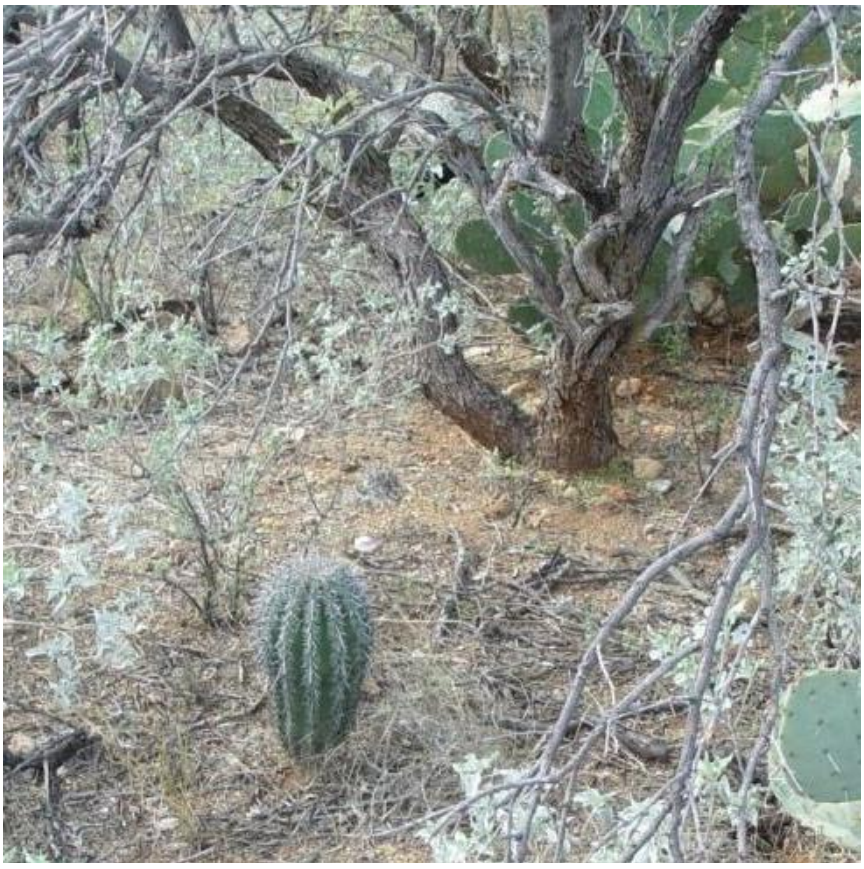
Three Decades of Ecological Change: the 2020 Saguaro Census

Part II: Changes in the Plant Community

Report to Western National Park Association, Part II of Projects #19-06 and #20-09



Saguaro and velvet mesquite "nurse tree" in Rincon Mountain District, Saguaro National Park

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Emily Fule, Dan Beckman, and Don E. Swann

Saguaro National Park
3693 South Old Spanish Trail
Tucson, Arizona 85730-5601

Executive Summary

An important part of the Saguaro Census in Saguaro National Park is the repeated surveys of 10 x 10 m perennial plant monitoring subplots that are co-located within 45 larger saguaro plots. The purpose of this part of the Census, the park's monitoring program for saguaros conducted every 10 years since 1990, is to document changes in the plant community associated with saguaros. During each survey we record all plants on each subplot and map their cover area. Although the 2020 Saguaro Census ended early due to the Covid-19 pandemic, we were able to complete surveys of both the saguaro plots (summarized in our Phase I report) and the smaller subplots.

The 2010 summary reported that the total number of plant and vegetative cover area in the park had both increased since 1990, and our 2020 results largely fit within these trends. However, there is variance among different types ("lifeforms") of plants. Some lifeforms have increased dramatically: for example, the number and cover of succulents and cacti in 2020 were more than 3 times what they were in 1990. On the other hand, trees have declined in both districts for 20 years.

Within this longer-term trend of increasing plants in the past 30 years, the 2020 surveys also revealed recent deviations from the longer-term trends. Overall plant numbers haoin the Rincon Mountains has decreased since 2010, largely driven by decreases in common small perennials such as brittlebush and desert zinnia, which had increased dramatically in the previous decade. However, total cover for these species has increased.

While it is not possible to assign causality to monitoring results, our interpretation of the past 30 years of data is that plant community trends are related to both long-term climate and land-use change and stochastic events. Results from 1990 and 2000 reflect favorable conditions for all plants due to the end of cattle grazing and wetter, cooler conditions during the 1980s and early 1990s. Since then, the park and desert Southwest have experienced extended long-term drought, occasionally interrupted by short wet periods. These generally drier, warmer conditions have been favorable for cacti such as prickly pear and cholla, but less so for shrubs and trees. Heavy summer rains in 2006 led to the surge in small subshrubs that were observed in 2010. Some individual plants were killed by a deep freeze in 2011, but the long-term effects appear to be relatively small.

The Saguaro Census is based on a randomized design, includes both an ecologically-important plant and its associated plant community, and has continued for 3 decades. We are very grateful for WNPA's support of this project despite the many challenges of the past two years. Our hope is that the Census will continue to provide insights into how Saguaro National Park's natural resources are responding to on-going changing climate. We are currently working with researchers at University of Arizona and US Geological Survey to develop a peer-review scientific paper based on this 30-year dataset.

Introduction

This report presents the results of the fourth survey of perennial vegetation on plots associated with the Saguaro Census in Saguaro National Park. The Census is a large-scale

monitoring effort for the park's signature plant, the saguaro cactus (*Carnegiea gigantea*), that takes place every 10 years (Winkler et al. 2018, O'Brien et al. 2021). Saguaro population monitoring occurs on 45 large (4 ha) permanent plots: 20 plots randomly located in the Tucson Mountain District, and 25 plots randomly located within saguaro habitat (lower elevations) in the Rincon Mountain District. Within these large plots are smaller subplots, each 100 square meters in size (10 x 10 m), where data are collected on density (number of stems) and cover area of perennial plants associated with saguaros.

The NPS Air Quality Division initiated this study in 1990, when contractors Dan Duriscoe and Sandy Graban (Duriscoe and Graban 1991) led the effort. The plots were re-surveyed in 2000 by Dale Turner, Pam Anning, and Carianne Funicelli (Funicelli et al. 2001), and in 2010 by Adam Springer and other park staff (Springer et al. 2010). In our Phase I report (O'Brien et al. 2021) we presented the results of the saguaro population monitoring aspect of the 2020 Saguaro Census, including educational results. Our objective for this Phase II report is to summarize the plant community results and highlight long-term trends during the past 30 years. We also look at recent changes since 2010, and place long- and short-term trends in the context of historic land use change (e.g. grazing and wood-cutting), climate change, and stochastic weather events.

While the Saguaro Census is a large citizen science event with more than 500 volunteers, surveys on the smaller subplots require plant identification skills that preclude a large volunteer effort. The 2020 surveys were completed by a small team led by park intern Emily Fule, with assistance from intern Olivia Thorp with park botanist Dan Beckman. Emily took the lead on data collection and summaries, with assistance from Lauren Kramer, Merrit Kramer, and Kara O'Brien. Don Swann and Viri Orono conducted data analysis, and Don was lead author on this report.

Study Area and Methods

Study area. Saguaro National Park is comprised of two districts separated by the city of Tucson, Arizona: the Rincon Mountain District (RMD) and the Tucson Mountain District (TMD). RMD ranges in elevation between 820 to 2,640 meters and TMD from 670 to 1,428 meters. The 45 Saguaro Census plots (Figures 1-2) are randomly located on the Arizona Upland subdivision of the Sonoran Desert, 20 at TMD and 25 at RMD 25. The region is characterized by a bimodal precipitation pattern, with up to fifty percent of precipitation falling between July and September due to the North American monsoon.

Field methods. We followed the same procedures used in 1990 and refined in 2000 and 2010 (Springer et al. 2010), with mostly minor adjustments. The 1990 and 2000 surveys were conducted using a plane table and alidade, and in 2010 surveyors used a Nikon DTM-330 Total Station Transit. Because our computers could no longer run the software associated with available NPS total stations, in 2020 we used a Geode GNS2 Multi-GNSS 1Hz Receiver (Juniper System, Logan, UT), which was slightly less accurate than the total station. As in previous surveys, we collected points at the ground stem of every plant within the plots. We measured the diameter of all plants that had a circular canopy and were roughly one meter or less in diameter, taking the mean of two perpendicular planes across the plant. If the canopy was irregularly shaped, we collected multiple points

around the perimeter of the plant. In 2020 we collected canopy points with the Geode unit, which automatically connected these points to create polygons for the maps. We recalculated canopy area in GIS to confirm values for the 1990-2010 surveys and combined these values with data from the 2020 survey to create maps for each subplot (Figure 3) and estimate canopy cover for each species.

As in previous surveys, in cases of overlapping canopies of the same species such as fairy duster (*Calliandra eriophylla*) it was often more efficient to collect points for each of the stems and then map the collective canopy for all plants in the cluster. Where the canopy of a plant rooted outside the plot extended into the plot, we followed methods of Funicelli et al. (2001) by including these plants in the stem count for the plot. Similar to previous surveys, we did not record annual species. We did not record individual grasses, ferns, or fern allies, but did estimate percent cover for the entire plot. However, because of special concern about invasive buffelgrass (*Pennisetum ciliare*), we collected both stem and cover data for each individual plant. Figure 3 illustrates that the vegetative communities of the plots are often recognizable across all four surveys. We followed Springer et al. (2010) by mapping only individuals >30 cm tall for three species that were super-abundant (>600 individuals per plot) in 2020: brittlebush (*Encelia farinosa*), desert zinnia (*Zinnia acerosa*) and hairyseed bahia (*Bahia absinthifolia)*. Smaller individuals were counted and diameter was estimated by selecting a random sample of plants in each size class. Because of expected taxonomic name changes, we adopted the current accepted names (USDA, NRCS 2010) for this report and followed Funicelli et al (2001) by excluding from analysis a few species that were mapped inconsistently during 1990 (see Figure captions).

Analysis and archiving. We evaluated changes during 1990-2010 in number of plants and cover area by species, family, and lifeform. We used six lifeforms: forbs, shrubs, subshrubs, succulents, trees and vines. We separated data by district because of the fundamental differences observed in vegetation communities at RMD and TMD. To assess the significance of change observed by species, family, and lifeform at the plot level we used the Wilcoxin Signed-Rank Test, a non-parametric version of the paired t-test. We extended alpha levels to 0.10, following Funicelli et al. (2001). We used R software for all statistical analysis. We archived all data on the Saguaro National Park server at "N:\GIS_Library\Vegetation\saguaro_census\subplots" and will upload to the NPS data center in 2022.

Results

Changes in plant cover and density, 1990-2020. During the past 3 decades, the total number of perennial plants increased in both districts of Saguaro National Park ($p<0.001$; Table 1). The total number of individual plants (stems) observed in the RMD was 2,659 in 1990 and 5,056 in 2020 (Figure 4-5), a gain of nearly 50%. In the TMD, the number of plants increased approximately 35% from 2,822 in 1990 to 4,394 in 2020. Total plant cover area also increased significantly ($p<0.001$) during the past three decades. In the RMD, cover increased from 1,049 m^2 in 1990 to 1,447 m^2 in 2020, and in the TMD it increased from 836-961 m^2.

Within this general trend of increasing plant numbers and cover since 1990, the past decade from 2010 to 2020 saw relatively little change in plant cover in either district, but

a significant decrease in the total number of plants ($p<0.001$). Mean density (plants per 100 m^2) in the RMD was 114 in 1990, 140 in 2000, and 332 in 2010, and 202 in 2020. In the TMD, mean density was 145 in 1990, 174 in 2000, and 185 in 2010, and 220 in 2020.

In the RMD, cover per plot was 43 m^2 in 1990, 59 m^2 in 2000, 57 m^2 in 2010, and 58 m^2 in 2020. In the TMD, mean cover per plot was 42 m^2 in 1990, 53 m^2 in 2000, 45 m^2 in 2010 and 48 m^2 in 2020.

Changes among different life forms. Among life forms since 1990, subshrubs, succulents, and vines all generally increased in both total numbers and cover area in both districts (Figure 6). However, trees decreased in both number and cover area in both districts during the 30-year period. Shrubs were intermediary, increasing slightly in number and cover from 1990-2020 except at RMD, where shrub cover decreased.

During the past 10 years, the results among life forms are more varied. In general the density of plants of all forms has decreased since 2010, particularly in the RMD, but the cover of both shrubs and subshrubs has increased in both districts, and the number of subshrubs has increased at TMD. Tree cover has continued to decrease in both districts, but the number of trees increased slightly at TMD.

Changes among different plant species
While the general number and cover area of plants has increased in the park since the 1990s, there are definitely winners and losers among species. Among common trees, the trend for velvet mesquite (*Prosopis velutina*) and foothills paloverde (*Parkinsonia microphylla*) has been downward, while white-thorn acacia (*Vachelia constricta*) and wolfberry (*Lycium* spp.) have increased. Among shrubs, creosote (*Larrea tridentia*), pelotazo or hoary abutilon (*Abutilon incantum*), and jojoba (*Simmondsia chinensis*) have been relatively stable in cover area and density, while fairy duster and limber bush (*Jatropha cardiophylla*) have increased. Nearly all common subshrubs have increased except for triangle-leaf bursage (*Ambrosia deltoidia*), a common species in the TMD, which has decreased slightly in cover and density (Figure 7). Brittlebush, which exploded in numbers in 2010 following heavy summer rains in 2006, decreased in number in both districts in 2020, but increased in cover.

Among cacti and succulents, prickly pear (Opuntia *engelmannii-phaeacantha* complex) stands out as a dominant cover plant, more than doubling in cover in the Rincons since 1990. Pincushion cacti (Mammillaria spp.) have also increased more than 100% since 1990, while barrel cactus (Ferocactus spp.) have declined more than 50%. Overall cover of three common cholla species increased during 1990-2020, mainly because of a large increase in jumping cholla (*Cylindropuntia fulgida*).

Discussion

Long-term monitoring of desert plants is important because many desert plants live for so long, often more than 100 years, and desert plant communities respond very slowly to land-use and environmental change (Webb et al. 1996). Although research on the saguaro in Saguaro National Park goes back more than 80 years, long-term datasets are largely

unavailable on other desert plants beyond this study. However, based on historic narratives and photographic evidence, most scientists (e.g., Pierson and Turner 1998, Orum et al. 2016, Conver et al. 2017) link the dramatic decline and then rebound of saguaros during the past 80 years, especially in the Cactus Forest area of the Rincon Mountain District, to major changes to the plant community as a whole. In the late 1800s and early 1900s, many saguaro "nurse trees" such as mesquites and palo verdes were removed for use as fuel, and other plants were reduced by heavy cattle grazing. The re-growth of trees and shrubs after the creation of the park in 1933, and subsequent cattle removal, likely led to large increases in native plant diversity, density, and cover and renewed saguaro establishment. By the 1980s these changes were visible in landscape photos (Turner et al. 2003). High saguaro establishment continued during a cool, wet period that lasted through the mid-1990s (Winkler et al. 2018), and our study suggests that many other plants responded positively to these changes as well.

However, plant communities are not just shaped by large-scale, long-term environmental change, but also by rare events such as wildfires, freezes, windstorms, and droughts. Since 1990 the park's plants have experienced prolonged drought and historically high temperatures (Winkler et al. 2018). Yet during the same period were three very wet winters in the early 1990s; a huge summer storm in 2006; and a deep freeze in 2011. While the drought has certainly had a significant impact, so have other factors. For example, the extremely wet summer of 2006 was followed by such huge increases in the subshrubs such brittlebush that surveyors in 2010 had to modify the sampling effort because it was impossible to map the many plants that were by then 3-4 years old (Springer et al. 2010). The number of these two species had decreased by 2020 – and many individuals of the cold-intolerant brittlebush appeared to die during the freeze of 2011 – but overall cover of these plants increased as they continued to mature.

The Saguaro Census complements other long-term studies in Saguaro National Park (e.g., Orum et al. 2016, Zylstra et al. 2020) that provide opportunities for the park to make broad inferences about the health of its saguaro population and other natural resources over an appropriate time scale for a national park that is committed to protecting these resources for future generations. In addition, as a high-profile public event, the Census is an ideal way to bring science and the concept of long-term ecological change to a broad community audience. In our previous report (O'Brien et al. 2021) we report on the many educational products of this WNPA project. The Saguaro Census overall include over 500 volunteers, received significant local and national media attention, and was featured in many social media posts. We are grateful for support from WNPA and the Friends of Saguaro National Park for allowing us to continue this long-term program. We also thank superintendent Leah McGinnis and the other staff of Saguaro National Park who helped with logistics, safety, volunteer support, outreach, and other aspects of the Census.

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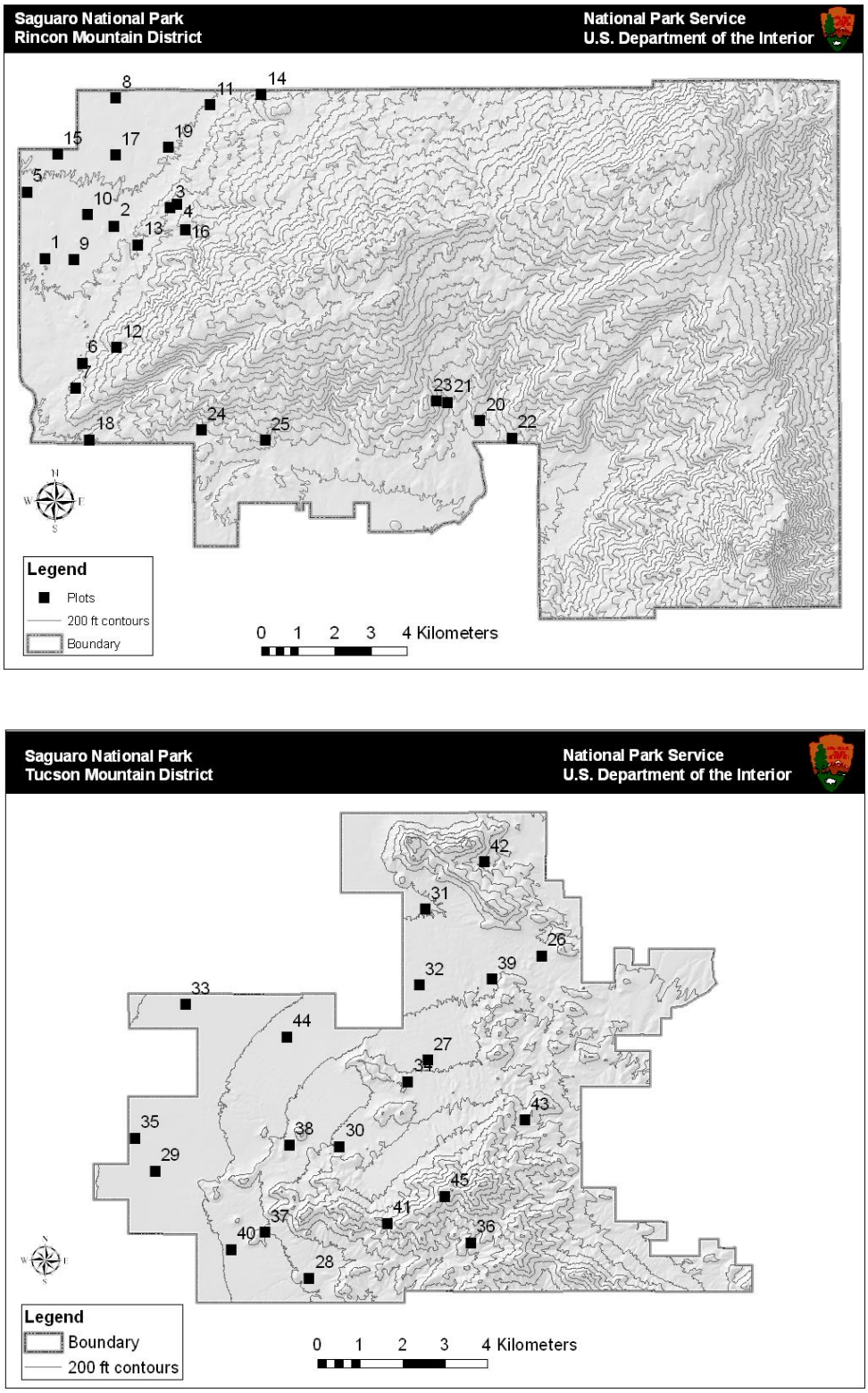
Figures and Tables

Table 1. Changes in total plant number and cover in both districts of Saguaro National Park and park-wide, 1990-2020. Numbers in parentheses indicate the percentage of change observed. Statistical significance based on Wilcoxin Signed-Rank Test; all results are significant.

No. of plants				
	RMD	TMD	Total	Results
1990 – 2020	2,659-5,056 (+90%)	2,822-4,394 (+58%)	5,481-9,450 (+72%)	V=19000 p=0.0000000028
2010 – 2020	3,489-4,394 (+26%)	9,068-5,056 (-44%)	12,557-9,450 (-25%)	V=30661 p=0.0018
Plant cover in m^2				
1990 – 2020	1,049-1447 (+38%)	836-961 (+15%)	1,886-2,407 (+28%)	V=30435 P=0.000000001
2010 – 2020	1,431-1,447 (+1%)	910-961 (+6%)	2,341-02,408 (+3%)	V=21,735 P=0.000000348



Figures 1-2. Location of Saguaro Census plots in the Rincon (above) and Tucson (below) Mountain Districts of Saguaro National Park.

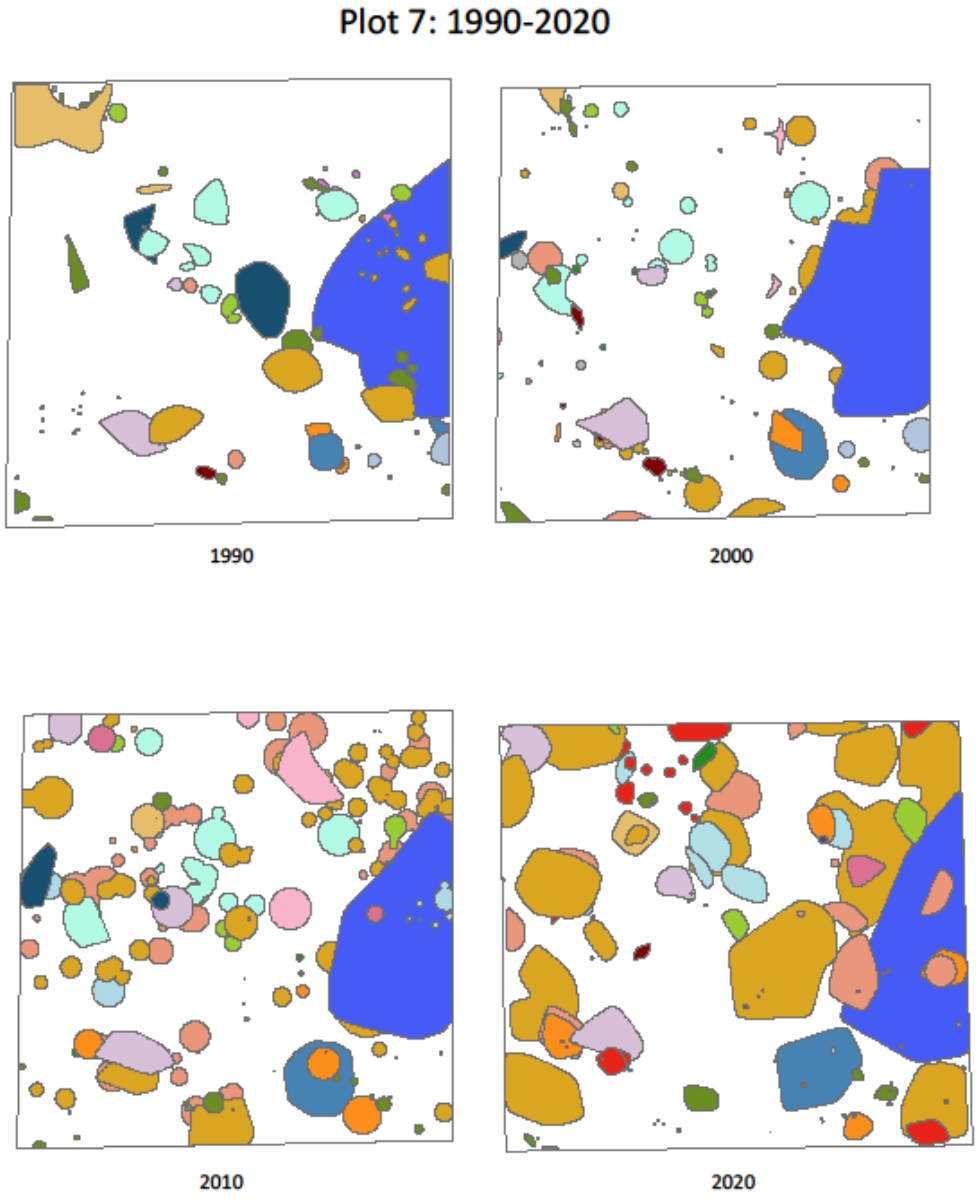


Figure 3. Vegetation changes in one plot (Plot 7) in the Rincon Mountain District during 1990-2020. The darker blue color is a velvet mesquite tree, gold is brittlebush, red is buffelgrass, and light blue is fairy duster. The gray-blue polygon in the lower right is ocotillo. The mesquite has not changed much in 30 years, the ocotillo has grown, and buffelgrass has increased. A major (and typical) change is the appearance of many small brittlebush plants in 2010; by 2020 there were fewer plants but they had expanded in cover area.

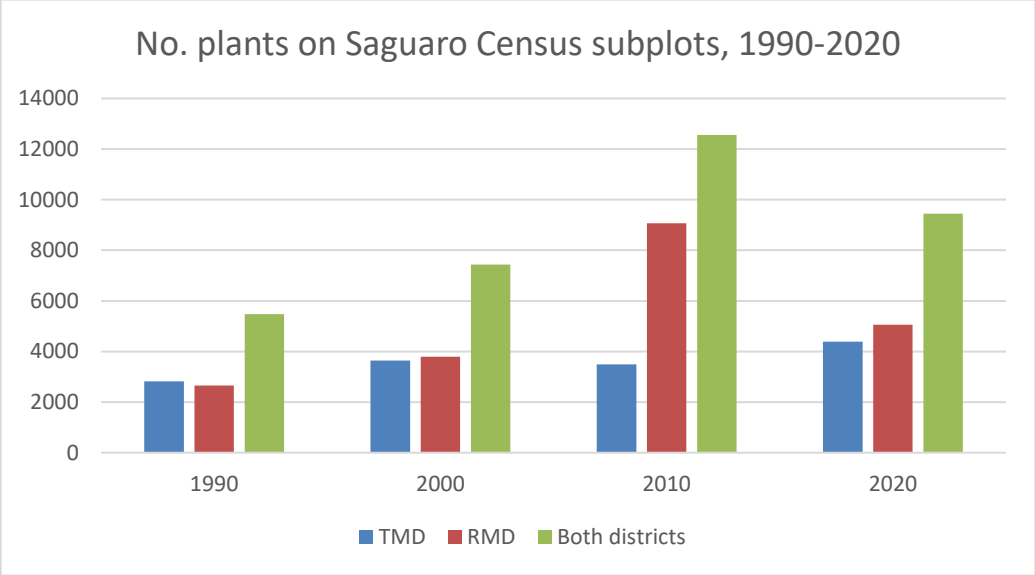


Figure 4. Total number of plants (stems) observed on Saguaro Census plant monitoring subplots during 4 surveys in 1990, 2000, 2010, and 2020.

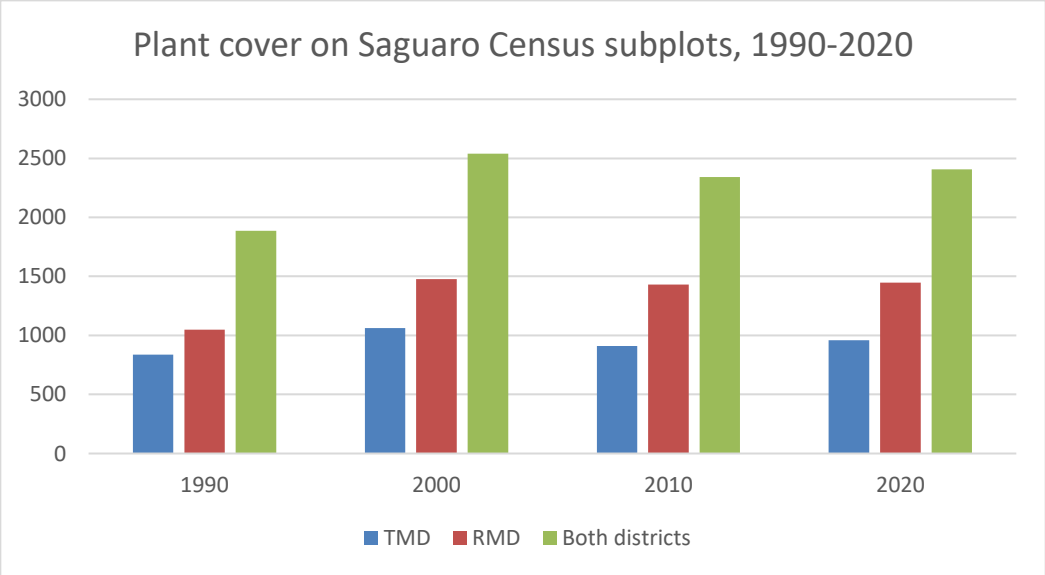
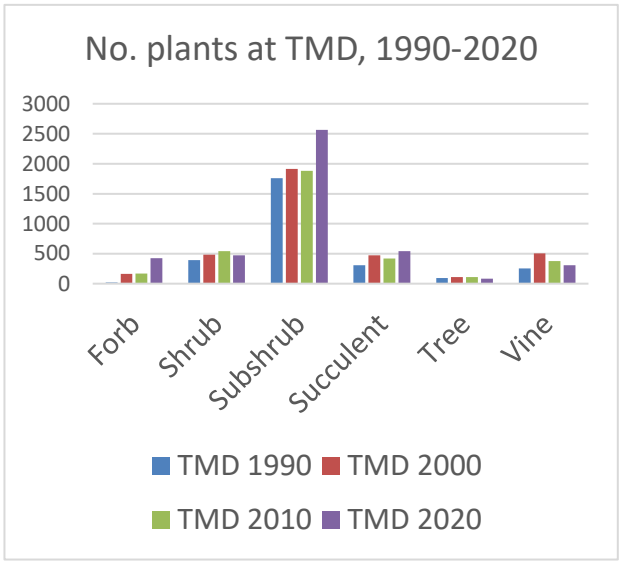
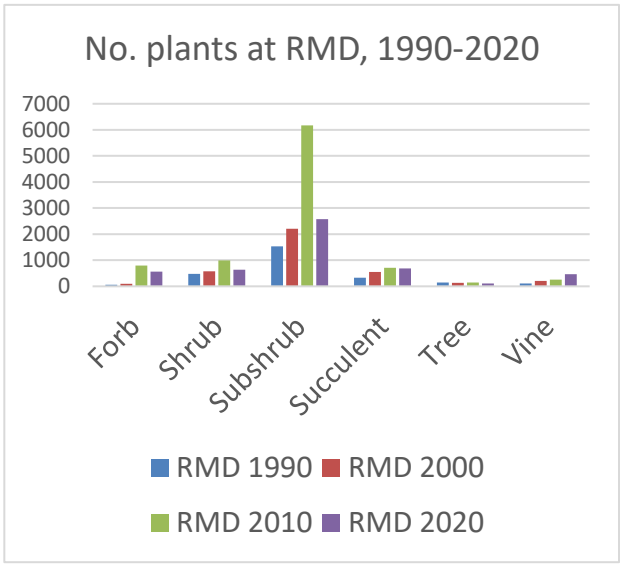
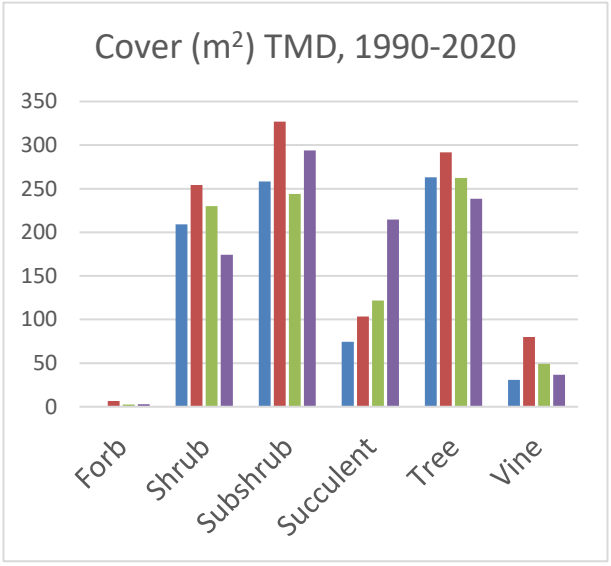


Figure 5. Total cover area in m^2 of perennial plants observed on Saguaro Census plant monitoring subplots during 4 surveys in 1990, 2000, 2010, and 2020.







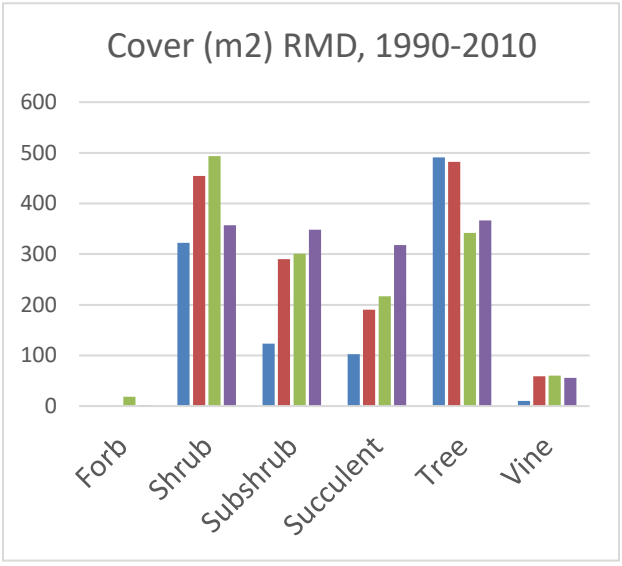
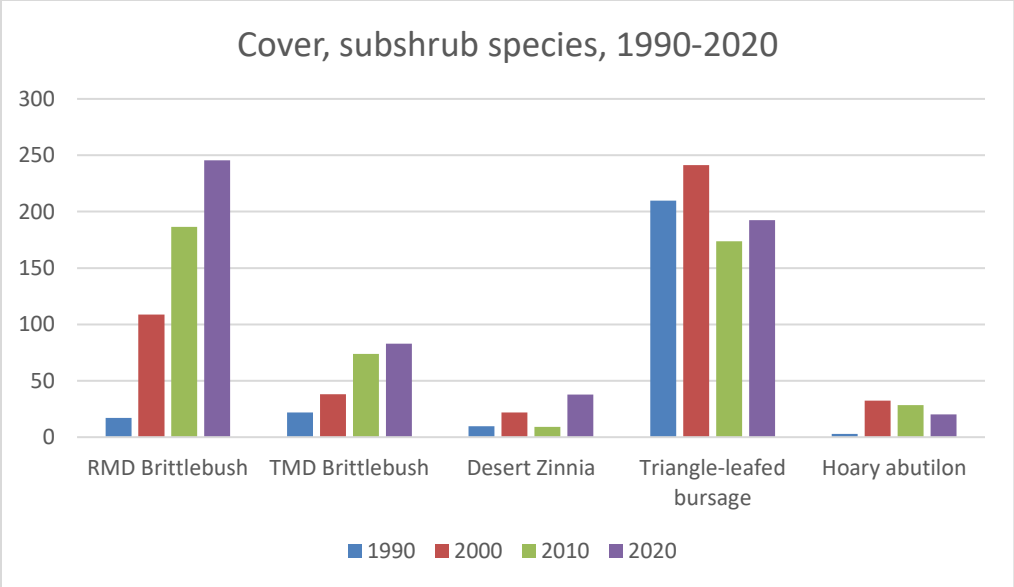


Figure 6 (above). Number of plants (above) and cover (below) observed by lifeform during 1990-2020 in the Tucson Mountain and Rincon Mountain Districts.



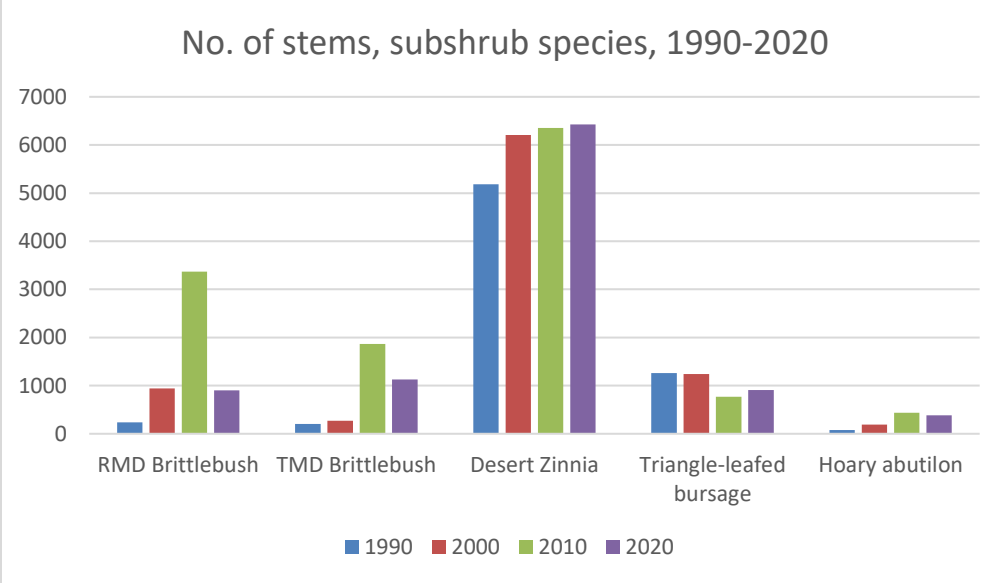


Figure 7. Number of plants (above) and cover area (below) of selected small perennials (subshrubs) in both districts of Saguaro National Park, 1990-2020. Notice the dramatic increase in stems of brittlebush in 2010, followed in 2020 by a decrease in stems and an increase of cover.