

A historical summary of saguaro cactus monitoring in Saguaro National Park from 1941-2006

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Saguaro National Park
Tucson, Arizona

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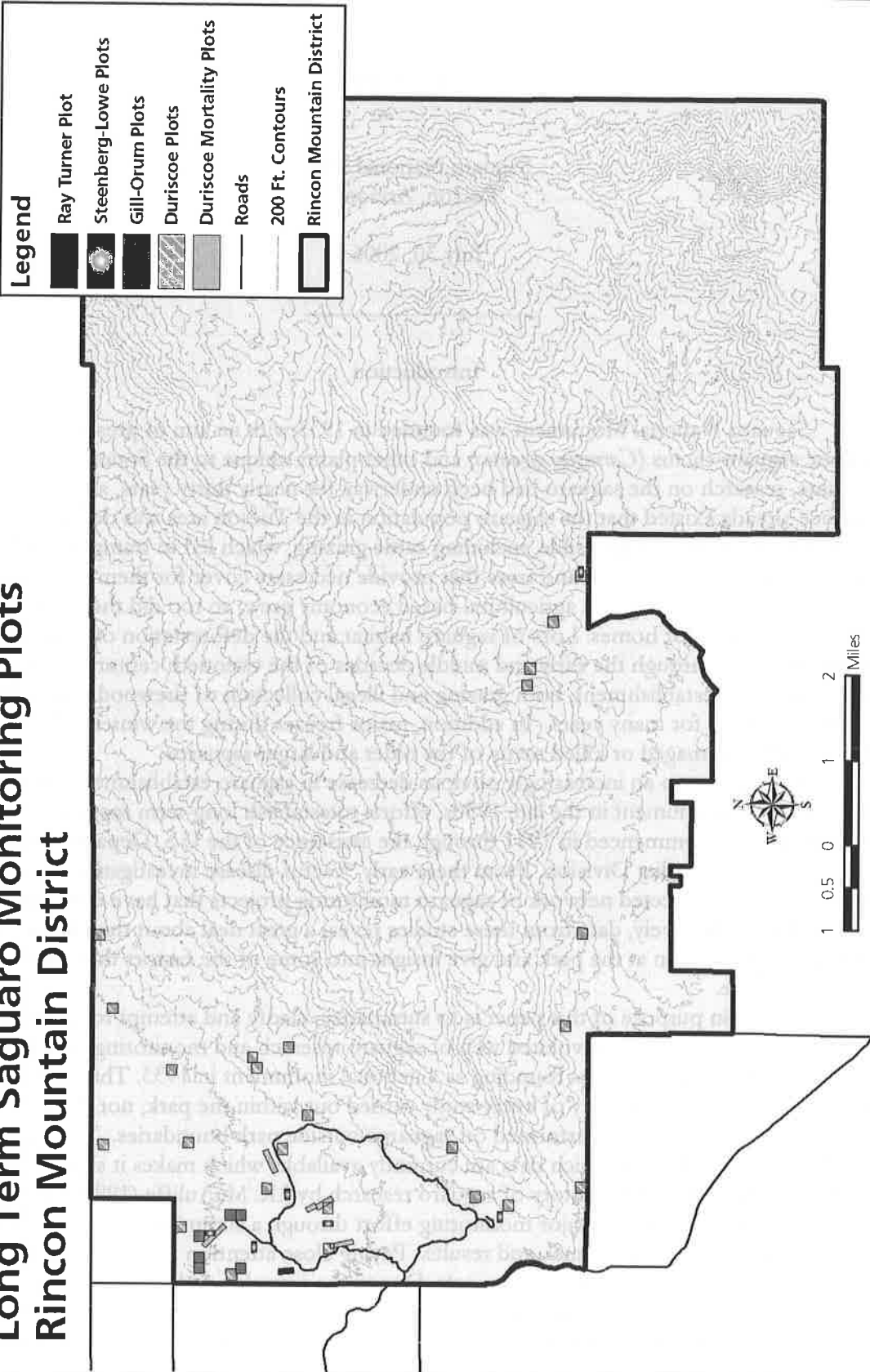
Introduction

Saguaro National Monument was founded in 1933 with an aim to preserve the majestic saguaro cactus (*Carnegiea gigantea*) and other plants unique to the Sonoran Desert. At that time, research on the saguaro had been underway for nearly thirty years, and some evidence already existed that the saguaro population in the Tucson area was declining. Many factors may have been responsible, including cattle grazing, which led to trampling of both young saguaros and the brush and trees that provide necessary cover for them to survive. As Tucson and its mining and agricultural-based economy grew, so too did the need for firewood and land for homes. Loss of saguaro habitat and the deforestation of Tucson-area timber increased through the early and middle decades of the twentieth century. Even after the monument's establishment, both grazing and illegal collection of firewood continued within its borders for many years. In addition, major freezes during the winters of 1937, 1940 and 1941 damaged or killed many of the older and larger saguaros.

In response to an increasingly obvious decrease in saguaro establishment observed throughout the monument in the late 1930s, efforts to establish long-term saguaro monitoring plots commenced in 1941 through the assistance of the U.S. Department of Agriculture's Air Quality Division. From these early "cactus disease investigations" blossomed a multi-faceted network of saguaro monitoring projects that have continued until present day. Collectively, data from these studies reveal a great deal about the fall and rise of the saguaro population at the park and give insight into some of the factors that affect the park's namesake.

The main purpose of this paper is to summarize, clarify and attempt to relate the comprehensive and often convoluted web of saguaro research and monitoring undertaken at Saguaro National Park since its founding as a national monument in 1933. This paper is by no means a complete summary of every study carried out within the park, nor does it highlight much of the work performed on saguaros outside park boundaries. The focus here is on long term studies for which data are currently available, which makes it slightly different from the excellent history of saguaro research by J.R. McAuliffe (1993). My objective is to simplify each major monitoring effort through a summary of its methods, goals, location, history, personnel, and results. Paying close attention to the sources listed will also facilitate future monitoring projects. Due to the complex and often confusing network of plots within the park, appendices 1 and 2 on the following pages illustrate the locations of all plots from each major long-term monitoring project. Each separate project and corresponding plot spread is then discussed in more detail throughout the paper in chronological order.

Long Term Saguaro Monitoring Plots Rincon Mountain District



Produced by Matthew Daniels, GIS Specialist

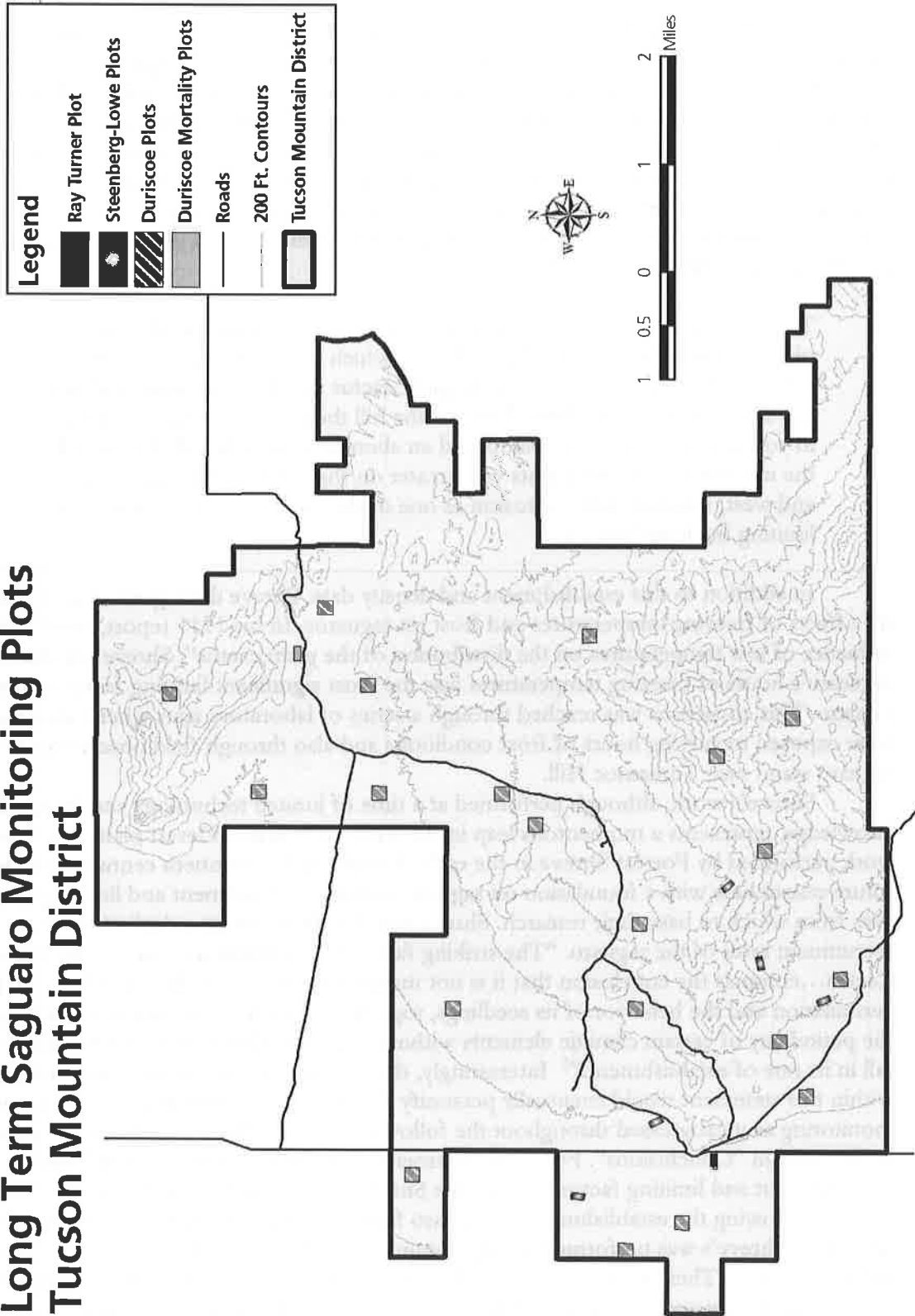
Data Sources: Saguaro National Park, USGS, Ray Turner, Tom Orum, Warren Steenberg, Charles Lowe

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July 2006

Appendix 1: Combined plot locations in Saguaro National Park, Rincon Mountain District (RMD).

Long Term Saguaro Monitoring Plots Tucson Mountain District



Appendix 2: Combined plot locations in Saguaro National Park, Tucson Mountain District (TMD).

The Early Work

In 1909, Forrest Shreve's surveys on the rate of establishment of the saguaro became the first recorded and published monitoring project concerning this unique giant cactus. Shreve's work focused chiefly on the saguaro population on Tumamoc Hill, just east of the Tucson Mountains and the present-day Tucson Mountain District of Saguaro National Park. His surveys focused on growth rates and recruitment. "... (A) n exact census was taken of some 240 giant cacti, which formed the entire population of a portion of the northern slope of Tumamoc Hill, including easterly and westerly slopes. All the unbranched individuals less than 5 m. in height were measured."¹ His findings represent some of the preliminary density, growth and duration data of saguaros.

The individuals under 5 m. in height, which is to say those less than 60 years old, formed 36% of the total population, which would indicate an average life expectancy of 175 years for the giant cactus in this location and habitat. On the steep rocky flanking slopes of the hill there was a noticeable poverty in young and middle-aged plants and an abundance of fallen skeletons, while the number of younger plants was greater on the gentle slopes facing east and west, which points to erosion as one of the most important factors in limiting the length of life.²

In addition to this establishment and density data, Shreve did a great deal of work on the affects of freezing temperatures and frost on saguaros. In his 1911 report, titled "The influence of low temperatures on the distribution of the giant cactus", Shreve concluded that successive hours of freezing temperatures was the most significant limiting factor of the saguaro. This consensus was reached through a series of laboratory tests where saguaros were exposed to varying hours of frost conditions and also through field observations of the saguaro stand near Tumamoc Hill.

Shreve's work, although performed at a time of limited technology and botanical knowledge, represents a momentous leap in the study of Sonoran Desert plant life. The work performed by Forrest Shreve in the early decades of the twentieth century provided future researchers with a foundation on saguaro growth, establishment and limiting factor data from which to base their research. Shreve was also first to note a decline in the recruitment rates of the saguaro. "The striking fall in the establishment rate of the Giant Cactus...compels the conclusion that it is not maintaining itself. A fuller knowledge of its germination and the behavior of its seedlings, together with a more complete knowledge of the periodicity of certain climatic elements within its range will be sure to throw light on the fall in its rate of establishment."³ Interestingly, the profound recommendations embodied within this statement would eventually personify the evolution and maturation of saguaro monitoring as it progressed throughout the following century. More about this progression is discussed in "Conclusions". For more information on Forrest Shreve's initial rate of establishment and limiting factor surveys, see Shreve (1910) and Shreve (1911).

Following the establishment of Saguaro National Monument, a survey similar to that of Forrest Shreve's was performed in the monument in 1939 by Carleton S. Wilder and Judith C. Wilder. Their study was not overly scientific but focused primarily on saguaro population density and recruitment. Their study took place in three separate locations, each representative of the terrain habitats upon which saguaros are found (lower desert floor, upper desert pocket, and foothill). The quadrant locations were not randomly selected.

¹ Shreve, Forrest. "The rate of establishment of the giant cactus." *The Plant World*. Vol. 13, No. 10, 1910. pp. 237

² *ibid.* pp. 237

³ *ibid.* pp. 240

Instead, “The quadrants were selective, however, in the choice of the general area for counting and in consciously tending, once the line was started, to make counts where small saguaros were seen.”⁴

In the “lower desert floor” section, observations found the saguaros to be taller and denser on the average than anywhere else in the park. Observations were also recorded about the relation in occurrence between saguaro cacti and palo-verde, a plant that would later be determined one of the saguaro’s preeminent nurse plants. The location for this portion of the survey is listed as near the public campground, approximately two miles from the north entrance gate in present-day RMD (exact location unknown).

The “upper desert pocket” habitat is listed to be below the Tanque Verde foothills. “The “pocket” is formed by the abrupt Observatory Hill rising about a mile north and west of the curving base of the Tanque Verde mountains.”⁵ Here the saguaros were not observed as being clumped around palo-verde as they had in the lower desert terrain. Instead, mature saguaros stood alone and small saguaros (those less than 6ft in height) were plentiful and located predominately beneath or near palo-verde and other desert scrub.

The “foothill” observations were made at the north end of the Skyline Loop Road where steep slopes transcend to the Tanque Verde ridge. Here was found the greatest abundance of small saguaros (those less than 6ft in height), many of which were growing beneath the granite boulders that composed the rocky slope.

The conclusions of the Wilder study generally complimented those of Shreve’s Tumamoc Hill survey thirty years prior; that the saguaros in the densest location (lower desert floor) were not replacing themselves as efficiently as the populations on the other two test locations. It was the belief of the researchers that “...the number of young plants indicates the possibility of a denser stand of mature trees in the future than exists on these areas at the present time.”⁶ Such results were alarming to park staff in that the esteemed “cactus forest” area of the park was not displaying sufficient levels of recruitment. These discouraging results played a part in fueling panic about saguaro extinction at the monument that would last nearly fifty years. For more information on the 1939 Wilder census survey, see Wilder and Wilder (1939).

The plot surveys: 1941-2006 I: USDA cactus disease investigations

Long-term monitoring of saguaros at Saguaro National Monument began in 1941 at the request of the Department of Agriculture’s Bureau of Plant Industry and their insistence with performing cactus disease investigations following severe freezes in the winters of 1937, 1940 and 1941. For this experimental survey, a portion of the northwest corner (S17, R16E, T14S) of Saguaro National Monument (east) was chosen. This so-called “Section 17” was divided into northern and southern halves, each of which covered approximately 320 acres, for a total test area of 640 acres. The objective of the USDA’s project was to test the effectiveness of sanitation measures on the deterrence of bacterial necrosis (epidermal rot), which had become a widespread phenomenon by the late nineteen thirties. The plan called for all infected saguaros and saguaro limbs from the southern “half” to be removed, burned and buried while the “...data from the north half [was to] serve as a check or means of judging the effectiveness of the sanitation work.”⁷ The progress of each half was then to be checked

⁴ Wilder, C.S., and J.C. Wilder. “Re-establishment of saguaros.” Southwestern Monuments Special Report, number 26. National Park Service, pp. 153-160. 1939. pp. 155

⁵ *ibid.* pp. 155

⁶ *ibid.* pp. 158

⁷ Gill, L.S. and P.C. Lightle. “Cactus disease investigations: an outline of objectives, plans and accomplishments on project j-2-8.” 1942. pp. 1

annually for at least the next five years. The map on the following page, Figure 1, illustrates the 640-acre USDA test area. Individual saguaros, which were mapped using a detailed aerial photo (a copy of this map is available at the Western Archeological Conservation Center and a digital copy is on the park's server) are characterized by a single black dot.

Each "half" was divided into 10-acre quadrants and each quadrant was subsequently labeled. "The staking [for the southern half] was begun in September, 1941 and completed in January 1942; 12, 968 living saguaros were thus identified."⁸ Information on saguaro height, mechanical injuries and disease condition was gathered at the time of staking. Similar information was gathered for the northern "half" from February through March, 1942. Infected plants that warranted removal were felled and removed from February 16 to 20, 1942, with over 313 plants being removed.⁹ Sanitation work was executed simultaneously. "Cacti marked for removal were felled, bucked, loaded on trucks, and dumped into one of four pits which had been previously excavated on the area. The cacti in the pits were fumigated and then immediately covered with at least a foot of earth."¹⁰ For more

⁸ *ibid.* pp. 2

⁹ *ibid.* pp. 3-4

¹⁰ *ibid.* pp. 3

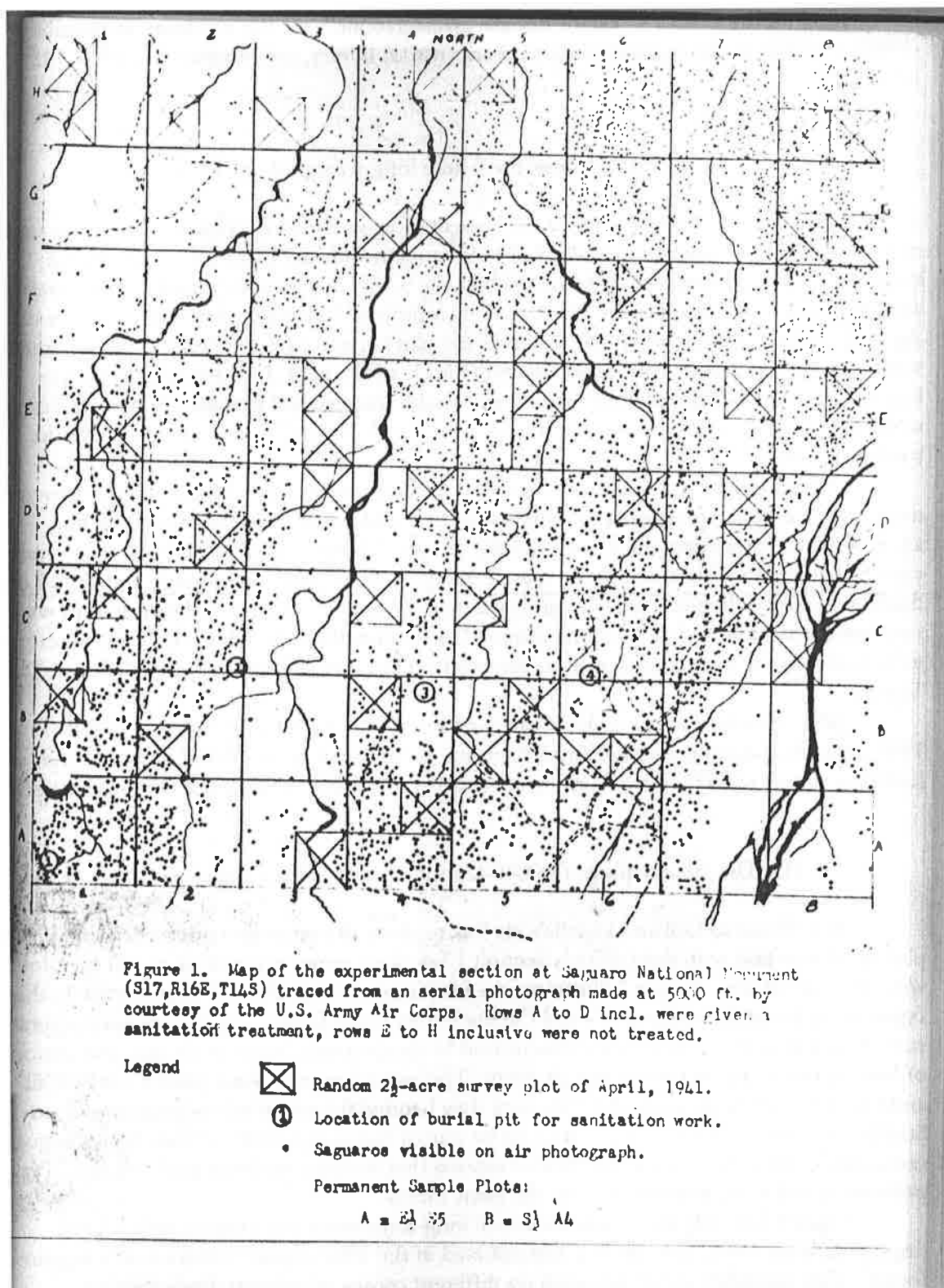


Figure 1: MAP OF THE USDA'S EXPERIMENTAL TEST AREA, "SECTION 17". Gill, L.S. and P.C. Lightle. "Cactus disease investigations: an outline of objectives, plans and accomplishments on project j-2-8." 1942.

information on the USDA's "cactus disease investigations", see the summary in Steenberg (1986), available at the Saguaro National Park (RMD) library, call number QK 495.C115 U72.

II: Gill and Lightle: the 5-acre long-term plots of 1941

The establishment of the first permanent plots intended for repeated and long-term monitoring also occurred in the fall of 1941 in tandem with the USDA's cactus disease investigations. The plots were established by Lake S. Gill and Paul C. Lightle as they were simultaneously spearheading the separate USDA project. Their plot monitoring began in April 1941 and consisted of six (6) 5-acre (2-ha) plots in and near the "cactus forest" area in what is today the Rincon Mountain District (RMD) of the park. Information on saguaro height, age (estimate) population density, and health (mechanical injuries, disease condition) were recorded. These plots were numbered 41A-F and marked by a wooden stake in the southwest corner.¹¹

The intent of this survey was to learn to recognize the developing stages of bacterial necrosis, observe the progress and behavior of bacterial lesions and the cactus' healing abilities, and to determine the cause(s) of the disease.¹² Interestingly, after 1941, thirty-four years would pass before these plots were resurveyed. When W.F. Steenbergh and C.H. Lowe finally resurveyed the plots in 1975, critical data on growth, mortality and recruitment was recovered from a period of time that spanned more than three decades. These plots, referred to hereafter as the 5-acre plots, were resurveyed yet again in 2002 by C.S. Funicelli and D.S. Turner.

Little information is known about the precise data recoded by Gill and Lightle in 1941 other than rudimentary height, density and recruitment figures listed in Steenbergh and Lowe's resurvey in 1975. Data from these plots is recorded in Steenbergh (1986 and 1986a).

III: The 10-acre plots: the Gill-Lightle/Alcorn/Orum ongoing survey

In addition to Gill and Lightle's six 5-acre plots, the same two researchers established plots in association with the USDA's Section 17 saguaro removal experiment. These plots were 10-acres in size. Figure 2 illustrates the locations of these plots. For reference in this figure, note the park headquarters and Cactus Forest Loop Drive. This monitoring program was/is unique in that it has been characterized by nearly annual surveys on the progression of bacterial necrosis on these same six plots. The annual surveys were carried out by Gill and Lightle up through the mid-1950s until they handed the reigns of the project over to Stanley M. Alcorn. Alcorn would go on to be one of the most prolific and dedicated saguaro researchers, publishing a great number of reports that focused predominantly on the pollination and germination nature of the giant cactus.

One of S.M. Alcorn's more elaborate long-term studies ran from January 1942 through January 1961. This study is summarized in the 1962 report "Attrition of a saguaro forest". This mortality survey reported on different causes of saguaro death with an emphasis on bacterial necrosis. Alcorn's conclusions were unfortunately (and unsurprisingly) grim. Not only had bacterial necrosis accounted for 29% of saguaro mortality (over the twenty-year survey), but the combined effects of grazing (not outlawed on park property until 1958) and wind made soil erosion enough of a problem that it seriously impeded the growth of seedlings. These findings led to Alcorn's 1962 conclusion that "...the sparsity of

¹¹ *ibid.* pp. 5

¹² *ibid.* pp. 17

juvenile plants indicates that this saguaro forest is failing to maintain an adequate rate of natural repopulation...the continual attrition of this forest by BN (bacterial necrosis) and wind is, however, eroding the base for repopulation.”¹³ For more information on this long-term mortality survey, see Alcorn and May (1962). In 1979, Alcorn passed the monitoring on the six 10-acre plots to the third generation researcher, Tom Orum, a former Alcorn graduate student who with his partner Nancy Fergusen have continued to monitor these plots through 2006. With the change in leadership has also come a change in focus. Whereas earlier years of the survey tended to focus on mortality and the progression of bacterial necrosis, the latter years of Alcorn’s surveys and most recently up through Tom Orum’s resurveys there has been a move in focus—a reversion if you will—towards insight on saguaro density and recruitment.

As previously stated, the Gill-Lightle/Alcorn/Orum 10-acre plot surveys are unique due to their consistency; the researches have resurveyed the same six plots within the original USDA test area in RMD from 1941/42. “Essentially each year since 1942 all saguaros in six study plots in Section 17 have been visited and their condition, including mortality, noted. In addition, a search is made for young saguaros, their location is noted on a map, and their height measured. The heights of all saguaros under six feet tall are measured each year. Heights of taller saguaros are estimated in 6 foot height classes and, periodically, are estimated using a clinometer.”¹⁴

This consistent set of surveys represents the longest ongoing saguaro monitoring effort in the park. And, although the methods have remained relatively consistent over the past sixty years, survey focus and results have changed significantly. Whereas earlier findings from the Gill and Lightle era exhibit a steady and alarming decrease in the saguaro population, a recent influx of growth and recruitment over the past twenty years (chiefly since Tom Orum has spearheaded the project) has largely diffused concern for the saguaro’s momentary future. More information on the ongoing Gill-Lightle/Alcorn/Orum mortality survey can be found in Orum (1991).

IV. Continued work on portions of the USDA experimental test area: 1944-1967

While focusing on their six 10-acre plots, Gill and Lightle also continued general research and follow-up to their large-scale experiment in the USDA test area. A February 1944 report on the progress of treated saguaros from the 1941/42 sanitation procedures led to encouraging and intriguing results. From the time the study began in 1941 until the resurvey in 1943, some 587 additional saguaros had died on the entire 640-acre test area. Of these, only 187 (32%) were on the southern (sanitized) section, whereas the remaining 400 (68%) were on the untreated northern half.¹⁵ In addition, it was discovered that the bacteria was presumed to be transmitted through a certain moth larvae and that the felling and burial of diseased saguaros was unreasonable. Instead, studies showed that many lesions could be healed if simply removed from the cacti, thereby allowing the plant’s natural healing process to take over.

Further data from the 1943 survey led to Gill and Lightle’s 1946 resurvey and publication on mortality. They discovered that overall mortality seemed to be decreasing since the study began five years prior. However, due to the slow growth and regeneration nature of saguaros it was unclear whether or not this decrease could be attributed in part to

¹³ Alcorn, S.M, and C. May. “Attrition of a saguaro forest.” *Plant Disease Reporter* 46, no. 3: 1962. pp. 158

¹⁴ Orum, T.V. and S.M. Alcorn. “Report on the long term saguaro mortality study, Saguaro National Monument, Rincon mountain unit, section 17.” 1991. pp. 1

¹⁵ Mielke, James L. “Summary of results of control experiments on saguaro disease, Saguaro National Monument. July 1944. pp. 1

the sanitation efforts of 1941/42. This uncertainty, combined with the brevity of the survey, led to the absence of any long-term mortality predictions. Gill resurveyed the area again in 1951 for a ten-year reconnaissance and concluded only that stem rot was determined to be positively associated with cactus height (and presumably age). This, combined with the general absence of stem rot on younger specimens (those less than 12 feet in height) led to the consensus that bacterial necrosis was not as threatening a disease as once perceived and that it was in no position to obliterate the saguaro as a species. More information on these two surveys as well as their results and findings can be found in Steenbergh (1986), as well as Gill and Lightle (1946) and Gill (1951).

Additionally, Alice M. Boyle did a survey in 1945 that looked deeper into the causes and spread of bacterial necrosis. Her search focused on how the disease was spread through the larvae of a common moth, *Cactobrosis fernaldialis*, whose young carry the bacterium and infect the cactus.

Finally, another one of Alcorn's studies, led by Ray Turner, ran for ten years, from July 1957 to the same month in 1967. This study took place on the USDA test area but encompassed more than the aforementioned six 10-acre plots. This survey focused on the survival of young transplanted saguaros. "Saguaros...were transplanted into 80 plots within a 4-ha tract on level terrain at the Saguaro National Monument on July 8-10, 1957."¹⁶ Sixteen treatment combinations were surveyed—some plots caged to deter rodents, some plots watered, some shaded. More than 1,800 plants were planted, 1,600 of which were less than 5cm in height. The results from the plots varied significantly. All plants in the unshaded and uncaged plots died or vanished within months of planting. Survival in the caged plots, although not rodent-proof, was more than twice as high as the uncaged specimens.

The study changed a bit in 1958 and 1963 when the researchers added the element of rodent-proof cages (cage edges buried 15cm underground) as well as the inclusion of plots on varying altitudes. The cages buried at a depth of 15cm completely inhibited rodent access yet interestingly these sites were synonymous with the highest rate of mortality by insects. Results from the varying-altitude plots were inconclusive other than average mortality was highest in the "mountain plot" and lowest in the "lowland plot". For more information on this 10-year mortality and transplant survey, see Turner et al. (1969).

¹⁶ Turner, R.M., S.M. Alcorn and G. Olin. "Mortality of transplanted saguaro seedlings." Ecology 50, No 5, 1969. pp. 837

V: R. M. Turner and J.R. Hastings: positive results from two 9.2-acre plots

In the 1960s, another large-scale effort for long-term saguaro monitoring was established by researchers R.M. Turner and J.R. Hastings, authors of the well-received book on long-term vegetation change, "The Changing Mile." Turner and Hastings established a set of ten (10) 400 x 1000 ft (9.2 acre) plots throughout southern Arizona and Sonora, Mexico. Of these ten, one was located in each of the two districts of Saguaro National Monument. The plots were reexamined five times up until 1989¹⁷, and have recently been remapped and re-surveyed in 2005-2006.

The plots have been monitored at intervals averaging about 10 years in which data on mortality, growth, and recruitment have been recorded.¹⁸ Additionally, one of the important findings of these plot studies is a marked increase of new recruitment that has occurred during the past 20 years within the area of the original saguaro forest at RMD...this abundance of young cacti represents a "phenomenal population surge" and has the potential for becoming a new saguaro forest in the next century.¹⁹

Turner and Hastings also discovered that although mortality in the RMD plot was significantly higher than in its TMD counterpart, recruitment in RMD was significantly higher than in the denser, healthier TMD plot. This suggested that the widespread fear of saguaro attrition and extinction in Saguaro National Monument was unfounded. The "cactus forest" area of RMD was in fact not "dying out". Rather, the old, mature cacti were dying off due to natural causes. Turner and Hastings felt that the fear of saguaro extinction had become established simply because not enough consideration was given to life cycles, i.e. recruitment. In the latter stages of the Turner survey, "attrition" had given way to an unprecedented surge in recruitment such that by 1989, 76% of the RMD plot population had been established since the study began in the early 1960s.²⁰ Conversely, the "younger" population in TMD is slowing in recruitment levels and is merely further behind on nature's due course and will thus be characterized by higher mortality in the coming decades. In short, the general conclusion reached by Turner and Hastings with the completion of their survey was that nature is merely taking her course on the saguaro populations of the monument.

It is now generally believed that if present trends continue in fifty to one hundred years the now majestic saguaro stands in TMD will resemble present day RMD, and that the now meager "cactus forest" will likely return to its 1940s splendor. Do recall that these positive conclusions were not reached until the early 1990s and that until this time the Turner-Hastings surveys reached similar results as did most other monitoring surveys since the time of Forrest Shreve; that the saguaro population was not reestablishing itself sufficiently.

Aside from quelling the extinction phenomena, Turner & Hastings' survey also played a significant role in advancing the effects of prolonged drought as one of the principal limiting factors of saguaro growth. According to their survey, amidst the 20-year

¹⁷ Turner, R.M. "Long-term saguaro population studies at Saguaro National Monument." In Proceedings of the Symposium on Research in Saguaro National Monument." 1992. pp. 3

¹⁸ McAuliffe, Joseph R. "Case study of research, monitoring, and management programs associated with the saguaro cactus (*Carnegiea gigantea*) at saguaro national monument, Arizona" USDI, 1993. pp. 20-21

¹⁹ *ibid.* pp. 21

²⁰ Turner, R.M. pp. 3

“population surge” stood a single year of variance, 1976, which was defined by extremely low levels of recruitment. Interestingly—and not coincidentally—this year also corresponds with one of the severest recorded droughts in the Tucson area since the beginning of the twentieth century.²¹ As a result this survey not only presented some of the initial encouraging data that led to the realization of the saguaro’s turnaround, but it also provided further insight into the giant cactus’ limiting factors. For more information on other limiting factor studies of saguaros see McAuliffe (1993). Additionally, a full report of R.M. Turner’s results from the TMD and RMD plots can be found in Turner (1992).

VI: The 5-acre plots resurveyed by Steenbergh and Lowe: the 34-year resurvey

Among the major contributors to modern knowledge of Saguaro cacti were NPS researcher Warren F. Steenbergh and the eminent ecologist Charles H. Lowe from the University of Arizona. Steenbergh and Lowe did a number of studies in Saguaro National Park and Organ Pipe National Monument and published their results in three parts. In 1971 the two researchers established a single 2-ha (100 x 200m) plot (labeled 71G) on the lower bajada adjacent to Kinney Road in TMD in which all living saguaros were tagged and recorded in November 1971 and surveyed annually through the establishment of four additional 2-ha plots in 1975.²² Also in 1975 the two researchers stumbled upon information that led to the relocation of Gill and Lightle’s original six 5-acre plots from 1941 in RMD. Of these six only five were reestablished and resurveyed, plots 41A-F with the exception of plot 41E. Additionally, a single 2-ha (100 x 200m) plot (labeled 75M) was established in 1975 approximately 1 mile east of the Madrona ranger station to provide long-term data on saguaros growing on south-facing slopes.²³

With their studies Steenbergh and Lowe kicked off a new era of long-term saguaro monitoring. The data retrieved from these now eleven (11) plots, primarily height and density information, documented a 34-year period of change. Overall results from this resurvey were consistent with other density conclusions from the time; that the saguaro’s rate of establishment was diminishing. More information and data from this 1975 resurvey by Steenbergh and Lowe can be found in Steenbergh (1986) and Steenbergh Lowe (1983). Following the 1975 resurvey the eleven long-term plots would not be studied again for another twenty-seven years. However, Steenberg and Lowe left behind documentation of their work, and the plots were re-surveyed in 2002 by Dale S. Turner and Carianne S. Funicelli. Figures 3 and 4 on the following page illustrate the locations of the eleven long-term plots from the Steenbergh and Lowe 1975 establishment/resurvey. Plots 41A-F represent the original six 5-acre Gill and Lightle plots from 1941. Note that plot 41E was not relocated.

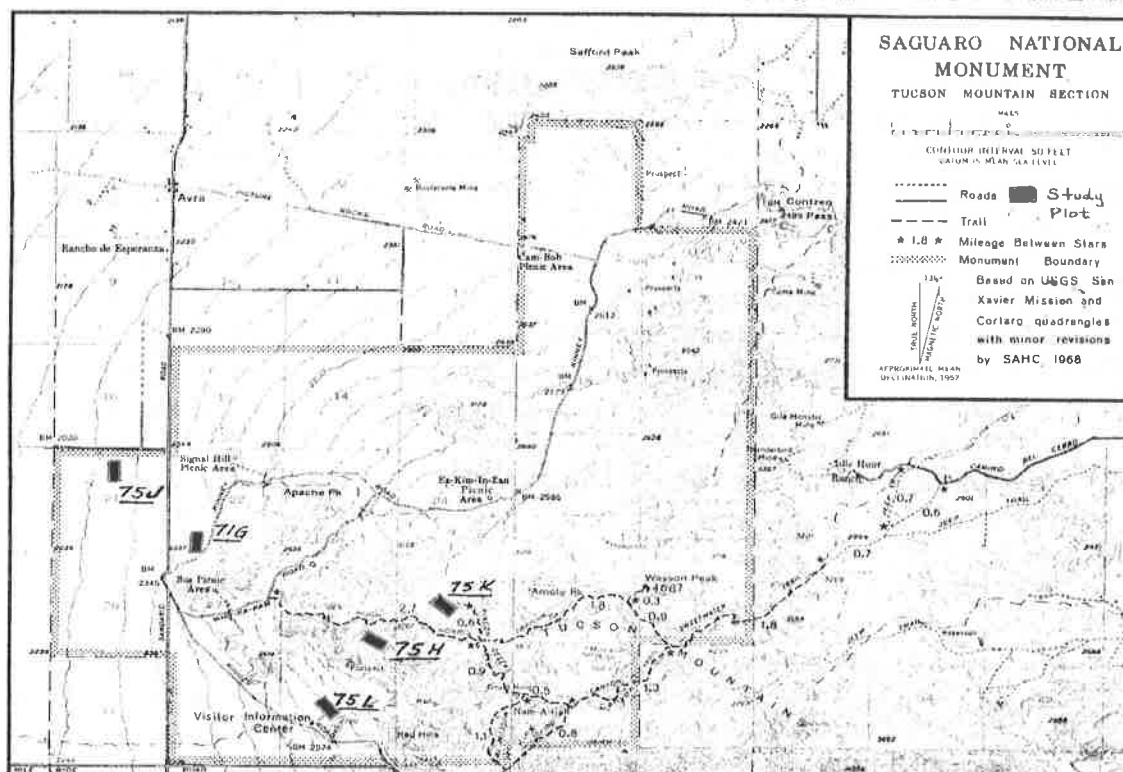
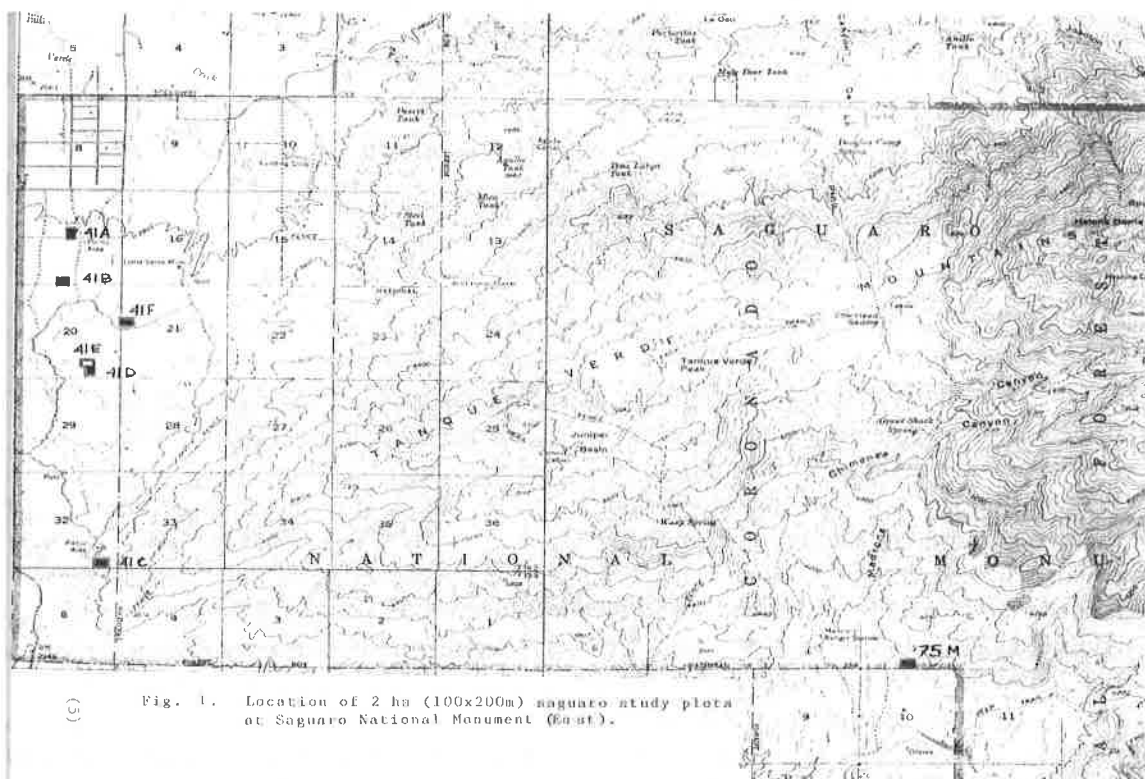
VII: D.M. Duriscoe and S.L. Graban: the new monitoring era and the 1990 census

The next major step and new split in long-term saguaro monitoring came in 1988/89 when researchers Dan. M. Duriscoe and Sandra L. Graban established a completely new set of forty-five (45) 4-ha plots throughout both districts of the monument. This project was carried out at the request of the Air Quality Division (AQD) due to the

²¹ *ibid.* pp. 21

²² Alcorn, S.M., and C. May. “Attrition of a saguaro forest.” *Plant Disease Reporter* 46, no. 3: 1962. pp. 158.

²³ Steenbergh, W. F. “Saguaro population study plots at saguaro national monument: 1941-1975.” 1986



Figures 3 and 4: THE ORIGINAL GILL & LIGHTLE SIX 5-ACRE PLOTS AS WELL AS THE 1971/75 INCLUSION OF STEENBERGH AND LOWE'S PLOTS. Steenbergh, W. F. "Saguaro population study plots at saguaro national monument: 1941-1975." 1986. *Note how plot 41E was not relocated as well as the locations of plots 75M and 71G.*

perception that epidermal browning—a brown scale on the skin of the plant—was positively associated with saguaro population declines. This perception was due in part to a 1987 AQD report that concluded that epidermal browning was a widespread phenomenon and in greatest concentration in areas of high saguaro mortality. Moreover, this report was released and the study commenced years before R. Turner published his census results from his TMD and RMD plots.

Of the forty-five Duriscoe-Graban plots, twenty-five are located in RMD and the remaining twenty are in TMD. The plots were selected by first dividing up the saguaro-type environment into forty-five quadrants, each containing approximately 1.5 square kilometers of “saguaro-type” habitat. From each of these quadrants was then chosen one of the 4-ha plots. This method provided for a more even and arbitrary spread of plot locations throughout both districts that were also representative of the different altitude levels and terrain habitats in which saguaros are found. The plots were two-tiered; each being 200 x 200m (4-ha) square and containing a smaller, 10 x 10m ecological plot from which precise data would be recorded on not only saguaros but also all vegetation species present. The focus of the study was to “...identify the extent of epidermal browning on giant saguaro cacti and to initiate long-term studies of population dynamics.”²⁴

The survey’s objective was to “...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.”²⁵

In each 4-ha plot, 30 saguaros of 2m and taller were selected for long-term monitoring, while all saguaros of 10cm and taller were marked and tallied. Within each 4-ha plot the smaller “ecological plots” of 10 x 10m were established for a more detailed survey of resident plant species. Each of these “ecological plots” contained one of the selected saguaros at its center. Plots were mapped via compass and the selected saguaros were mapped, photographed and measured. All hand-drawn field maps were digitized using the AutoCAD software.²⁶ Additionally, Duriscoe and Graban concluded that

...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...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.²⁷

The establishment of these six mortality plots in both districts was due in part to the fact that the mature saguaro population in the “cactus forest” area was proven to be in decline. Findings were as expected; that mortality of the “browner” specimens was significantly higher than the less infected, “greener” specimens. More information on the Duriscoe and Graban mortality transects can be found in Appendix A of Duriscoe and Graban (1991).

²⁴ Duriscoe, D. M., and S.L. Graban. “Epidermal browning and population structure of giant saguaro cactus (*Carnegiea gigantea*) in saguaro national monument, Arizona.” Eridanus Research Associates: California, 1991. pp. 2

²⁵ *ibid.* pp. 3

²⁶ *ibid.* pp. 8-10

²⁷ *ibid.* pp. 31

The general findings of the study were that the severity of epidermal browning was positively associated with height and negatively associated with spine retention and that the condition tended to be more severe on south-facing slopes, suggesting the process is worsened or expedited by more direct sunlight. Another interesting find, and one that reinforced R. Turner's 1989 findings, was that 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 0.5m in height in many plots."²⁸ This information helped lead researchers in the mid 1990s to conclude that the saguaro population in Saguaro National Monument was making a surprising comeback. Figure 6 illustrates the locations of the 45 monitoring plots; the very same plots that would eventually be resurveyed ten years later in 2000.

As previously stated, the Duriscoe-Graban survey of 1990 set the stage for the new era of long-term saguaro plot monitoring at Saguaro National Monument. Although the first recognized plots intended for long-term monitoring were the six 5-acre plots established by Gill and Lightle in 1941, research on those plots went on a thirty-four year hiatus as much information on the research area(s) was discarded or lost. And, although these original plots were re-surveyed by Steenbergh and Lowe in 1975 and again by Turner and Funicelli in 2002, the level of consistency, data analysis and ease of repeatability does not compare to the Duriscoe study of 1990.

²⁸ *ibid.* pp. 2

VIII: C.S. Funicelli and D.S. Turner resurvey of the 45 Duriscoe plots: the 2000 census

The first resurvey of the 45 "Duriscoe" plots was completed in 2000-2001 by researchers Dale S. Turner and Carianne S. Funicelli. The study, sponsored in part by Canon Inc., made area headlines and was broadcasted on national television through a series of TV and satellite interviews (recordings of these interviews and news coverage of the study are available at the Western Archaeological Conservation Center (WACC) in Tucson, Arizona). Turner and Funicelli in effect turned in two separate reports. One focuses on the larger, 200 x 200m plots and is titled "Ten-Year Resurvey of Epidermal Browning and Population Structures of Saguaro Cactus (*Carnegiea gigantea*) in Saguaro National Park, Arizona." A separate report focusing on the smaller 10 x 10m plots is titled "Long-Term Vegetation Monitoring at Saguaro National Park: a Decade of Change." The two reports were published four months apart, in August and November 2000.

The Turner-Funicelli resurvey in 2000 used the Duriscoe-Graban study as a template for gathering information. In doing so, vital data was recovered that may not have had the resurvey not followed its forbearer so closely. The protocol and structure of the studies are in effect identical except for a slight advancement in the technology used. Location of plots and specific saguaros by way of compass and grid orientation gave way to GPS coordinates, and digitized backups of plot maps on 5 ¼ inch floppy disks gave way to CD-ROMs. Still, the principle remained the same. Individual saguaros tagged in 1990 were relocated, studied and re-photographed. Original plots were relocated and re-photographed, and precise information on vegetation growing within each 10 x 10m ecological plot was recalculated. The end result was an astonishing collection of previously undocumented data on saguaro growth, cohabitation, density and recruitment.

In addition, the 2000 follow-up survey represents a critical ten (10) year period of change. The 2000 resurvey came at a time following back-to-back-to-back encouraging saguaro census results from R. Turner, T. Orum and D. Duriscoe. Fortunately, Funicelli and Turner's survey in 2000 only strengthened these results and helped lead to a more positive outlook on the saguaro's future. A similar re-survey is scheduled to be completed again in 2010. For more information on the 2000-01 Funicelli and Turner resurvey(s) of the forty-five (45) plots from the 1990 Duriscoe study, see Turner and Funicelli (2000) and Funicelli et al. (2000).

IX: The 5-acre plots resurveyed by Funicelli and Turner: the 27-year resurvey

The most recent effort of long-term saguaro monitoring was completed by Funicelli and Turner in 2002. This re-survey, titled "Relocation and restudy of historic saguaro plots at Saguaro National Park" represents a second re-survey of the eleven Steenbergh and Lowe plots from 1971 and 1975, including the original five (5) [formerly six; recall plot 41E was not relocated] 2-ha plots established by Gill and Lightle in 1941. Results from this 2002 resurvey differed greatly from Steenbergh and Lowe's assessment. The 1975 census data turned up grim results on saguaro mortality and recruitment. Such results, owed largely to killer frosts and the lasting effects of grazing, led chiefly to the widespread fear that the saguaro population in the monument was in danger of dying off. The 2002 Funicelli and Turner resurvey reached similar results as their 2000 resurvey of the Duriscoe-Graban plots; that saguaro recruitment was on the rise. This consensus was reached due to the relatively high density of young saguaros (those less than 6ft in height) discovered throughout the relocated plots.

The plots were located by using a hand-drawn map from W.F. Steenbergh and were studied from February 2001 through May 2002. Saguaro density and recruitment data was

collected and compared to the 1941 and 1975 studies to attain the encouraging results. "The current project provides a unique opportunity to put the results of Turner and Funicelli (2000) into a longer ecological time frame through the comparison of these data with data from the 11 plots that were established in 1941, 1971 and 1975 by Gill and Lightle (1942) and Steenbergh and Lowe (1983)."²⁹ The 2002 Funicelli and Turner resurvey took a significant step in organizing this specific set of plots for future study. The final report contains plot locations via GPS coordinates as well as the aforementioned data in comparison to the 1941 and 1975 results. As of yet there is no scheduled resurvey for these plots. For more information on the 2002 Funicelli and Turner resurvey, see Funicelli and Turner (2002).

Conclusions

The future of both the saguaro cactus and the monitoring efforts to study it appear bright. A great deal has changed regarding the methodology and conclusions of the surveys over the years. Even more intriguing is how the focus of saguaro monitoring has changed. It is here that I believe the history of saguaro monitoring in Saguaro National Park can be divided into three categories. 1) *The initial findings, i.e. the "state of saguaros"*; 2) *identifying the agent of decline (and gaining a better understanding of the saguaro itself) and implementing a cure*; 3) *the second round of census results and the population surge*.

The first category is synonymous with the Shreve and Wilder surveys that focused on saguaro population density, establishment and recruitment. Their grim conclusions largely prompted the second category. The initial "cactus disease investigations" focused predominantly on the cause(s), spread and cure of bacterial necrosis and epidermal rot. Other studies centered on climactic (frost) and humanistic (grazing, deforestation and air quality) factors. Also included in the second category are the Alcorn studies on the science of the saguaro itself—it's respiratory and circulatory systems, germination tendencies, cell structure and root system. This second category is, if you recall from earlier, a realization of Forrest Shreve's 1910 mentioning that a "fuller knowledge" of the saguaro must ensue. The third and final category has been characterized by a reversion to the census. The past decade has seen a greater focus on preserving the saguaro and quelling the once-proven fact that the saguaro population was dwindling. Encouraging census results gathered by R. Turner, J.R. Hastings, D. Duriscoe, C.S. Funicelli and D. Turner have all helped turn the tide on the realization of the giant cactus' future. These categories are by no means exclusive or rigid, but more general in nature. Each is distinct, yet all three are interwoven in that the latter was brought about by the former.

Thus, despite an immense change of methodology the overriding purpose is clear; to scrutinize and study the saguaro in its respective habitats to better understand the nature of the plant and therefore provide proper and successful measures of preservation for its future. Such perpetuation is, after all, the inherent ambition of the National Park Service.

-Note-

It is important to realize that this paper highlights only long-term saguaro plot monitoring surveys completed within the confines of Saguaro National Monument (Park), as recognized by the National Park Service and contained within its archives. The dates this paper covers are roughly 1941 through present day. Additionally, it is important to know that independent and short-term studies were being done on the saguaro cactus and other

²⁹ Funicelli, C.S., and D.S. Turner. "Relocation and restudy of historic saguaro plots at saguaro national park." 2002. pp. 2

forms of life in and near the present-day borders of Saguaro National Park since the dawn of the twentieth century. This paper by no means covers every one of these surveys. Aside from the researchers and scientists mentioned herein, many short-term and periodic surveys were completed on saguaros by such individuals as W.V. Turnage, A.L. Hinckley, W.A. Niering, W.T. McDonough, E.E. Snyder, C. Steelink, W.H. Earle, L. Benson, D.C. Bertelsen and the list continues. Current work on saguaros owes much of its foundation to these and other individuals for their work and dedication. These lesser-known but no less significant studies ranged from the carbon dioxide exchange of saguaros, to determinants of growth, to the characteristics of saguaro tissue fluids. For more information on these comprehensive surveys see the literature-cited pages of any of the three installments of Steenbergh and Lowe's "Ecology of the Saguaro" series or browse sources in the NRBIB-SAGU master file.

Saguaro National Park has been making a great effort in the past decade to re-locate original plots and data, map plots, digitize the data and preserve the original work, and to use this work in developing long-term monitoring at the park. The goal is that these data can be available for future researchers and managers so that Saguaro National Park can learn from the good work of the past to better understand its resources for making good decisions in the future. Much of the data for this "research atlas" project, preserved with great care by generations of researchers, is now in digital format in Saguaro National Park in the location n/gps/gis-work/mattworking/saguaro data.

The work represented in this paper was supported by the Western National Parks Association and the National Park Service. The park is very grateful for the many researchers who have done work at the park over the years and whose work is cited in this report.

An electronic copy of this report as well as the included maps and diagrams are available on the SAGU network under <N:\GPS\SwannProjects\Saguaro Monitoring Project Report 2006>



The following diagram loosely illustrates the relation between saguaro monitoring surveys in Saguaro National Monument/Park from 1941-2006.

Forrest Shreve, 1910: Tumamoc
Hill surveys on saguaro establishment and
affects of freezing temperatures.

USDA "cactus disease investigations."
640-acre section comprising "Section 17"
of present-day RMD, 1941



Establishment and annual resurveys of
the same six 10-acre plots by Gill
& Lightle. Various other surveys on
the USDA test area were ongoing as well.



S. M. Alcorn takes over operations on the six
10-acre plots in the late fifties. He also conducts
surveys throughout the USDA test site



T. Orum takes over operations on the
six 10-acre plots. He conducts annual
resurveys up through 2005



Turner and Hastings' establishment of ten
9.2-acre regional plots, two of which are
located on park land—one in each district.
Plots are examined from 1961-1989.



Duriscoe and Graban 1990 survey of 45
newly established long-term plots



Funicelli and Turner 2000 resurvey of
The 45 Duriscoe plots.



Future resurvey planned for 2010

Six 5-acre plots established by Gill &
Lightle in 1941 intended for long-term
monitoring. These plots were not

surveyed for 34 years, until 1975



Resurvey of the six 5-acre plots by
Steenbergh and Lowe in 1975.
Only five (5) plots relocated in RMD.

Two (2) additional 2-ha plots
(71G and 75M) established in TMD
and RMD, respectively. These combined
with four additional plots in TMD to

make a total of eleven (11) plots.



Eleven plots resurveyed in 2002 by
Funicelli and Turner. Encouraging results
obtained and study properly organized for
future resurvey.

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**Note: All sources except [Steenbergh, Warren F. "USDA bureau of plant industry, cactus disease investigations: reports and related correspondence, 1941-1951."] are available in NRBIB-SAGU master file, filed alphabetically by author. This other source is located in the SAGU-RMD library. Call number QK 495.C115 U72.*

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