

EPIDERMAL BROWNING AND POPULATION STRUCTURE
OF GIANT SAGUARO CACTUS (*Carnegiea gigantea*)
IN SAGUARO NATIONAL MONUMENT, ARIZONA

FINAL REPORT

by

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ABSTRACT

Forty-five (45) permanent vegetation plots each comprising an area of four (4) ha were established in the Sonoran Desert zone of Saguaro National Monument, including both the east and west units. The purpose of the plots was to identify the extent and severity of epidermal browning on giant saguaro cacti and to initiate long-term studies of vegetation dynamics. The results indicate that epidermal browning is a widespread condition. Little geographic pattern to the condition was found, although cacti observed in plots in the westernmost portion of the Cactus Forest area exhibit some of the most severe browning. Browning was found to be much more severe on the south-facing sides of cacti than on the north-facing sides, suggesting the condition is exacerbated by exposure to intense sunlight. Severity of browning was found to be positively correlated with cactus height (and presumably age) and negatively correlated with retention of spines. Brown saguaros were found to be often associated with dry-site plant species, such as foothill paloverde (*Cercidium microphyllum*), brittle-bush (*Encelia farinosa*), and ocotillo (*Fouquieria splendens*), while saguaros associated with mesquite (*Prosopis velutina*), a plant indicative of wetter soil conditions, were found to be greener than average. An influx of young saguaros into the Cactus Forest population of the past 10 or 20 years was documented by the finding of significant numbers of plants less than 0.5 m in height in many plots.

BACKGROUND

In November of 1987, the National Park Service Air Quality Division filed a report on observations of the decline of giant saguaro cacti (*Carnegiea gigantea*) in the Rincon Unit of Saguaro National Monument. Severe browning of the epidermis was reported to be coincident with areas of numerous dead and dying cacti, and healthier (greener) cacti were observed in the area of washes, co-existing with mesquite trees. Observations of healthy saguaro stands in areas adjacent to the Rincon Mountain Unit, particularly the San Pedro Valley, led to the conclusion that the severe browning and decline of the cactus forest may be a localized phenomenon, possible related to airborne contaminants (Stolte 1988).

As a result, the NPS Air Quality Division sought to establish a systematic network of long-term cactus plots throughout both the east (Rincon) and west (Tucson Mountain) units of Saguaro National Monument. According to Stolte (1988):

The sprawling urban development of the Tucson area threatens to degrade both these units. Establishment of long-term plots will enable the National Park Service to monitor the stability of this species relevant to increasing levels of urban pollutants.

OBJECTIVES

The overall objectives of long-term monitoring of the saguaro population were elucidated in our Work Assignment: "to determine whether the existing cacti in the Rincon Mountain Unit of Saguaro National Monument are still declining and to develop a mechanistic understanding of the nature of the decline. Of particular interest will be the characterization of the development of the epidermal browning symptom and the relationship of that symptom to susceptibility of the cacti to freeze injury."

In order to achieve these objectives, we felt that the plots should represent an unbiased sample of the entire population of

saguaros within the boundaries of the National Monument. They should also be large enough to represent the area in which they are located in terms of density and age structure of individuals.

Thus our work had the following specific objectives: establish a system of relocatable plots that represent an unbiased, independent sample of the population and of sufficient size and number to describe the condition of the population in 1989-90 in terms of incidence and severity of epidermal browning, population density and structure, and the occurrence and importance of associated plant species.

METHODS AND MATERIALS

Sampling Design

The study area was defined by the political boundaries of the National Monument. Within these boundaries the areal extent of a target population was identified with the aid of vegetation maps. Budgetary considerations was the primary factor in determining the total number of plots that could be established-- a total of 45 in both units. With this in mind, we set out to devise an unbiased sampling design that would give good geographic coverage of the sample area while maintaining independence of sample points. We chose an areally stratified random approach to locating plot sites. This method has been described by Taylor (1977).

The area defining the saguaro type in the Rincon Unit was divided into 25 equal area using horizontal (east-west) and vertical (north-south) lines on the map. First, five east-west belts of equal area were defined, then each of these was divided into rectangular areas that included approximately 1.5 square kilometers of saguaro type. Twenty-five (25) sub-populations, scattered throughout the monument, were thus defined (Figure 1).

This was done to prevent plot clumping and/or the occurrence of large contiguous areas of saguaro type left unsampled, possible outcomes of simple random sampling. Because each of the sub-

populations consists of an equal area, each site on the ground still has an equal chance of being picked if one site per sub-population is chosen. A 100 x 100 m grid was placed over the map, defining 1 ha areas. In each of the 25 units, a grid cell was picked at random. We then attempted to establish a plot at each of these randomly chosen sites. Of the 25 random points first chosen, only one had to be rejected after field checking and a second try made. The same procedure was employed for the Tucson Mountain Unit, except that the total number of plot sites selected was 20. Figures 2 and 3 identify the location of each plot as they were actually installed; the plot boundaries are shown to scale.

Plot Design

We chose a fixed area quadrat as our sampling unit. The use of permanent quadrats is appropriate for studies of vegetation dynamics (Austin 1981). A fixed area for all plots allows easy comparison of the relative importance of many plant species over the long term. We chose an area of 4 ha (approximately 10 acres) for each plot based on observations of the relative densities



Figure 1. Map of the Rincon Unit showing the methods used in the sampling design. Bold horizontal and vertical lines divide the area of saguaro type into 25 equal sub-populations, within which a site was picked at random.



Figure 2. Map of the Rincon Unit showing the plot locations and their numbers. The square symbol represents the actual size of each plot.

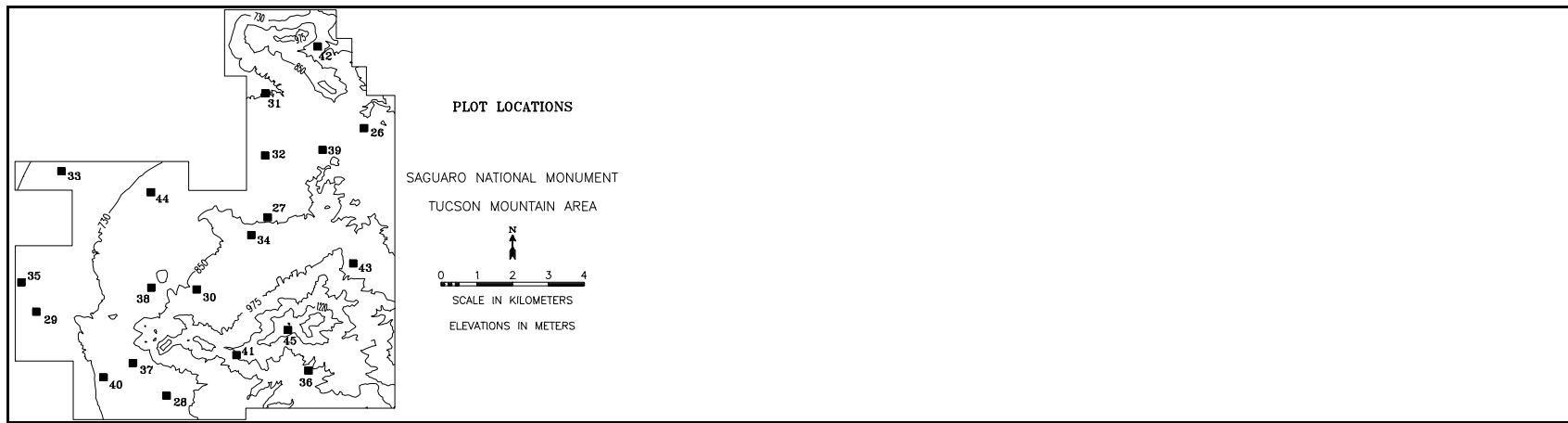


Figure 3. Map of the Tucson Mountain Unit showing the plot locations and their numbers. The square symbol represents the actual size of each plot.

of saguaros within the sampled area. The minimum number of saguaros of a height of 2 m or greater was set at 30 per plot, and we projected that the use of 4 hectares would insure finding this many in nearly all areas mapped as saguaro type. The 4 ha area was surveyed in as a square 200 m on each side, accurate to about $\pm 2\%$. Rebar stakes with yellow plastic caps were placed at each of the plot corners. A stake, numbered with an aluminum tag, was placed just north of each selected saguaro.

Every saguaro of a height of 10 cm and greater was tallied in each plot. Plants 2 m tall and taller were then selected for detailed measurement and long-term monitoring. Thirty (30) such plants within each plot were randomly picked from all those found. This was done by marking all 2+ m saguaros found within the 4 ha systematically with consecutively numbered flags as the field crew walked through the plot, then drawing 30 numbers from a random number table. These 30 saguaros were considered to represent the sub-population of saguaros within the 4 ha, and the 1.5 square km sub-population in which the plot was located. The total number of cacti found taller than 2m ranged from 32 to 400 (see Table 1).

Within each plot, a much smaller "ecological plot" of 100 square meters (10 x 10 m square) was established for the purpose of monitoring small perennial plant species, including grasses. The methods for these plots followed those applied by researchers at Tumomoc Hill near Tucson (Goldberg and Turner 1986). Within each ecological plot, the stem(s) and canopies of each individual plant were mapped and the species identified. The plot boundaries were aligned along cardinal compass directions and each was centered upon one of the selected saguaros.

Data Collected

The location of each plot was mapped on 7 1/2 minute topographic sheets to within 30 meters of the actual location, as determined by triangulation in the field with a Brunton Pocket Transit. Each of the 30 saguaros selected for long term

monitoring was mapped in relation to the plot boundaries, the topography, and each other to within ± 1 m using the Brunton compass and a fiberglass tape in most plots; optical surveying with transit and stadia rod was used in the Tucson Mountain Unit where the topography was steep enough to allow long unobstructed views from ridgetops. Each cactus was also photographed in color using Kodachrome 64 color transparency film in 35 mm format. The photo points were selected to be as near to due south from the cactus as other existing vegetation would allow for an unobstructed view, and at a distance from the cactus that would include the whole stem in the frame. Close-up photographs of the south facing side each cactus stem centered at a height of 1.34 m were also taken. These maps and photographs accompany this report in a separate box (see Appendix B).

The following variables were measured and recorded at each tagged saguaro: 1) the height of the main stem to ± 0.5 m using a clinometer, 2) a visual estimate of the percentage of the stem and arms covered with epidermal browning on both north and south sides of the main stem and arms of the plant, 3) a visual estimate of the percentage of spines retained on both the north and south sides of the main stem and arms, 4) the number and estimated total length of arms to the nearest meter, 5) microsite characteristics as defined by one of six moisture availability classes, based on the presence or absence of soil and the slope, 6) a count of squares on a 225-square grid made of 1/2 inch hardware cloth in a wooden frame that contained areas of epidermal browning, scarring, and undamaged tissue when the grid was placed at 1.34 meters above ground level on both the north and south sides of the plant, and 7) the presence or absence of scars from mechanical damage, nesting birds, freezing, and discoloration caused by betacyanin. Percent visual estimates were made in classes following the Horsfall-Barrett system of plant disease measurement (Horsfall and Cowling 1978), which takes into account the human brain's ability to more precisely

estimate smaller percentages of cover than when the ratio of diseased/undiseased areas is near 50/50. Percentage values were recorded as the midpoints of classes of widths that varied accordingly, specifically 0, 2, 5, 10, 15, 20, 30, 40, 50, 60, 70, 80, 85, 90, 95, 98, and 100%. Associated tree, shrub, and succulent species in the immediate vicinity of each cactus were interpreted from the photographs.

The data was transcribed into digital form in a DBase III+ file, which is included on 5 1/4" floppy disc in a separate box, along with a printout (see Appendix B). Data on each cactus which may aid in its relocation in the field was extracted and listed as a separate report for each plot. These data accompany the stem maps for each plot. We recommend that the 7 1/2 minute sheets, the stem maps, the photographs, and the cactus data reports all be used in the field for future relocation of these individuals saguaros.

Ecological plot maps were constructed in the field using plane table methods and are accurate to ± 10 cm. The originals were digitized and presentation maps constructed using the software AutoCad. Each species was placed on a separate layer, and a count and total canopy area were obtained for each species in each plot using a customized computer program. These data are printed on the maps in the form of a legend. The total area covered by perennial grass species in each plot was estimated in the field as a percentage of the plot area and noted on each map; individual grass plants were not mapped. The maps are included in a separate box accompanying this report both on floppy disc as AutoCad drawing files and plotted in 8 colors on 11x17 inch paper. A representative map is reproduced in black and white in this report as Figure 4. Analysis of data derived from these maps was not part of our Work Assignment.

RESULTS AND DISCUSSION

Epidermal Browning

Two obvious patterns emerged from the epidermal browning data: 1) taller cacti are browner and 2) the south-facing sides of cacti are browner than the north sides. The first relationship is illustrated in Figures 5a-b. The heights of individual plants have been "binned" into 0.25 meter classes up to 7.5 meters, 0.5 meter classes between 7.5 and 10 meters, and the relatively small number of cacti observed with heights greater than 10 meters were placed in two classes, 11-12 and 12-14 meters to help illustrate the relationship. The mean and standard error bars of percent browning on the south side of cactus stems are then plotted at the center point of each bin in Figure 3a. The plotted points describe a curve that may be interpreted in two ways: either as a power function passing through the origin or two linear functions with an inflection point at about 4 meters in height. This inflection point may be called a "threshold height" above which the browning follows a steeper linear model. Figure 3b appears to support the power function model by revealing a linear relationship when the points are plotted on logarithmically scaled axes.

When results from individual plots are considered separately, departures from the model for the entire population may be interpreted as representing the severity of the "disease" in a given area. Figure 6 illustrates this idea

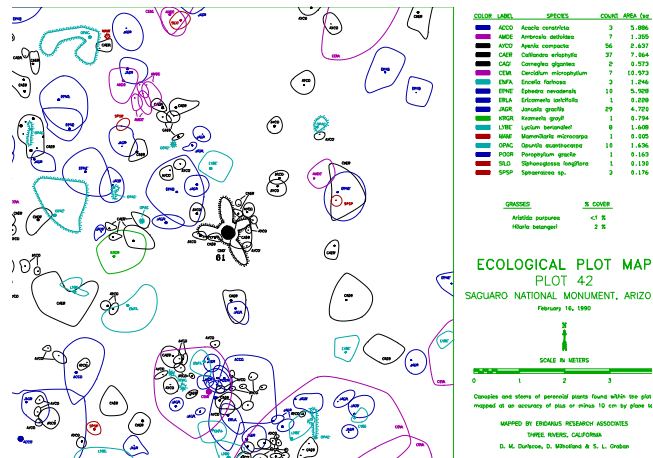
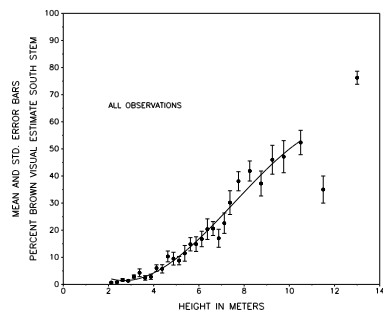
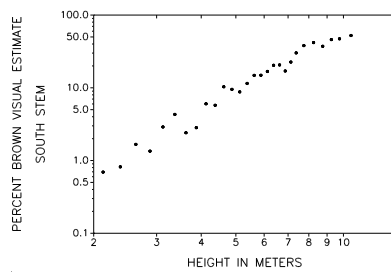


Figure 4. Ecological plot map reproduced in black and white. Original maps are in digital form using AutoCad software which allows automated analysis shown in the legend. A tagged saguaro is at the center of each plot.



a.



b.

Figure 5. Graphical representation of the relationship between severity of epidermal browning with height of saguaros showing (a) means and standard error and (b) mean browning index by height class.

with data from two plots, plots 9 and 41. Plot 9 contains a large proportion of green cacti, as evidenced by the clustering of points near the zero line until about the 7 m height level, beyond which a steep upward trend is defined by three points. By contrast, data from plot 41 define a threshold of about 4.5 meters, beyond which the scatter of points indicates a similar steep upward trend.

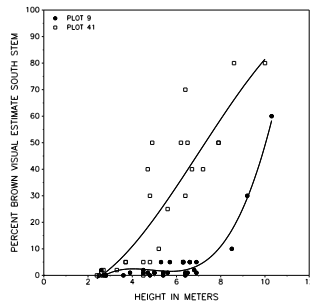


Figure 6. Comparison of epidermal browning-height relationship for cacti in two different plots, one containing primarily green cacti (Plot 9) and one with more severe browning (Plot 41). Polynomial regression lines are shown for each plot.

At first glance this may imply that the area of plot 41 is experiencing a more severe attack of the browning disease. However, it is reasonable to conclude that the severity of browning is not so much a function of height as of age. The power function model would fit this concept nicely, for the age vs. height curve for the saguaro has been shown to approximate a power function (Steenbergh and Lowe 1983). Also, saguaros grow at widely differing rates depending on their environment, which includes differences in elevation, topography, and/or soil

structure (Steenbergh and Lowe 1977). These environmental factors may vary over relatively small distances, and two different plots may easily be in different environments. Plants 5 m in height may be the same age as 8 m tall plants growing in a more favorable environment. Plot 9 is in a relatively well watered flat area with good soil development. Plot 41 is a steep, severe southwest-facing rocky slope where moisture availability may be more limited. Thus the "threshold" heights of 7.0 and 4.5 meters may in fact represent plants of the same age.

An ideal "index" of the severity of epidermal browning would therefore account for the age of the plant. Unfortunately, it is not possible to determine the age of a saguaro merely from its height, or any other direct means at a given point in time. Indexing the simple percentage of browning recorded in the field with cactus height does account at least in part for the advanced age of taller plants. We used this ratio as a "browning index" for comparing the severity of browning on one cactus with another, and for plot-to -plot comparisons:

VISUAL ESTIMATE OF BROWNING ON SOUTH-FACING
SIDE OF STEM (%) BROWNING INDEX =

HEIGHT (m)

Since we sampled cacti of 2 m in height and taller, the maximum index value in our sample would be 50 (100%/2m) and the minimum 0 (for cacti of any height with no browning at all). This linear model of browning may be considered a rough approximation, ignoring the effects of threshold heights, different age-height functions for different areas, and the possible non-linear response (increased browning) of saguaros to increasing age. It is, however, much preferred to comparing percentage of browning directly regardless of the height (and associated relative age) of the plants. Index values of individual saguaros were averaged

over all 30 plants within a plot and a "plot index" was obtained for geographic comparison. It should be noted that this index does not account for differing environmental conditions.

Table 1 lists plot level data for all 45 plots, and averages by unit (Rincon and Tucson Mountain), along with some physical characteristics of each plot. Variables include browning index, average height, numbers of saguaros counted in each of five height classes and the total number, percent brown observed on the south-facing side of the stem, percent spines retained on the south stem, and the elevation, general aspect and topographic position of the

Table 1. Means of selected variables by park unit and by plot.

Height Class		UTM Coordinates		Number of Plants by						
Plot	No.	Northings	Easting	Height	Percent Topographic	Percent Brown	Browning	.1-.5	.5-1	1-1.5
1.5-2	>2.0	TOTAL	Elevation	(m)	Position	Spines	Index			
Entire Population										
14	142	276	911	5.02 243	13.43	68.43	2.08	58	38	24
Rincon Unit										
All				4.79	11.25	70.03	1.86	31	35	25
15	123	228	969	261						
3	1	3561700	525500	5.09	20.67	59.07	3.37	4	0	1
	32	40	904	310	Bajada					
2	2	3562620	527380	5.98	14.00	50.40	1.99	4	0	0
	105	111	875	340	Bajada					
4	3	3563130	528905	4.19	12.10	69.67	2.30	15	25	16
	73	133	975	280	Foothills					
13	4	3563220	529105	3.69	13.03	66.33	2.89	13	15	20
	60	121	1000	300	Foothills					
15	5	3563610	524980	6.00	25.00	41.83	3.53	28	24	29
	57	153	867	350	Bajada					
17	6	3558840	526490	4.42	8.23	74.07	1.27	19	22	28
	109	195	975	290	Foothills					
27	7	3558180	526330	4.23	12.50	64.27	1.96	30	55	42
	167	321	1000	250	Foothills					
2	8	3566120	527440	6.91	4.70	56.73	.64	6	1	0
	56	65	818	0	Bajada					
2	9	3561720	526275	5.72	5.20	69.45	.67	5	2	3
	43	55	890	350	Bajada					
3	10	3562930	526620	5.75	5.83	69.53	.84	1	4	1
	75	84	872	999	Bajada					
6	11	3565960	530030	4.40	2.40	84.03	.42	13	13	11
	100	143	860	330	Bajada					
25	12	3559300	527430	4.62	18.43	50.83	3.35	56	50	36
	188	355	1113	190	Slopes					
12	13	3562120	528020	4.55	9.90	70.27	1.50	28	22	19
	176	257	902	260	Foothills					
4	14	3566220	531425	4.29	6.80	79.30	1.22	4	8	7
	37	60	1052	300	Foothills					
7	15	3564600	525875	6.62	38.07	32.80	4.99	30	41	36
	94	208	844	30	Bajada					
22	16	3562505	529315	3.96	19.00	62.43	4.06	58	58	41
	196	375	1024	210	Slopes					
3	17	3564455	527490	5.11	6.27	70.07	1.04	40	23	7
	95	168	843	340	Bajada					
7	18	3556760	526705	4.63	1.27	93.77	.28	8	17	16
	63	111	920	180	Bajada					
12	19	3564800	528880	4.43	5.13	84.53	.76	59	49	35
	127	282	844	290	Bajada					
9	20	3557340	537430	4.34	5.03	91.40	.99	27	21	13
	113	183	1042	90	Foothills					
17	21	3557790	536555	5.20	13.23	77.50	1.90	35	54	28
	220	354	1128	200	Slopes					
19	22	3556800	538300	3.81	6.37	88.59	1.39	17	35	18
	200	289	1067	190	Slopes					
0	23	3557840	536225	4.46	6.20	88.30	.80	12	5	3
	68	88	1231	80	Slopes					
37	24	3557070	529765	3.63	10.37	83.87	1.87	75	83	64
	207	466	1052	200	Slopes					
99	25	3556750	531520	3.84	11.63	71.60	2.44	183	239	159
	409	1089	1119	170	Slopes					
Tucson Mountain Unit										
All				5.29	16.15	66.44	2.36	93	43	22
13	165	336	839	220						
28	26	3575920	487600	5.93	29.37	49.00	3.95	37	36	26
	235	362	747	30	Foothills					
6	27	3573380	484860	5.02	6.13	76.67	.97	30	21	10
	52	119	847	0	Bajada					

	28	3568440	482100	5.56	13.80	71.60	2.06	49	29	25
8	282	393	805	250	Foothills					
	29	3570760	478460	5.19	15.67	70.97	1.70	8	6	4
1	66	85	689	280	Bajada					
	30	3571380	482900	6.83	24.93	50.97	3.00	19	31	18
5	194	267	869	340	Foothills					
	31	3576920	484850	5.38	11.63	55.60	1.60	49	26	5
5	98	183	732	330	Bajada					
	32	3575180	484840	4.86	7.20	74.07	1.33	7	5	3
3	77	95	777	350	Bajada					
	33	3574680	479150	4.93	7.83	79.53	1.02	28	7	10
7	57	109	686	310	Bajada					
	34	3572880	484400	5.33	14.30	68.43	2.45	24	26	11
8	133	202	899	80	Slopes					
	35	3571580	478130	5.74	13.93	71.87	2.02	100	22	4
4	64	194	680	280	Bajada					
	36	3569160	485980	4.66	21.70	70.40	3.71	306	122	48
14	156	646	1061	200	Slopes					
	37	3569340	481160	6.15	14.13	68.43	1.79	149	89	45
15	227	525	786	170	Foothills					
	38	3571430	481650	4.79	20.93	61.67	3.45	176	75	50
44	400	745	823	160	Foothills					
	39	3575330	486460	4.57	8.60	80.00	1.35	91	38	27
11	250	417	780	330	Foothills					
	40	3568930	480350	6.54	25.27	43.13	3.06	51	13	9
7	344	424	738	270	Bajada					
	41	3569580	484010	5.19	28.53	52.17	4.00	196	86	41
22	178	523	1091	240	Slopes					
	42	3578220	486330	4.97	14.77	67.07	2.31	37	26	24
25	144	256	792	80	Slopes					
	43	3572110	487230	4.36	13.87	77.03	2.37	120	33	20
12	81	266	960	180	Foothills					
	44	3574090	481640	5.69	20.17	59.77	3.11	22	11	3
8	89	133	747	330	Bajada					
	45	3570260	485400	4.20	10.27	80.50	1.94	362	151	57
26	176	772	1280	190	Slopes					

plots. The mean browning index was slightly greater for the Tucson Mountain Unit than for the Rincon Unit (2.36 and 2.08 respectively). Mean index data by plot are shown graphically in Figures 7 and 8, which are maps of the Rincon and Tucson Mountain Units with the relative severity of browning illustrated at each plot location by graduated circles. No apparent geographic pattern is evident in the Tucson Mtn. Unit, while the Rincon area reveals some zones of similar browning severity. An area of relatively green saguaros appears to run in a general northeast-southwest line in the center of the bajada area north of the Tanque Verde Ridge, defined by six plots with relatively small browning indices. Three plots near the west boundary of the Rincon Unit indicate an area of greater browning, while plots in the foothills and on the slopes of Tanque Verde Ridge are generally intermediate in severity.

The statistical significance of these apparent differences between plot means may be estimated by comparing the means and 95% confidence intervals for browning index of all 45 plots (Figure 9). Further statistical testing was not conducted because of severe departures from normality and inhomogeneity of variance observed in the data. The within-plot variability is seen to increase with increasing values for the mean, as revealed by wider 95% confidence intervals. It may be roughly concluded that plots with means of 3.0 or greater are significantly different than plots with means of 1.0 or less, and that plots lying between these values are different from only a few plots with extreme values (15, 16, 18). Plots in the Rincon Unit appear to exhibit a wider range of browning indices than Tucson Mtn. plots. Of particular interest are plots 8, 9, 11, and 18 which have mean index values below 0.7 and narrow confidence intervals indicating the majority of sampled cacti have little or no browning. Plots 8, 9, and 18 are all near major washes. Plots 15 and 16 have the highest browning indices, 4.99 and 4.06 respectively, of all plots.

The severity of browning was found to be greater on the south side of all plants investigated than on the north side. This phenomenon is apparent to even the casual observer; Table 2 presents some numerical results. This implies that the light and/or heat of the sun has a definite role (if not the cause) in the formation of the epidermal browning. Yet in many instances, severely brown cacti were seen growing right next to green, healthy cacti of the same height, implying some sort of plant-specific process is involved in



Figure 7. Graduated circle map showing the severity of epidermal browning observed at each plot in the Rincon Unit.

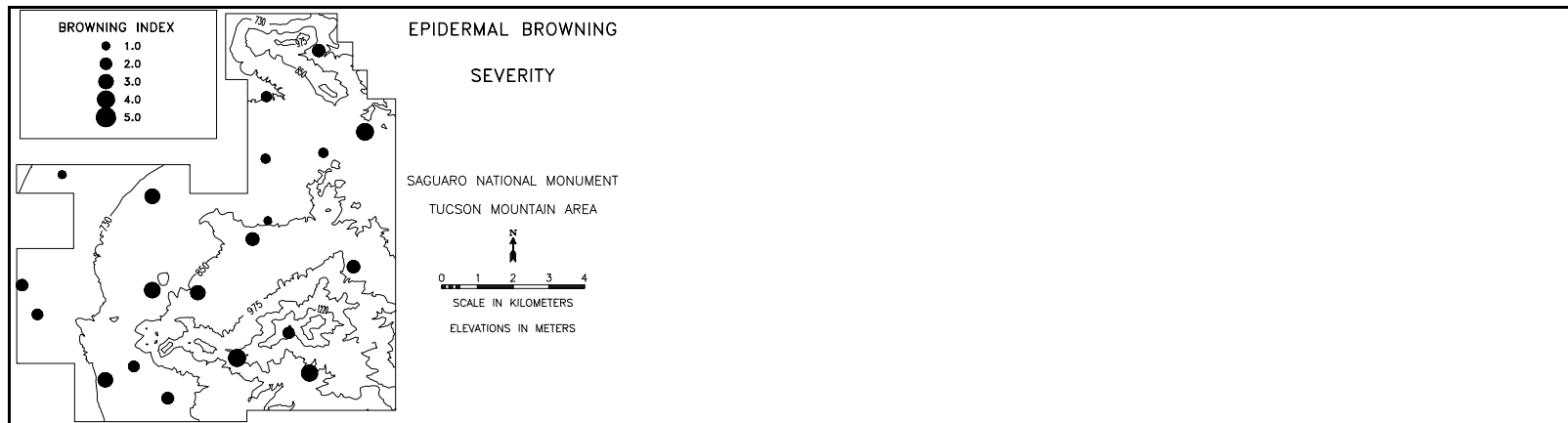


Figure 8. Graduated circle map showing the severity of epidermal browning observed at each plot in the Tucson Mountain Unit.

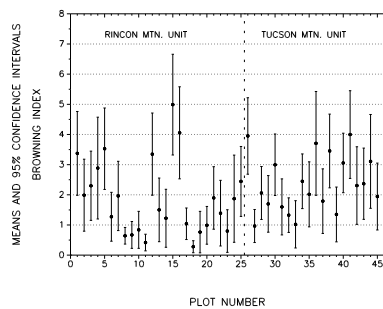


Figure 9. Means and 95% confidence intervals of the browning index observed in each of the 45 plots.

Table 2. Comparison of the appearance of north and south sides of cactus stems.

Variable	Mean	Std Dev	N
Epidermal Browning on Main Stem:			
South	13.4	20.4	1350
North	2.9	6.7	1347
Epidermal Browning on Grid:			
South	23.5	36.5	1334
North	5.2	15.4	1339

its formation.

The effect of variations in micro-habitats on the severity

of epidermal browning was investigated by describing the site factors at each cactus as one of six site classes: 1) flat rock, 2) sloping rock, 3) flat soil, 4) sloping soil, 5) ridge, and 6) basin. Comparisons of the mean browning index for each of these six groups indicated no statistical significance between sites and no definite trends.

The habitat in which a particular cactus grows may also be inferred by plant species associated with it. We looked for differences in mean values of browning index, percent browning on the south-facing side of the stem, and height among groups of cacti associated with selected individual species and groups in which these species were not present. The following associated species were investigated: mesquite (*Prosopis velutina*), paloverde (*Cercidium microphyllum*), teddy-bear cholla (*Opuntia bigelovii*), ocotillo (*Fouquieria splendens*), and brittlebush (*Encelia farinosa*). The means for each group were compared by an independent sample T-test (Table 3). Cacti associated with mesquite were found to yield the lowest mean browning index (1.31), which was significantly lower than cacti which were not associated with mesquites (2.32). Saguaros growing in association with foothill paloverde had a significantly higher browning index (2.36) than those not in association with paloverde (1.60), as well as a higher index than the mesquite-associated cacti. This difference may be a reflection of the different soil moisture regimes where the trees often grow, the mesquites commonly along washes and the paloverdes above the washes and on the drier bajadas (Larson and Larson 1977). These index averages may also be compared with the average for all cacti sampled, 2.07, implying that saguaros associated with mesquite are greener than average and that saguaros associated with foothill paloverde are browner than average. Two other dry-environment species, ocotillo and brittlebush, also appear to be associated with browner cacti (Table 3). A comparison of mean browning index of saguaros growing in the presence and absence of

teddy-bear cholla revealed no significant difference. This species grows primarily in the thermal belt of the mountain slopes.

Spine retention was seen to be highly negatively correlated with the severity of browning. Figure 10 shows plot-level means of percent visual estimates of spines retained on the south stem graphed against mean percent brown grid squares counted on the south sides of saguaros. A fairly good linear relationship is evident, with a correlation coefficient of -0.85 and a

Table 3. Comparison of means for selected factors among groups of saguaro growing in the presence or absence of various other plant species.

Species: Independent T-Test		Present		Absent		
Factor		Mean	N	Mean	N	t
Prob.						
<u>Prosopis velutina:</u>						
% Browning South Stem		8.32	336	15.12	1014	
5.32 < 0.001						
% Browning South Grid		15.46	331	26.25	1003	
4.69 < 0.001						
Browning Index		1.31	332	2.32	1003	
5.40 < 0.001						
% Spines South Stem		71.85	335	67.31	1012	-
1.98 0.047						
Height (m)		5.12	332	4.97	1003	-
1.15 0.249						
<u>Cercidium microphyllum:</u>						
% Browning South Stem		15.71	836	9.73	514	-
5.26 < 0.001						
% Browning South Grid		27.29	827	17.51	507	-
4.77 < 0.001						
Browning Index		2.36	827	1.60	508	-
4.57 < 0.001						
% Spines South Stem		65.39	834	73.39	513	
3.94 < 0.001						
Height (m)		5.12	827	4.82	508	-
2.67 0.008						
<u>Opuntia bigelovii:</u>						
% Browning South Stem	13.40	72	13.43	1278	0.01	0.990
% Browning South Grid	25.73	72	23.45	1262	-0.51	0.608
Browning Index	2.31	72	2.05	1263	-0.71	0.479
% Spines South Stem	65.38	72	68.61	1275	0.73	0.463
Height (m)	4.59	72	5.03	1263	1.83	0.067
<u>Fouquieria splendens:</u>						
% Browning South Stem	14.70	457	12.78	893	-1.63	0.104
% Browning South Grid	25.09	451	22.81	883	-1.08	0.281
Browning Index	2.44	453	1.88	882	-3.32	0.001
% Spines South Stem	69.37	456	67.96	891	-0.68	0.498
Height (m)	4.65	453	5.19	882	4.79	< 0.001

Encelia farinosa:

% Browning South Stem	15.92	316	12.67	1034	-2.47	0.014
% Browning South Grid	28.47	313	22.08	1021	-2.71	0.007
Browning Index	2.71	313	1.87	1022	-4.41	< 0.001
% Spines South Stem	66.71	316	68.97	1031	0.97	0.335
Height (m)	4.61	313	5.13	1022	4.03	< 0.001

Entire Population

% Browning South Stem	13.43	1350
% Browning South Grid	23.58	1334
Browning Index	2.07	1335
% Spines South Stem	68.44	1347
Height (m)	5.01	1335

slope near -1 (-0.90). This, in itself, is not enough to imply cause and effect. Spine retention and browning co-vary with height, which is related to age, so decreased spine retention may be a normal ageing process. Table 4 is a correlation matrix of many of the variables measured summarized to the plot level by averaging; thus, N=45 for all comparisons. Much of these data are not normally distributed, so the matrix should be used only as a guide for further investigation into the processes which may be involved, not as a definitive analysis of such processes. Noticeably absent is any distinct linear correlation between any variable and elevation except average height ($r = -0.57$). This would indicate that plots located on steep, rocky slopes (which, in this area, occur almost exclusively in the higher elevations) contain a smaller proportion of tall cacti than plots on the bajadas.

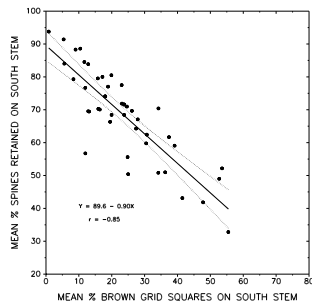


Figure 10. Scatterplot with regression line and 95% confidence belts showing the relationship between epidermal browning and spine retention on the south-facing side of cactus stems. Plot-level means are used as data points.

Population Density and Structure

The data collected allow a plot to plot comparison of numbers of saguaros of various height classes and the total number of saguaros.

By dividing these **Table 4.** Correlation matrix of selected variables using plot-level means.^a

		Percent Brown Visual Estimate		Percent Brown Grid Count		Percent Spines Visual Estimate		Elevation
Height Brown Index		S Stem	N Stem	South	North	S Stem	N Stem	
Height	1.0000	.2010	.4405	.4771	.4302	.3675	-	-.5657
	(45)	(45)	(45)	(45)	(45)	(45)	.6547	(45)
	p=.	p=.186	p=.00	p=.00	p=.00	p=.01	(45)	p=.000
			2	1	3	3	p=.00	
							0	0

Browning Index		.2010 (45) p=.186	1.0000 (45) p=.	.9431 (45) p=.00 0	.7385 (45) p=.00 0	.9141 (45) p=.00 0	.6922 (45) p=.00 0	- (45) p=.00 0	- (45) p=.00 0	.0485 (45) p=.752
Percent Brown Visual Estimate	S. Stem	.4405 (45) p=.002	.9431 (45) p=.000	1.000 0 (45) p=.	.8448 (45) p=.00 0	.9629 (45) p=.00 0	.7710 (45) p=.00 0	- (45) p=.00 0	- (45) p=.00 0	-.1193 (45) p=.435
	N. Stem	.4771 (45) p=.001	.7385 (45) p=.000	.8448 (45) p=.00 0	1.000 0 (45) p=.	.7825 (45) p=.00 0	.8094 (45) p=.00 0	- (45) p=.00 0	- (45) p=.00 0	-.1941 (45) p=.201
Percent Brown Grid Count	South	.4302 (45) p=.003	.9141 (45) p=.000	.9629 (45) p=.00 0	.7825 (45) p=.00 0	1.000 0 (45) p=.	.7628 (45) p=.00 0	- (45) p=.00 0	- (45) p=.00 0	-.1357 (45) p=.374
	North	.3675 (45) p=.013	.6922 (45) p=.000	.7710 (45) p=.00 0	.8094 (45) p=.00 0	.7628 (45) p=.00 0	1.000 0 (45) p=.	- (45) p=.00 0	- (45) p=.00 0	-.1351 (45) p=.376
Percent Spines Visual Estimate	S. Stem	-.6547 (45) p=.000	-.7298 (45) p=.000	- (45) p=.00 0	- (45) p=.00 0	- (45) p=.00 0	- (45) p=.00 0	1.000 0 (45) p=.	.9506 (45) p=.00 0	.2950 (45) p=.049
	N. Stem	-.5617 (45) p=.000	-.7886 (45) p=.000	- (45) p=.00 0	- (45) p=.00 0	- (45) p=.00 0	- (45) p=.00 0	.9506 (45) p=.00 0	1.000 0 (45) p=.	.1885 (45) p=.215
Elevation		-.5657 (45) p=.000	.0485 (45) p=.752	- (45) p=.00 0	- (45) p=.00 0	- (45) p=.00 0	- (45) p=.00 0	.2950 (45) p=.04	.1885 (45) p=.21	1.0000 (45) p=.

p=.43	p=.20	p=.37	p=.37	9	5
5	1	4	6		

^a Pearson's r
 (N)
 2-tailed prob.

numbers by 4, density values in plants per hectare may be obtained for comparison with previous work. Table 5 lists these figures for each plot. The results are displayed in map form in Figures 11 and 12, where a histogram

Table 5. Density of saguaro cacti found in plots in one meter size classes and total density.

						Density in plants/ha by			
Height Class									
Plot ^a	10-11 ^a	11-12 ^a	12-13 ^a	13-14 ^a	Density ^a	5-6 ^a	6-7 ^a	7-8 ^a	8-9 ^a
9-10									
1	1.00	1.00	0.80	1.60	2.40	1.33	0.80	0.00	0.27
0.53	0.27	0.00	0.00	0.00	10.00				
2	1.00	0.50	0.88	3.50	1.75	4.38	11.37	1.75	1.75
0.88	0.00	0.00	0.00	0.00	27.75				
3	10.00	5.00	6.69	4.26	1.22	3.65	0.61	1.22	0.61
0.00	0.00	0.00	0.00	0.00	33.25				
4	7.00	8.25	4.00	6.00	2.00	2.50	0.50	0.00	0.00
0.00	0.00	0.00	0.00	0.00	30.25				
5	13.00	11.00	0.47	2.37	2.37	2.37	1.90	1.90	1.90
0.95	0.00	0.00	0.00	0.00	38.25				
6	10.25	11.25	7.27	3.63	8.18	4.54	0.91	0.00	2.73
0.00	0.00	0.00	0.00	0.00	48.75				
7	21.25	17.25	13.92	6.96	4.17	9.74	5.57	1.39	0.00
0.00	0.00	0.00	0.00	0.00	80.25				
8	1.75	0.50	0.00	0.47	0.93	0.93	4.67	4.67	1.40
0.93	0.00	0.00	0.00	0.00	16.25				
9	1.75	1.25	1.07	0.72	1.43	2.51	3.94	0.00	0.36
0.36	0.36	0.00	0.00	0.00	13.75				
10	1.25	1.00	0.63	1.25	3.13	4.38	6.25	1.88	0.63
0.63	0.00	0.00	0.00	0.00	21.00				
11	6.50	4.25	4.17	5.00	10.00	4.17	0.83	0.00	0.00
0.83	0.00	0.00	0.00	0.00	35.75				
12	26.50	15.25	12.53	9.40	9.40	1.57	4.70	7.83	1.57
0.00	0.00	0.00	0.00	0.00	88.75				
13	12.50	7.75	5.87	14.67	10.27	2.93	5.87	2.93	0.00
0.00	1.47	0.00	0.00	0.00	64.25				
14	3.00	2.75	0.93	4.01	1.23	1.85	0.93	0.31	0.00
0.00	0.00	0.00	0.00	0.00	15.00				
15	17.75	8.25	3.13	3.13	1.57	4.70	3.92	2.35	1.57
0.78	0.78	0.00	1.57	0.00	52.00				
16	29.00	15.75	16.33	9.80	8.17	9.80	3.27	1.63	0.00
0.00	0.00	0.00	0.00	0.00	93.75				
17	15.75	2.50	2.37	2.37	3.17	8.71	5.54	1.58	0.00
0.00	0.00	0.00	0.00	0.00	42.00				
18	6.25	5.75	2.10	2.62	5.25	2.10	2.62	1.05	0.00
0.00	0.00	0.00	0.00	0.00	27.75				
19	27.00	11.75	7.41	7.41	5.29	5.29	4.23	0.00	1.06
1.06	0.00	0.00	0.00	0.00	70.50				
20	12.00	5.50	5.65	7.53	7.53	3.77	0.94	2.83	0.00

0.00	0.00	0.00	0.00	0.00	45.75				
21	22.25	11.25	3.67	12.83	12.83	7.33	12.83	1.83	0.00
0.00	3.67	0.00	0.00	0.00	88.50				
22	13.00	9.25	11.67	16.67	16.67	3.33	1.67	0.00	0.00
0.00	0.00	0.00	0.00	0.00	72.25				
23	4.25	0.75	4.53	2.27	5.10	3.40	0.57	0.57	0.00
0.00	0.00	0.00	0.00	0.57	22.00				
24	39.50	25.25	24.15	12.07	5.17	3.45	3.45	1.73	1.73
0.00	0.00	0.00	0.00	0.00	116.50				
25	105.50	64.50	34.08	34.08	10.22	10.22	10.22	0.00	3.41
0.00	0.00	0.00	0.00	0.00	272.25				
26	18.25	13.50	9.79	9.79	3.92	3.92	9.79	1.96	11.75
5.87	1.96	0.00	0.00	0.00	90.50				
27	12.75	4.00	2.17	2.60	2.17	1.73	1.73	1.73	0.43
0.43	0.00	0.00	0.00	0.00	29.75				
28	19.50	8.25	4.70	7.05	23.50	7.05	9.40	11.75	4.70
0.00	2.35	0.00	0.00	0.00	98.25				
29	3.50	1.25	2.20	3.85	2.75	1.10	3.30	1.65	1.10
0.55	0.00	0.00	0.00	0.00	21.25				
30	12.50	5.75	0.00	3.23	8.08	8.08	4.85	6.47	8.08
6.47	3.23	0.00	0.00	0.00	66.75				
31	18.75	2.50	4.08	3.27	3.27	6.53	1.63	2.45	0.82
0.82	0.82	0.82	0.00	0.00	45.75				
32	3.00	1.50	0.64	5.13	5.13	5.13	1.93	0.00	1.28
0.00	0.00	0.00	0.00	0.00	23.75				
33	8.75	4.25	1.90	3.80	2.37	2.37	0.95	0.95	1.43
0.47	0.00	0.00	0.00	0.00	27.25				
34	12.50	4.75	3.33	5.54	4.43	3.33	12.19	3.33	0.00
1.11	0.00	0.00	0.00	0.00	50.50				
35	30.50	2.00	2.13	1.07	2.67	1.60	5.87	1.07	0.00
0.00	1.07	0.53	0.00	0.00	48.50				
36	107.00	15.50	7.80	7.80	9.10	5.20	6.50	1.30	1.30
0.00	0.00	0.00	0.00	0.00	161.50				
37	59.50	15.00	7.57	5.67	5.67	7.57	3.78	15.13	3.78
3.78	3.78	0.00	0.00	0.00	131.25				
38	62.75	23.50	16.67	13.33	33.33	13.33	6.67	10.00	3.33
3.33	0.00	0.00	0.00	0.00	186.25				
39	32.25	9.50	8.33	22.92	6.25	12.50	4.17	2.08	4.17
2.08	0.00	0.00	0.00	0.00	104.25				
40	16.00	4.00	2.87	11.47	8.60	11.47	14.33	20.07	8.60
2.87	2.87	0.00	2.87	0.00	106.00				
41	70.50	15.75	8.90	4.45	10.38	4.45	8.90	4.45	1.48
0.00	1.48	0.00	0.00	0.00	130.75				
42	15.75	12.25	7.20	6.00	6.00	6.00	1.20	4.80	4.80
0.00	0.00	0.00	0.00	0.00	64.00				
43	38.25	8.00	7.42	2.70	3.38	2.02	2.03	2.03	0.00
0.68	0.00	0.00	0.00	0.00	66.50				
44	8.25	2.75	2.23	0.00	4.45	5.19	5.19	4.45	0.74
0.00	0.00	0.00	0.00	0.00	33.25				
45	128.25	20.75	8.80	11.73	13.20	4.40	1.47	4.40	0.00
0.00	0.00	0.00	0.00	0.00	193.00				

^a

Density values for these height classes were extrapolated from a

random of sample of 30 cacti with heights of
2 m and greater within the 4 ha plot.



Figure 11. Map of the Rincon Unit showing histograms of saguaro population structure and density at each plot location.

Figure 12. Map of the Tucson Mountain Unit showing histograms of saguaro population structure and density at each plot location.

of height structure for each plot is placed on the map at its respective plot location. Since all cacti greater than 2 m in height were not measured, data for the height range 2-13 m were extrapolated from the random sample of 30 that were measured. No test of the precision to which these values represent the true values was made in any of the plots.

It is evident from the maps that a different population structure exists for bajada areas than for mountain slope areas. This is consistent with the results of Steenbergh and Lowe (1983).

Rocky slopes generally possess a so-called "stable" population with many more smaller cacti than tall ones. The bajada areas, particularly north-west of the Tanque Verde ridge in the Rincon Unit (Figure 11) display a distinct peak in the distribution at about 6 or 7 meters in height. The density of cacti of all heights is also much smaller. In the Tucson Mtn. area (Figure 12) many plants in the .1-1.0 m height class are seen in the high mountain plots. At plot 45, elevation 1280 m (4200 feet), this density reaches 128/ha, highest of any in our sample. Of interest in the bajada plots of both units is the existence of a sharp peak in the .1-1m class. This agrees with recent work of Turner (in manuscript), in that it documents a possible recovery of the cactus forest population in years to come. This recovery is not evident in every plot, however. Plots 1, 2, 8, 9, and 10 do not exhibit this increase in recruitment over the past decade or two.

In these areas, our data indicate the population of saguaros is still in decline.

CONCLUSIONS

Epidermal browning of saguaro cacti is a widespread condition; no area within the Monument may be said to be free of it. It appears to form in the presence of sunlight, though cacti up to 8 m tall (at least 70 years old according to Steenbergh and Lowe) with many arms were found without a trace of browning, very green with good spine retention. Therefore some plant-specific

factor must be involved. Browning appears to be well correlated with age, suggesting it may be a normal ageing process. In some plant the process may be accelerated for a reason that is not conclusively proven from this study. However, saguaros growing on drier sites may be more susceptible to the condition. A decrease in spine retention was found to correlate with increased epidermal browning. Since the browning often begins at the areoles of the cacti, this result may indicate a cause-effect relationship between incidence of browning and loss of spines that bears investigating.

The saguaro population appears to be stable in most foothill and mountain environments sampled. In the bajadas, a large anomaly in the population structure still exists in the presence of a peak in density at 6 to 8 meters in height. A number of young plants in the 0.1-1.0 meter height class were observed in many of the bajada plots, indicating some recruitment has taken place after many decades of steady decline with little or no recruitment.

The data set amassed by this project will serve as a basis for future monitoring of the individuals studied. Such long term monitoring will provide greater insight into the cause of the epidermal browning and document the ever-changing distribution of plants in this area of the Sonoran Desert.

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APPENDIX A

PLOTS FOR IDENTIFYING MORTALITY OF BROWN AND GREEN SAGUAROS

PLOTS FOR IDENTIFYING MORTALITY OF BROWN AND GREEN SAGUAROS

INTRODUCTION

With the completion of the permanent biomonitoring plots, a need was seen to augment this plot system with a number of saguaro cactus mortality transects to add the dimension of a shorter time frame for observation of cactus death in relation to browning. It has been observed and documented that semi-mature and mature saguaros are still rapidly declining in certain sections of the Cactus Forest of RMD. The areas of decline seem to be concentrated on the bajadas while the nearby wash areas are apparently inhabited by healthier, more vigorous stands of saguaros. The placement of transects along washes where predominantly green saguaros are found and on adjacent bajadas where high densities of the brownest cacti reside will permit the detection of different mortality rates between brown and green groups. If, in fact, saguaros with the epidermal browning symptom are sick individuals and more likely to succumb to stress, this would be revealed by comparison of mortality rates between groups. This would be observable in a shorter time frame than obtainable from the saguaro plot network, since the "sickest" individuals are deliberately compared with the greenest.

METHODS

A total of six saguaro trend plots or mortality transects were established in the east and west units of the national monument. The initial approach of setting up the transects randomly (as to point of origin and compass direction) and in pairs with parallel, adjacent orientation proved to be impossible in the field. This was the methods proscribed in the work assignment. The cactus stands in target areas are simply too sparse for this to be practical. Our solution was to recon the areas by car and foot and then to pick sites subjectively that 1) fit the wash/bajada categories, 2) were comprised of relatively dense saguaro stands, and 3) were feasible to map, as well as conforming to the brown/green classification. In the Rincon Unit we located two green transects in wash areas and two brown between washes on the bajadas. In the Tucson Mtn. Unit we settled on two transect locations which were not so well stratified as to site factor but which contained wash and bajada elements and good densities of saguaros. In these transects, all saguaros greater than four meters were selected for monitoring regardless of their degree of browning.

The four RMD trend plots were laid out and mapped with the use of theodolite/EDM contraption. In the TMD, a Brunton compass, fiberglass tape, and hand-held sonic distance measurer were the primary surveying instruments. By observing the topography and cactus density we derived an appropriate starting point and compass direction for the center line layout. Rebars were pounded in the ground along this line, usually at 100-meter intervals. All saguaros two (2) meters in height and greater were mapped on a set of cartesian coordinates, using the starting point as (0,0) and the longitudinal axis of the transect as the x-axis. Transect width varied according to the density of saguaros from 40 m to 100 m. Only those saguaros of a height four (4) meters and greater were then picked for the study. In the east monument plots only green saguaros (defined as <20% brown on south stem) in the wash transects and only brown saguaros (defined as $\geq 30\%$ brown on south stem) in the bajada transects were selected. The transect length was dictated by the character of the stand in the Rincon unit plots. The west monument transects were made as long as necessary to gather our target number of 500 total cacti, ideally half being green and half brown. We wound up with 497 total plants, 229 green (<20% browning on the south stem), 249 brown ($\geq 30\%$ brown on the south stem), and 19 in between.

The following data were taken on the chosen plants: height, percent spines on south stem (visual estimate), dbh and number of ribs (at dbh). Since the Tucson Mountain transects were not separated into "green" and "brown" plots, a measurement of percent brown of south stem (visual estimate) was recorded for the cacti in these plots to facilitate later grouping. Heights to 0.5 m were measured by clinometer. Dbh was

determined with calipers to the nearest 0.5 cm. Ribs were carefully counted at breast height (1.34 m above ground). Whole cacti were photographed from the south side using 35 mm camera with Kodachrome film. Heights were also recorded for all saguaros ≥ 2 meters tall that did not qualify for the study. Most of this data-gathering was similar to that done in the saguaro biomonitoring plots, with the exception that we added the dbh and rib measurements to look for possible correlation between browning and turgidity/flaccidity of cactus stems.

Stem maps were plotted from the data with the location and number of each chosen saguaro as well as the location and height of each other cactus measured (all saguaro cacti ≥ 2 meters). Rebar locations were placed on the maps. Mapping with EDM is accurate to ± 5 cm, with Brunton, tape, and sonic distance measurer to ± 30 cm. Two of the east unit transects intersected permanent biomonitoring plots, so the plot boundaries were included as were tagged and untagged saguaros in these plots. Plot corner rebars and saguaro tag numbers were placed on the maps. Transects were mapped to scale on 7 1/2 minute quadrangles (also containing the permanent plot locations).

RESULTS AND DISCUSSION

Printed maps, cactus data, and photographs were the primary products from this work. These products are included in a separate box with this report. Table A-1 summarizes some of the results of the data collection. A brief discussion follows which we include for informational purposes only.

Statistical analyses were run to examine comparisons of group means of height, percent spines, dbh and rib count between the brown and green groups of saguaros. As could be expected, mean height of brown cacti was significantly greater than that of green cacti for our chosen individuals, even though we tried to mellow out this factor by selecting only cacti of fairly great height (≥ 4 meters). The mean height difference was nearly 2 meters: 5.66 meters for green cacti and 7.64 for brown cacti. Figure A-1 displays the height distributions of the two groups as a double histogram. Also expected was the big difference in mean spine retention: 76.56% for the green group and 15.40% for the brown group. Results of somewhat more interest came out of the dbh and rib count statistics. Mean dbh measurement of brown saguaros was 44.21 compared with 46.2 cm for the green saguaros. Rib count was slightly smaller for the whole group of brown cacti than for the green (Table A-1).

In view of the height difference between groups and presumed corresponding age differences, a table of average values by one meter height classes for dbh, ribs and spine retention was derived (Table A-1). Dbh is seen to generally increase with increasing height, and within all height classes the brown cacti are smaller in diameter than the green ones. Average number of ribs appears to be independent of height, as the averages for each height class are nearly the same within brown and green groups for all heights. The brown cacti have slightly fewer ribs in nearly all height classes than the green cacti, as reflected in the grand means (18.3 for green and 17.7 for brown).

Table A-1. Descriptive statistics for selected variables by height class and injury class.

VARIABLE:		Groups					
Height	All	Green		Brown			
Class	Mean	Std Dev	N	Mean	Std Dev	N	Mean Std Dev N

DBH:

All	45.03	6.01	497	46.19	6.0	229	44.21	5.79	249
4.0-5.0	41.70	6.31	84	43.66	5.08	63	35.60	6.47	16
5.0-6.0	44.32	6.11	88	45.74	5.42	72	37.36	5.09	12
6.0-7.0	45.38	5.70	123	47.72	5.63	68	42.49	4.41	51
7.0-8.0	45.37	5.76	86	49.17	7.80	17	44.46	4.81	67
8.0-9.0	46.56	4.76	67	53.01	6.94	7	45.81	3.93	58

RIBS:

All	17.98	2.26	495	18.30	2.41	229	17.70	2.10	247
4.0-5.0	17.72	2.51	84	17.95	2.53	63	16.75	2.23	16
5.0-6.0	18.36	2.23	88	18.61	2.28	72	17.08	1.72	12
6.0-7.0	17.92	2.20	122	18.14	2.32	68	17.62	2.07	50
7.0-8.0	18.16	2.14	86	18.05	2.27	17	18.17	2.15	67
8.0-9.0	17.71	2.36	66	19.85	2.96	7	17.45	2.19	57

SPINES:

All	44.31	34.99	497	76.56	22.71	229	15.40	11.32	249
4.0-5.0	74.47	33.53	84	91.28	15.46	63	21.56	20.30	16
5.0-6.0	66.88	29.11	88	76.95	20.11	72	15.83	9.25	12
6.0-7.0	46.39	32.39	123	69.94	21.14	68	16.09	12.90	51
7.0-8.0	23.74	22.37	86	57.05	27.04	17	14.65	8.08	67
8.0-9.0	19.32	16.64	67	48.57	24.10	7	15.60	11.77	58

A subsample of cacti with heights in the range 6-7 m were selected for comparing green and brown group means in an attempt to factor out the correlation of dbh with height. Within this group, an average rib width was computed for each group. Smaller rib widths may be interpreted as indicating cacti that are more flaccid, or shrunken. The averages are only slightly different; 2.61 cm for green cacti and 2.40 cm for brown. The range of rib widths observed was between a maximum of 3.28 cm and a minimum of 1.72 cm.

Figure A-1. Double histogram comparing distribution of heights of green and brown saguaros in Mortality Plots.

APPENDIX B

LIST OF ATTACHMENTS

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Attachment 1: 7 1/2 minute Quadrangles showing plot locations (rolled in cardboard tube).

Attachment 1A: Tanque Verde Peak Quadrangle

Attachment 1B: Mica Mountain Quadrangle

Attachment 1C: Avra Quadrangle

Attachment 2: Field Guide for locating individual tagged cacti within plots (plot maps showing topography, plot boundaries, and location of tagged cacti, and a list of selected cactus data for each plot, unbound in a box).

Attachment 3: 35mm color transparencies of individual tagged cacti, including a photo of the entire plant from the south and a photo of the south stem near breast height, in three separate albums.

Attachment 3A: Volume 1

Attachment 3B: Volume 2

Attachment 3C: Volume 3

Attachment 4: Raw data, 5 1/4 " floppy disc, DBase III+ format in an envelope.

Attachment 5: Raw data, paper copy with explanation of each variable listed, in a binder.

Attachment 6: Ecological plot maps (45), 5 1/4" floppy discs, AutoCad Release 10 drawing files (.DWG) format, in a box.

Attachment 7: Ecological plot maps (45), paper copies plotted on 11 x 17" paper in 8 colors, rolled in a tube.

Attachment 8: 35 mm photographs of cacti in Mortality Transects, in an album, delivered to Ken Stolte in Tucson, Arizona April 1991.

Attachment 9: Mortality Transect Stem Maps, printed on vellum, rolled in a tube.

Attachment 10: Raw data for Mortality Transects, 5 1/4" floppy disc, with printed explanation, in an envelope.