungrazed plots in 1976 or 2007. These data do, however, indicate an increase in warm-climate plants such as prickly pear and perennial grasses.

These results have potential implications for saguaro recruitment (e.g. decreased nurse plants), fire occurrence (increased fine fuels, though not substantially as of 2007), and perhaps exotic plant encroachment (depending on outcomes of inter-specific competition). This significant change in composition could be attributed to several drivers including long term succession in response to drought, ground water decreases, or changes in climate.

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Appendix A: Survey methodology

A. Plot Selection: Plots were chosen in 1976 based upon grazing history. Plots 01 and 02, 03 and 04, 05 and 06, 07 and 08 are all paired plots. Plots 09 and 10 are unpaired (Table 1).

Plot Number	Grazing Status	Location	UTM X	UTM Y
01	Ungrazed	Near loop drive, Rincon Mountain Overlook	527683	3560904
02	Grazed	Near loop drive, Rincon Mountain Overlook	527792	3560799
03	Grazed	Immediately adjacent to Mica tank, NW slope	531325	3564717
04	Ungrazed	Douglas Springs Trail nearby Mica tank, NW slope	531147	3565631
05	Grazed	Near Aguila Tank, N slope	532216	3565265
06	Ungrazed	Douglas Springs Trail nearby Aguila Tank, N slope	532169	3565702
07	Grazed	Adjacent to Mica Tank, S slope	531230	3564809
08	Ungrazed	Douglas Springs Trail nearby Mica tank, S slope	531210	3565272
09	Grazed	Douglas Springs Trail nearby Tina Larga Tank	533634	3565589
10	Grazed	Near Douglas Springs Campground, 4800 ft	537224	3565891

Table 1: Grazing Status. The plot numbers along with their grazing status, general location, and a GPS coordinate point.

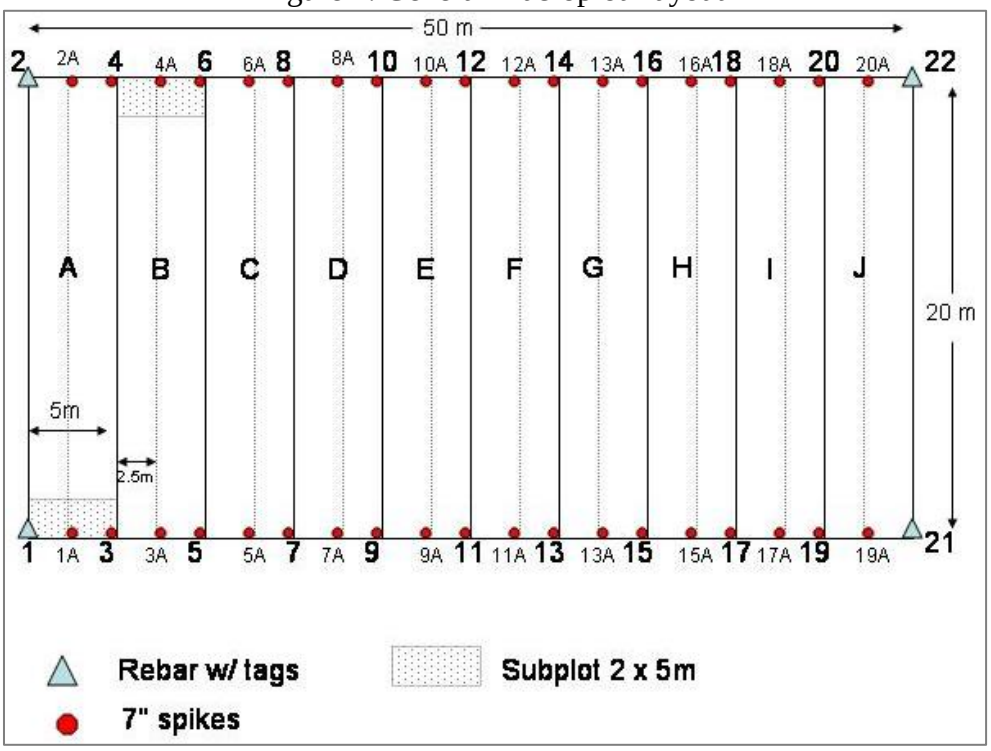
B. Plot Layout: All plots are 20 x 50 meters, rectangular in shape, with rebar at each of the four corners. The rebar have brass tags designating the plot number and corner number (example 7602 1, Fig.1). Along each of the 50 m sides of the macroplot, 7" galvanized spikes were placed every 2.5m, marking the beginning and end of each 20m transect. Some spikes may be missing due to rocks or bedrock (Table 2). Several spikes disappeared between 1976 and 2007; these were replaced when possible. Repeat studies should also replace spikes if needed.

Plot	Missing Spikes
0701	5A, 7, 12, 17
0702	2A, 8A, 13A
0705	13A
0707	12 (in trail)
0708	5A, 19

Table 2: Missing Spikes Locations. Refer to spike location within Fig. 1

Field tape was used to designate the lines within the macroplot. All of the lines start at the uphill spike on the 50m side of the plot (this point being 0 meters on the field tape) and run downhill 20 meters. The downhill spikes may not be at exactly 20m due to vegetation or rocks. All tapes were kept as close to the ground and taught as possible.

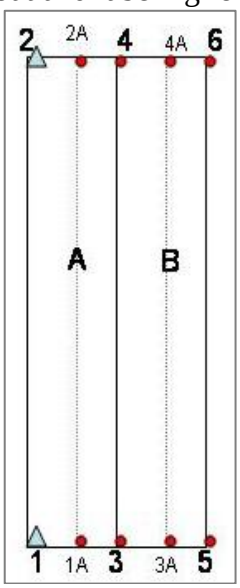
Figure 1: General Macroplot Layout



C. Data Collection

1. **Line Intercept**: The line intercept method of Canfield (1941) was used to record all living perennial plants, rocks, and trail crossings. This method was applied to determine cover on twenty-one 20m transects spaced every 2.5m in each macroplot. This corresponds to all of the locations with 7” galvanized spikes (Fig. 1). For example, the first line in Fig. 2 would be line 1-2, followed by 1A-2A, 3-4, etc. All macroplots were read from uphill to downhill. In the majority of plots, the upper corner, (0m on both tapes), corresponded to rebar 1, creating line 1-2. Occasionally, the upper corner of the plot corresponded to rebar 2, creating line 2-1. The plot was still read uphill to downhill, and the line was still called line 1-2 to avoid confusion.

Figure 2: Layout and labeling for line-intercept



Height

The height of each individual plant was measured to the nearest .5cm. The maximum height of the entire plant was recorded, regardless of whether or not the tallest portion fell on the line. Maximum height was measured by holding a meter stick along side the plant and measuring to the tallest living parts without straightening anything. Ephemeral portions such as fruit or inflorescence were not considered when measuring maximum height.

Cover

Cover measurements were determined by recording the locations along the 20m tape at which a plant first intercepts ("crown in"), and then exits, ("crown out") the line. A meter stick was used to determine a perpendicular line from the edge of the crown to the line. The "in" and "out" intercept were recorded to the nearest .5cm. The cover was determined by subtracting the "out" intercept from the "in" intercept.

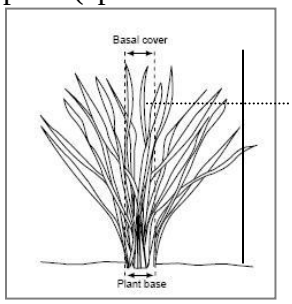
No cover measurements are recorded outside of the end points; nothing before 0m and nothing after 20m. Even if the nail extended beyond 20m, measurements were stopped at 20m as determined by the field tape.

An individual plant was recorded if it crossed the line for >.005m. In circumstances in which it was difficult to distinguish individuals (ex. *Calliandra eriophylla*), gaps between when the plant first crossed and when it exited were permitted, as long as they were <.5m. Gaps within an individual or groupings of plants >.5m warranted two separate entries. When it was obvious that two plants of the same species were separate individuals, even if they were closer than .5m apart, they were counted separately.

The following sections describe the methods as they apply to the different plant types encountered:

<u>Grasses</u>

Maximum height for grasses was recorded the same way as described above. The tallest living parts (apical meristem or blade) were measured without straightening the blades.



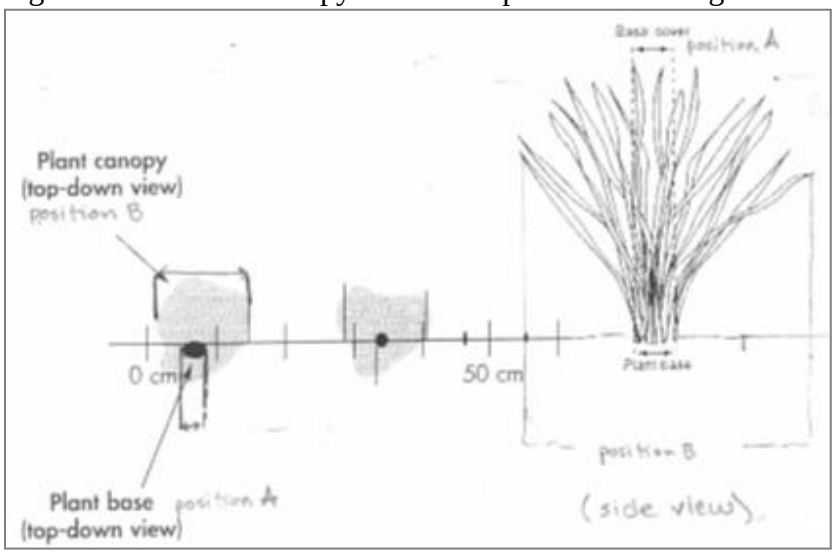
Maximum height

For grasses only, both a basal and canopy cover was measured along the line. Some portion of the grass base had to overlap the line to be recorded at all. The base has to be at least 0.5cm for the individual to be counted.

Basal Cover: Where the base of the grass first touched the line, the number along the tape (to the nearest 0.5cm) was recorded as "base in" and the last point the base touched is recorded as "base out" Base cover was obtained by calculating the "out" intercept minus the "in" intercept. The distance covered in Figure 3 position A corresponds to the base cover.

Canopy Cover: The crown of the grass was also measured along the line. Where the first blade intercepted the line, the number (to the nearest 0.5cm) was recorded as "crown in". The number where the last blade intercepted the line was recorded as "crown out". Crown cover was obtained by calculating "crown out" minus "crown in". The distance covered in Figure 3 position B corresponds to crown cover.
In many cases in 1976, the crown was so heavily grazed that it was practically non-existent. In these instances, the base and crown were considered to have the same intercept, since it was not clear where the base ends and the crown begins.

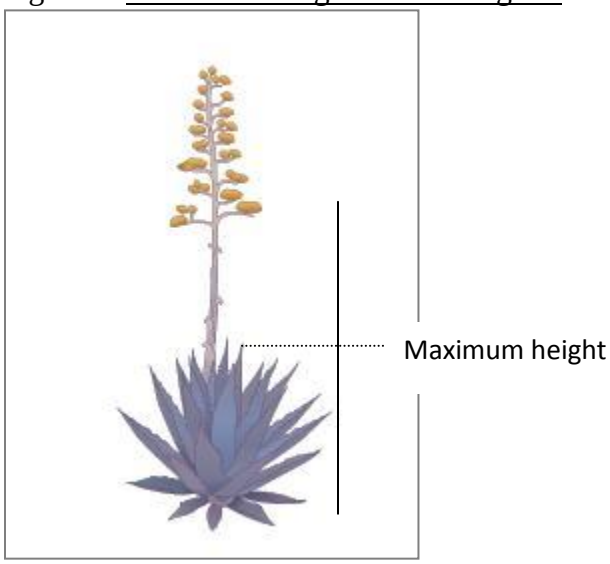
Figure 3: Basal and canopy line intercept measures for grasses.



Forbs, Cacti, Shrubs & Trees

Using a meter stick or measuring tape, the maximum height (to the nearest .5cm) of the plant was measured without counting ephemeral portions, as described in the previous section (Fig. 4). For cacti, spines were considered leaves and counted in the height measurement; fruits were not considered in height measurements. In some species such as brittle bush (*Encelia farinosa*) and catclaw (*Acacia greggi*), it was difficult to determine if the upper most parts were alive or dead. In such cases, the part was considered alive if it was flexible and dead if it was brittle.

Figure 4: Maximum Height for a Non-grass

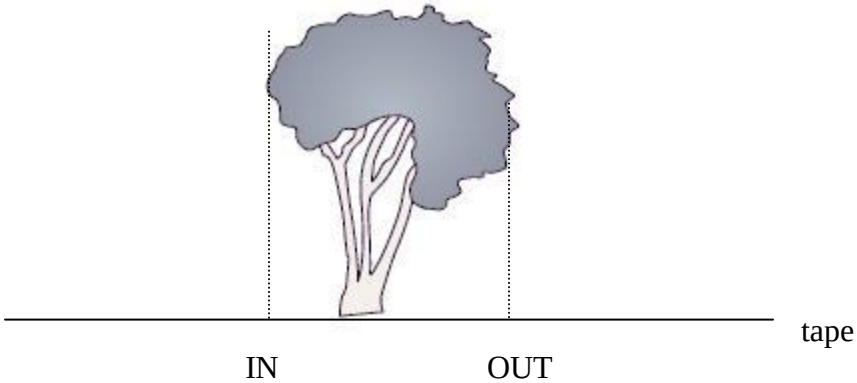


For plants on a slope, the meter stick was held perpendicular to the ground and along side the plant, to measure to the tallest living part.
For plants over 2 meters tall, the following height categories were used: 2-2.5m, 2.5-3m and >3m.

Cover
For non-grasses, basal cover was not measured. The crown of a non-grass was measured along the line with regard to aforementioned rules. The plant may be above or below the tape. Crown cover was obtained by calculating “crown out” minus “crown in” (Fig. 5).

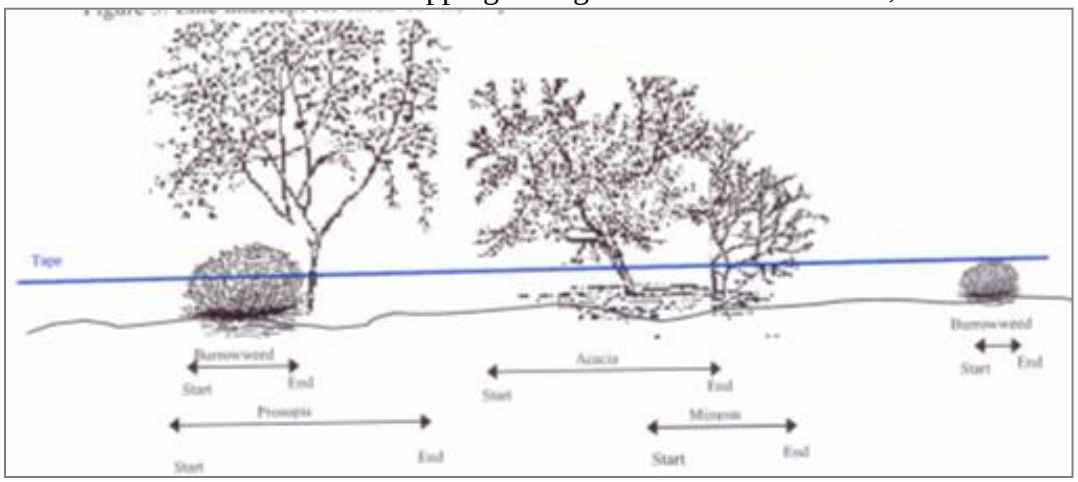
Only the living portions of a plant were recorded. Cacti spines are considered living parts but not the fruits. “Crown in” was determined as the point at which the first living portion of the plant crossed the line. “Crown out” was determined as the last point at which living portions of the plant crossed. This holds true regardless of any dead portions of the plant that fall in-between the living intercepts.

Figure 5: Cover Measurements for Non-grasses



Estimating the crown for some trees and cacti was more difficult because of their sprawling nature. Despite this difficultly, the actual "crown in" and "crown out" measurements were recorded as accurately as possible. A meter stick was used to create a perpendicular line between location at which the plant crossed the line and the field tape. In the cases when a meter stick could not be used to create the perpendicular line between the plant and the tape, an imaginary line was estimated by standing under the part of the crown overlapping the intercept line, and projecting a line from the crown edge to the field tape.

Figure 6: Cover Measures for Overlapping Non-grasses. Start = crown in, End = crown out



Rock

Rock was regarded as either bedrock or boulder if it intercepts the line for >.5 meters. The cover for bedrock and boulders were recorded where the rock intercepts the line in the same manner as for canopy cover. In the plant field the term "rock" was entered. If there is enough soil between bedrock outcroppings to support developing vegetation, the continuity of the rock is interrupted.

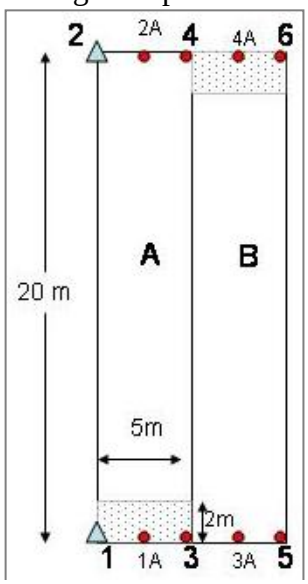
Plot Density Measurements

There are two types of subplots designed to measure density within the macroplot, the 20 x 5 meter subplot and the 2 x 5 meter plot (Fig. 7). For both sizes of subplots, a plant was counted if any portion of its stem was rooted in the plot. Grasses were considered part of the subplot if their

base was inside the plot. If the base of an individual falls on the line dividing two density plots, it will be counted in the subplot closest to the first line (1-2).

The 20 x 5 meter subplots were labeled using capital alphabetical letters. Every macroplot contained 10 subplots, creating subplots A – J (Fig. 1, Fig. 7). The smaller 2 x 5 meter subplots were identified by the larger subplot in which they were contained, and the 2 spike positions along the 50 meter line that formed their boundaries. For example, the first subplot in fig. 7 would be termed A 1-3. These subplots alternated between the uphill and downhill sides of the macroplot, for example, A 1-3, B 4-6, C 5-7, etc. Refer to plot diagrams from 1976 to ensure the subplots are relocated correctly.

Figure 7: Layout and Labeling for Plot Density Measurement. "A" represents the 20x5m subplot, while the shaded region represents A 1-3 the 2x5m subplot.



20 x 5 meter subplot (letters)
Using the tapes laid out for the line intercept, those spaced at 5m apart, not 2.5m, were used to define the 20 x 5 m subplot. For each of the ten 20 x 5 m subplots (A-J), all individuals over .25m in height were tallied by species. Height was not measured but height range in the datasheet was recorded as >25cm.
See original methodology for special sampling methods for plot 7609.

2 x 5 meter subplot (identified by the letter subplot and the 2 spike positions-ex. A1-3)
The total number of individuals by species was recorded in each subplot. In addition, in 2007 the tallest individual of each species was noted. This was not completed in 1976 but should be continued in future surveys. Note that every individual was counted; there were no height restrictions in these smaller subplots

Appendix B. Camera points associated with grazing plots at the Rincon Mountain District of Saguaro National Park.

Camera Point(s)	Location Description
7601 - 7604	Plot 7601, outside fence, loop drive.
7605 - 7608	Plot 7602, inside fence, loop drive.
7609 - 7612	Plot 7607, south slope, Mica tank.
7613 - 7616	Plot 7603, north slope, Mica tank.
7617 - 7620	Plot 7604, north slope, near fence gate, near Douglas Spring Trail.
7621 - 7624	Plot 7605, north slope, near Aguila tank.
7625 - 7628	Plot 7606, north slope, near junction of Douglas Spring Trail and first jeep road which crosses it.
7629 - 7632	Plot 7608, south slope, second hilltop south of trail, near fence.
7633 - 7636	Plot 7609, north slope by trail, 2 mi before Douglas Spring.
7637 - 7640	Plot 7610, flat area, east of Douglas Spring.
7641, 7642	At catchment pool, near Tina Larga tank.
7643	First wash NE of plot 7601, inside fence, loop drive.
7644	Beside fence, 10 meters beyond first large wash south of gate at parking lot entrance of Douglas Spring Trail.
7645	30 meters from Douglas Spring Trail, at 180 degrees from a point on the trail which is 18 meters from the very large, sandy wash (at junction of Douglas Spring Trail and prominent cattle trail) about 0.4 mi from start of trail.
7646	Near trail, 35 meters west of the point at which trail becomes level after initial steep climb (about 0.9 mi after start of trail). Jojoba habitat.
7647	Near trail, 50 meters east (80 degrees) of point mentioned for 7646.
7648	Near trail and Tina Larga tank. 123 degrees, 100 meters from junction of trail and second jeep road which crosses it.
7649	In large wash just after above point.
7650	In wash, Mica tank, between plots 7603 and 7607.
7651	Just off trail, between Douglas Spring and upper fence in pine-oak habitat.
7652	In wash (scoured bare rock), pine zone above 7651
7653	Wash SW of 7601, outside fence, 100 meters 150 degrees from parking area. This parking area is the large one 5 mi. after start of loop drive.
7654	Same wash, inside fence
7655	Inside fence, 200 meters, 115 degrees from parking area 5.6 mi on left, after start of loop drive.
7656	Outside fence, 110 meters, 115 degrees from same parking area.
7657	Inside fence, 250 meters, 155 degrees from parking area 6.2 mi from start of loop drive, on left. Follow deep wash.
7658	First wash north of entrance through gate on trail to Juniper Basin (starts in monument picnic area).
7659	Second wash north of above gate. Turn NE, go 40 meters into wash.
7660	Hill facing south, just north of above wash.

Appendix C. Plot Characteristics

Plot Number	Pairing Status	Grazing Status	Burn Year(s)	Elevation	Slope	Aspect	Soil Type	Location	UTM X	UTM Y
01	Paired	Ungrazed	1994	990m/ 3247ft	10°	315°	Lampshire-Romero-Rock Outcrop Complex	Near loop drive, Rincon Mountain Overlook	527683	3560904
02		Grazed	1994 1999	1006m/ 3299ft	7°	290°	Lampshire-Romero-Rock Outcrop Complex	Near loop drive, Rincon Mountain Overlook	527792	3560799
03	Paired	Grazed	Unburned	1100m/ 3608ft	13°	290°	Lampshire-Romero-Rock Outcrop Complex	Immediately adjacent to Mica tank, NW slope	531325	3564717
04		Ungrazed	1989	1040m/ 3411ft	10°	350°	Lampshire-Romero-Rock Outcrop Complex	Douglas Springs Trail nearby Mica tank, NW slope	531147	3565631
05	Paired	Grazed	1989	1145m/ 3755ft	8°	310°	Lampshire-Romero-Rock Outcrop Complex	Near Aguila Tank, N slope	532216	3565265
06		Ungrazed	1989	1120m/ 3672ft	4°	275°	Lampshire-Romero-Rock Outcrop Complex	Douglas Springs Trail nearby Aguila Tank, N slope	532169	3565702
07	Paired	Grazed	Unburned	1080m/ 3542ft	17°	150°	Lampshire-Romero-Rock Outcrop Complex	Adjacent to Mica Tank, S slope	531230	3564809
08		Ungrazed	1989	1085m/ 3558ft	20°	215°	Lampshire-Romero-Rock Outcrop Complex	Douglas Springs Trail nearby Mica tank, S slope	531210	3565272
09	Unpaired	Grazed	1989	1330m/ 4362ft	10°	54°	Lampshire-Romero-Rock Outcrop Complex	Douglas Springs Trail nearby Tina Larga Tank	533634	3565589
10	Unpaired	Grazed	1989	1430m/ 4690ft	5°	315°	Lampshire-Romero-Rock Outcrop Complex	Near Douglas Springs Campground, 4800 ft	537224	3565891

Appendix D. Soil Crust and Soil Stability Survey Materials

Soil Quality Monitoring Protocol for Sonoran Desert Network Parks

Standard Operating Procedure

Conducting the Biological Soil Crust Measurements

January 2006

Revision History Log:

Prev. Version #	Revision Date	Author	Changes Made	Reason for Change	New Version #

This Standard Operating Procedure explains the procedure for conducting the aggregate soil stability measurements. Samples are collected along the line intercept transects labeled #A - #A. Samples are tested in groups of 15, so two test boxes are conducted per plot.

Procedures:

A. Gather all equipment for biological soil crust quadrat

1. 0.5m x 0.5m quadrat
2. pin flag
3. Datasheets, pencils, and clipboard

B. Collecting the biological soil crust cover data (1 person):

Measurements are conducted along the line intercept transects (#A-#A) using a 0.5m x 0.5m quadrat. The basal cover is recorded at all intercepts of string and string and string and PVC. Biological soil crusts are recorded as light cyanobacteria, dark cyanobacteria, moss, and lichen by color.

1. Sampling locations are along the line intercept transects at pre-determined locations. Those locations are listed on the data sheet.
2. Place the 0.5m x 0.5m quadrat adjacent to the line intercept transect with one edge parallel to the transect. One corner of the quadrat should touch the sampling location and one corner should touch the sampling location plus 0.5m (For example,

along 1A-2A the first sampling location is 6m. One corner of the quadrat should touch 6m and one corner should touch 6.5m)

   a. If vegetation prohibits you from placing the quadrat at the assigned sampling point, shift the quadrat up to 1m in either direction and make a note on the data sheet.

3. At each string/PVC and string/string intercept, carefully lower the pin flag and record touch the tip of the pin flag to the soil surface. Note the soil surface (basal) cover. There are 25 intersections within the quadrat.

4. Place a tally mark under in the appropriate row under the "Tally" heading on the datasheet. If the soil cover is a lichen, place a tally mark for the appropriate color.

5. When you have finished the 25 intersections, visually survey the quadrat. Under the "Present" column, place a tally mark for any biological soil crusts (cyanobacteria, moss, and lichen by color) that you see.

6. Move to the next sampling location and repeat steps 2-5.

Saguaro NP
Field Data Sheet: Biological Soil Crusts
Version: draft

Pg _____ of _____
Copied by: _____ Entered by: _____
Verified by: _____Validated by: _____

Site and Location Information

Plot Name:	Date:
Recorder Name:	Observer Name:

Sampling locations , 3 per transect (Transect: points on transect):

1A-2A: 6m, 9m, 16m
3A-4A: 0m, 3m, 19m
5A-6A: 5m, 7m, 15m
7A-8A: 2m, 5m, 14m
9A-10A: 5m, 9m, 15m
11A-12A: 4m, 8m, 12m
13A-14A: 2m, 10m, 15m
15A-16A: 2m, 13m, 19m
17A-18A: 4m, 14m, 19m
19A-20A: 0m, 5m, 17m

Biological Soil Crust Cover (30 quadrats, 25 points/quadrat, 750 points total)

	Soil Cover	Tally	Present
	Bare ground		
	Litter		
	Gravel (<64mm)		
	Rock (>64mm)		
	Cyano Lt.		
	Cyano Dk.		
	Moss		
Lichens by Color	**Black**		
	Orange		
	Copper		
	Green		
	White		
	Red		
	Yellow		
	Other		

Light Cyanobacteria		Dark Cyanobacteria	
Black Lichen		Copper Lichen	
Green Lichen Example 1		Green Lichen Example 2	
Orange Lichen		Red Lichen	
White Lichen		Yellow Lichen	
Moss against rock		Moss (wet)	

Soil Quality Monitoring Protocol for Sonoran Desert Network Parks

Standard Operating Procedure

Conducting the Aggregate Soil Stability Measurements

This Standard Operating Procedure explains the procedure for conducting the aggregate soil stability measurements. Samples are collected along the line intercept transects labeled #A - #A. Samples are tested in groups of 15, so two test boxes are conducted per plot.

Complete soil stability kit with water and samples		Sample trimmed to 6-8mm square	
Collecting sample 1m from transect		Sample placed in sieve	
Brush away loose surface gravel		Place first sample in water	

Procedures:

A. Gather all equipment for soil stability test (Figure 1)

1. Two tackle boxes
2. 15 sieves
3. Metal spatula
4. 2.5L distilled water (~1L per test run)
5. Stopwatch
6. Datasheets, pencils, and clipboard

B. Collecting the samples (1 person):

Samples are collected 1m off the line intercept transect. Samples can be collected for one transect at a time and stored in the dry box with the **lid open** until samples for 5 transects have been completed (fill one box)

1. Sampling locations are along the line intercept transects at pre-determined locations. Those locations filled in on the data sheet.
2. Place a 1m stick or piece of PVC pipe at the pre-determined location perpendicular to the measuring tape.
3. The sample is collected at the end of the stick away from the transect (Figure 2)
4. Determine the dominant vegetation and basal cover class over the point. Cover classes and codes are on the data sheet. If biological soil crust is present, go to Step 5, otherwise go to step 6.
5. If biological soil crust is present:
    a. Determine major morphological group
    b. Record morphological group in the "Basal" column using the codes on the datasheet
    c. If the major morphological group is dark cyano, lichen, or moss, do not collect a sample and record a "6" in the "#" column
6. Record the dominant cover class in the "Cover" column using the codes on the datasheet.
    d. If the basal cover is rock or vegetation, record a "6" in the "#" column and do not collect a sample.
7. Collect a surface sample by
    e. Brushing away the loose gravel on the surface (if present, see Figure 3)
    f. Slice a square 15mm square using metal spatula
    g. Lift sample into hand and trim to 6-8 mm square (Figure 4)
    h. Gently place sample in the appropriate sieve (Figure 5) and place sieve in the appropriate cell of a dry box.

C. Testing the samples (1-2 persons):

1. Ensure samples are dry before testing. If samples are not dry after collecting, allow to airdry with the lid off
2. Fill the empty (no sieves) box with distilled water filling each compartment to within 1/2in of top.
3. Lower the first sieve and sample in to the appropriate compartment in the water filled box (Figure 6). It should take approximately 1 second for the sieve to be lowered into the water.
4. Start the stopwatch when the sample touches the water
5. Observe the sample for 5 seconds and assign stability class rating as appropriate, recording the rating in the "#" column on the datasheet. See tackle box and datasheet for description of ratings.

6. After 15 seconds, add the second sample and follow steps 3-5. Continue adding samples every 15 seconds according to the sequence on the data form following steps 3-5.
7. Observe the samples from initial immersion to 5 minutes and record a stability rating as appropriate in the "#" column on the datasheet.
8. At 5 minutes on the stopwatch, it is time to sieve the first sample.
9. Take 1 second to raise the sieve completely out of the water and 1 second to lower it to the bottom without touching the bottom or the tray. Repeat this cycle 4 more times.
10. Determine the stability class of the sample and record in the "#" column on the datasheet.
11. Repeat with all samples according to the sequence on the data form following steps 9-10. All samples should be sieved.

Table 4. Stability class ratings.

Stability Class	Criteria for assignment to stability class
1	50 % of structural integrity lost (melts) within 5 seconds of immersion in water, or soil too unstable to sample (falls through sieve).
2	50% of structural integrity lost (melts) 5-30 seconds after immersion.
3	50% of structural integrity lost (melts) 30-300 seconds after immersion or <10% of soil remains on the sieve after five dipping cycles
4	10-25% of soil remains on the sieve after five dipping cycles.
5	25-75% of soil remains on the sieve after five dipping cycles.
6	75-100% of soil remains on the sieve after five dipping cycles.
Circle if samples are hydrophobic (floats after trying to gently push into water)	

Table 5. Cover and basal code key for soil stability analysis.

Cover codes			Basal codes	
N	None		V	Vegetation
F	Forb		R	Rock (>64mm)
GR	Grass		G	Gravel (<64mm)
S	Shrub		CD	Dark Cyanobacteria
PV	Palo verde		LC	Lichen
M	Mesquite		MC	Moss
SA	Saguaro			
T	Tree			

Table 6. Soil stability analysis data sheet

Sieve Num	Location	Cover	Basal	In Time	Dip Time	#
1	1A-2A, 5m			0:00	5:00	
2	1A-2A, 11m			0:15	5:15	
3	1A-2A, 19m			0:30	5:30	
4	3A-4A, 0m			0:45	5:45	
5	3A-4A, 3m			1:00	6:00	
6	3A-4A, 12m			1:15	6:15	
7	5A-6A, 0m			1:30	6:30	
8	5A-6A, 6m			1:45	6:45	
9	5A-6A, 15m			2:00	7:00	
10	7A-8A, 3m			2:15	7:15	
11	7A-8A, 10m			2:30	7:30	
12	7A-8A, 12m			2:45	7:45	
13	9A-10A, 6m			3:00	8:00	
14	9A-10A, 6m			3:15	8:15	
15	9A-10A, 19m			3:30	8:30	