

SONORAN UPLAND VEGETATION MONITORING at SAGUARO NATIONAL PARK, 1999-2005 [DRAFT]

Introduction

Saguaro National Park was first established as a National Monument in 1933 on the far-eastern side of Tucson, AZ. The original monument, now the park's east district, includes the renowned saguaro Cactus Forest at about 850m in elevation. From there, the park rises up into the Rincon Mountains (elevation approx. 2,650m). In 1961 the Tucson Mountain District, on the west side of Tucson, was added to the monument; the west district ranges from 670m to 1,400m in elevation. The entire park is about 37,000 hectares in area.

Saguaro National Park is located in south-central Arizona, in the Sonoran Desert bioregion. The saguaro cactus and its associated vegetation are found in the assemblage known as the Arizona Upland subdivision of the Sonoran Desert, characterized by its multi-storied canopy of columnar cacti, leguminous trees, shrubs and sub-shrubs, and other smaller cacti (Turner and Brown 1994). The saguaro cactus (*Carnegiea gigantea*) has figured prominently in park research; however, the existence of other native vegetation is important in the ecology of the saguaro cactus.

In 1990, researchers installed 45 4-hectare saguaro monitoring plots in both districts of Saguaro National Park. The saguaro monitoring plots were randomly placed where saguaro cacti are found in dense populations within the park, areas between 1000m - 1,200m in elevation and lower (Dimmitt 2000, Turner and Brown 1994). Park staff returned to these plots in 2000 to re-measure saguaros, and added a vegetation monitoring component to examine plant species diversity, cover and composition, and to record the presence of non-native plants.

Methods

In the late summer of 1999, we relocated the 45 long-term saguaro monitoring plots installed in the park in 1990; 25 were randomly located in the Rincon Mountain District (RMD) and 20 were placed in the Tucson Mountain District (TMD). Plot corners had been marked with plastic-capped rebar; we replaced these markers with aluminum caps stamped with plot numbers and mounted on rebar. We chose the southeast corner of each plot as the starting point of each vegetation monitoring transect. For each transect we chose a random azimuth, ran a measuring tape on that azimuth from the southeast plot corner, and permanently marked the end-point at 50 meters with another aluminum-capped rebar. Both transect end locations were also recorded using a geographic positioning system (GPS) unit.

Each transect received the same ID number as its corresponding saguaro plot; the first 25 transects are in RMD, and transects numbered 26 through 45 are in TMD. In both park districts, we read odd-numbered transects in odd-numbered years (e.g., transects 1, 3, 5,

etc. were read in 1999, 2001, 2003, etc.) and even-numbered transects in even-numbered years. We read each transect twice a year, at green-up following winter precipitation (spring), and after mid-summer “monsoon” precipitation (summer). We started reading transects in late summer of 1999 and finished in spring of 2005, so we have three complete years of data, with both spring and late summer data, for each transect.

New lands were added to both districts of the park in the 1990s, and we added a total of 8 new transects (four per district) for long-term monitoring using the same alternate even / odd number monitoring schedule as the other transects. This created a total of 29 vegetation monitoring transects in RMD and 24 transects in TMD. In summer 2001, using random monitoring points from a previous study, we chose four new transects for long-term monitoring on the new park expansion lands south of RMD (transect numbers 51, 52, 55 and 56), and collected four seasons of data on the odd-numbered transects and five seasons of data on the even-numbered ones. We installed four new transects on new lands on the east side of TMD using randomly-chosen origin points (transect numbers 46, 47, 48 and 49). We installed and first read these transects in the summer of 2002, and have three seasons of data for these transects.

We measured vegetation along each transect using point-intercept: a pointer was dropped or raised vertically every 0.5 meters along a stretched 50 meter tape and any plant that touched the pointer was recorded; there were 100 points on each transect. Each species was only recorded once per point, even if intercepted a number of times on a point (multiple branches of a tree canopy, for instance).

Dead perennial vegetation, when identifiable, was recorded by species as dead, but dead perennial vegetation still attached to a living plant was recorded as living. Grass species were always identified as living. Ephemeral and annual plants were recorded only if alive. Unidentifiable plant species on the transects were collected and later keyed out and identified; plants that lacked flowers or other identifiable characteristics were keyed to their lowest taxonomic (usually family or genus) level and labeled ‘unknown.’

We also recorded the presence of every plant species that occurred within one meter on both sides of the transect line but not intercepted on the point-intercept transect (we termed these ‘plot species’). Each species within the 2-meter belt was only recorded once, regardless of abundance. Unidentifiable plant species were treated the same as above.

Results

Species Diversity on Transects

Species diversity on transects was calculated by totaling all species encountered on all transects cumulatively for both districts; on all spring and all summer transects cumulatively in both districts; and, for each separate spring and summer monitoring season in both districts.

A total of 329 plant species were encountered on all monitoring transects between summer 1999 and spring 2005 in both districts. A total of 304 species were encountered on all RMD transects, and a total of 175 species were encountered on all TMD transects.

On all RMD spring transects, a total of 235 different species were encountered, ranging from 81 species in 2000 to 137 species in 2001. On all RMD summer transects, a total of 199 species were encountered, with the number ranging between 75 species in 2003 and 127 species in 2001.

On all TMD spring transects, a total of 152 different species were encountered, ranging between 50 species in 2000 and 2002, to 96 species encountered in 2005. On all TMD summer transects, a total of 99 species were encountered, and ranged from 45 species in 2004 to 60 species in 2003.

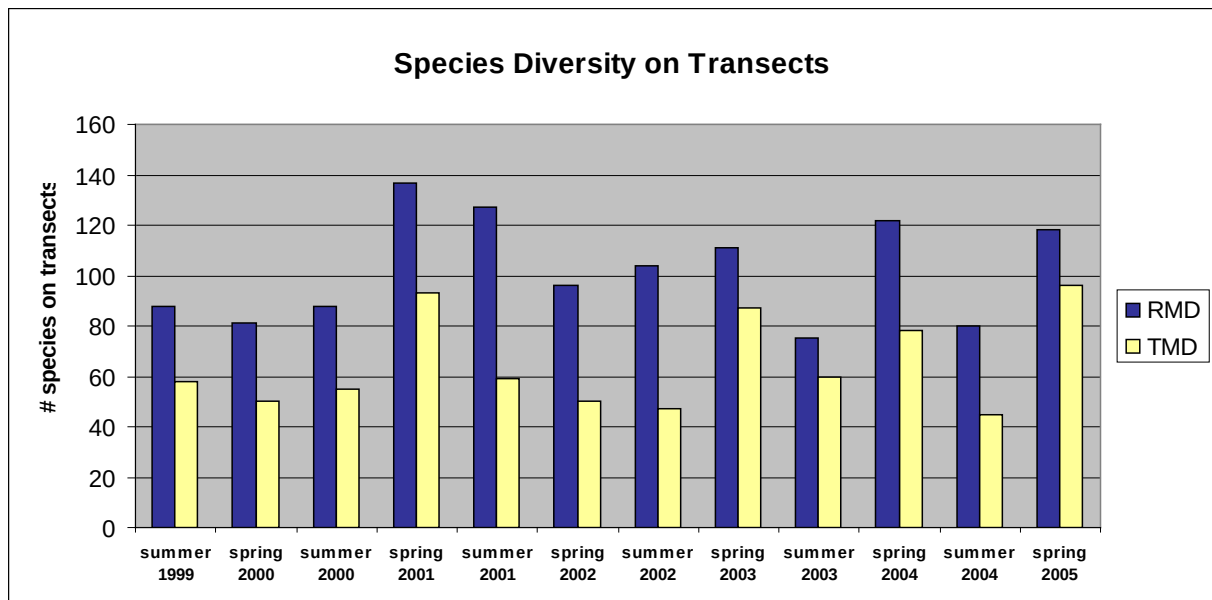


Diagram 1: Species Diversity on Vegetation Monitoring Transects, summer 1999-spring 2005

Species Diversity of Transects and 'Plot Species'

Besides species tallied on the 50 meter transects, we also noted all 'plot species,' those plant species not intercepted on transects but that occurred within one meter of both sides of each transect. Identifying additional plot species allows us to measure plant species diversity for the larger area, but cannot be used to calculate species frequency or cover.

A combined total of 428 species were encountered on transects and as plot species for both districts through entire monitoring period, almost 100 species more than all those encountered on transects alone. A combined total of 407 species were encountered at RMD, and 228 combined species were encountered at TMD.

At RMD, a total of 86 plot species were observed in all spring monitoring, and an additional 78 plot species were observed in the summer. At TMD, a total of 45 additional plot species were observed in all spring monitoring, and 36 additional species were observed in the summer monitoring (see Table 1, below).

	Transect species	Plot species	TOTAL SPECIES
ALL TRANSECTS	329	99	428
All RMD transects	304	103	407
All TMD transects	179	49	228
RMD spring	235	86	321
RMD summer	199	78	277
TMD spring	152	45	197
TMD summer	99	36	135

Table 1: Cumulative Plant Species Diversity by District on Transects and Combined Transects and Plots, 1999-2005

Canopy Cover

Canopy cover is the amount of cover provided by vegetation, compared to bare ground. Canopy cover was calculated by dividing the number of intercept points on a transect with any plant by the total number of intercept points on the transect (100).

The average canopy cover for all RMD transects was 64% ($\pm 14.7\%$); the average spring canopy cover was 67% ($\pm 13.3\%$) and was 61% ($\pm 15.4\%$) for all summer transects. Average spring season canopy cover ranged from 58% (2002) to 80% (2001) and ranged from 48% (2003) to 71% (2002) in summer.

The average canopy cover for all TMD transects was 59% ($\pm 14.5\%$); the average spring canopy cover was 64% ($\pm 13.4\%$) and summer canopy cover was 54% ($\pm 13.9.0\%$). Spring seasonal averages ranged from 51% (2002) to 82% (2005) and summer averages ranged from 45% (2004) to 68% (1999).

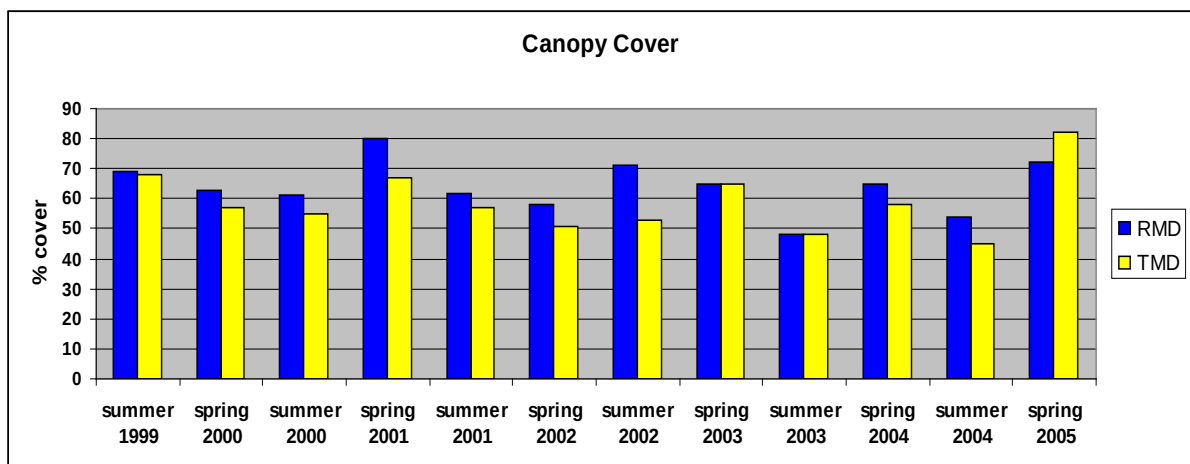


Diagram 2: Plant Canopy Cover on Vegetation Monitoring Transects, summer 1999-spring 2005

Total Cover

In comparison to canopy cover, the total cover represents the cumulative cover of all plants intercepted on transects. Because more than one plant may be intercepted at a single point (e.g., a forb under a shrub beneath a tree canopy), total cover can exceed canopy cover, especially in years with abundant growth of ephemeral plants. Total cover was calculated by dividing the total number of plant intercepts per transect by the number of transect points (100); because more than one plant may be intercepted at one transect point, it is possible that total cover could exceed 100%, and did so in some seasons.

The average total cover for all RMD transects was 95%; the average total cover for all spring transects was 104% ($\pm 40.20\%$) and was 86% (± 30.3) for summer transects. Seasonal total cover averages ranged from 79% (2002) to 165% (2001) in the spring and ranged from 63% (2003) to 108% (2002) in the summer.

The average total cover for all TMD transects was 81%; average spring total cover was 91% (± 32.5), and summer total cover was 71% (± 23.1). Spring seasonal averages ranged from 65% (2002) to 135% (2005) and summer average total cover ranged from 53% (2004) to 95% (1999).

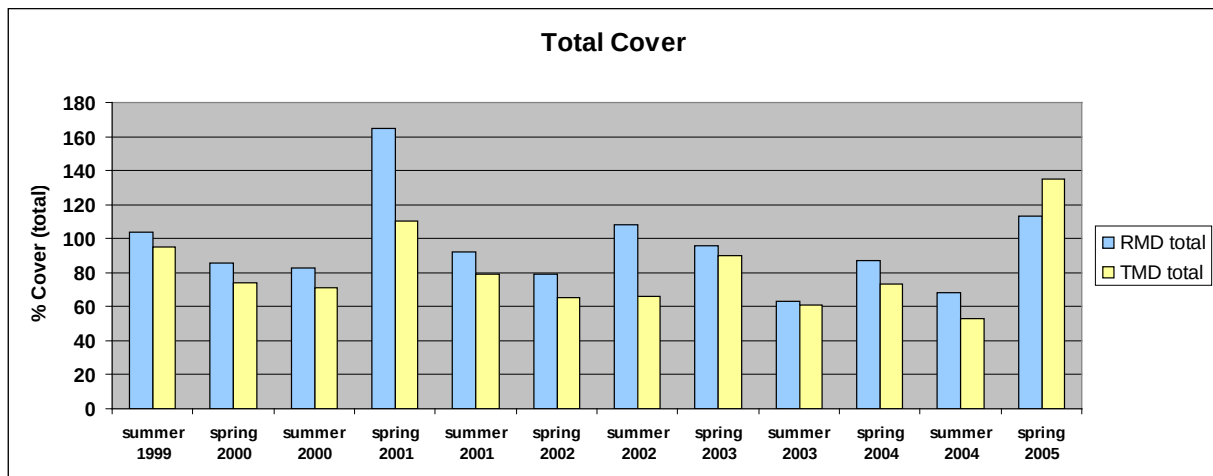


Diagram 3: Total Vegetative Cover on Vegetation Monitoring Transects, summer 1999-spring 2005

Frequency

The frequency of a specific species is the number of transects occupied by that species, divided by the total number of transects surveyed for that monitoring season. Frequency was calculated for both living native and non-native vegetation.

On average, the most frequently encountered living plant species on all transects at RMD was bush muhly (*Muhlenbergia porteri*), encountered on 68% of spring transects and 69% of summer transects. Other consistently encountered species on transects in both seasons include white-thorn acacia (*Acacia constricta*) (57% in spring, 61% in summer), fairy duster (*Calliandra eriophylla*) and mesquite (*Prosopis* spp.) (about 58% and 56%, respectively, for both seasons).

On average, the most frequently-encountered living plant species on all transects at TMD was triangle-leaf bursage (*Ambrosia deltoidea*), on 75% of spring and 70% of summer transects. Other consistent frequently-encountered species on transects for both seasons include foothill palo verde (*Cercidium mycophyllum*) (68% in both spring and summer) and buckhorn cholla (*Opuntia acanthocarpa*) (around 58% for both seasons).

The two most frequently-encountered spring annual plant species in both districts were nievitas (genus *Cryptantha*) and combbur (genus *Pectocarya*). On average, *Cryptantha* was encountered on 57% of spring transects at RMD and 38% of transects at TMD, but was as high as 92% in spring 2001 at RMD. On average, combbur was encountered on 56% of spring transects in both districts, but was as high as 80% at RMD and 92% at TMD in spring 2005.

Other frequently-encountered spring annual plants at RMD included pursh plantain (*Plantago patagonica*), hill locust (*Lotus humistratus*), peppergrass (*Lepidium virginicum*), filago (*Filago* spp.), wild carrot (*Daucus pusillus*) and starflower (*Eriastrum diffusum*). Frequent spring annual plants at TMD include the non-native Mediterranean grass (*Schismus barbatus*), pursh plantain, a number of caterpillar weeds (*Phacelia* spp.), and wild carrot. Unknown or unidentifiable forbs were encountered, on average, on 18% of all transects at RMD and 22% of all transects at TMD.

Cover by Plant Species

At RMD, the species with the highest average cover over all monitoring periods included mesquite with 6.2% cover, bush muhly at 5.3% cover, brittlebush (*Encelia farinosa*) at 4.1% cover, and the annual forb combbur at 3.3% cover. For all spring transects at RMD, combbur had the highest average cover (6.7%), followed by mesquite, bush muhly and brittlebush. On all summer transects, mesquite had the greatest average cover (6.6%), followed by bush muhly, cat-claw acacia (*Acacia greggii*), and prickly-pear cholla (*Opuntia phaeacantha*).

At TMD, the species with the highest average cover over all monitoring periods was triangle-leaf bursage with 11.36% cover, followed by foothill palo verde at 5.8% cover, combbur with 5.0% cover, and resurrection plant (*Selaginella arizonica*) at 4.8% cover. For all spring monitoring at TMD, triangle-leaf bursage had the highest average cover (12.4%), followed by combbur, foothill palo verde, and resurrection plant. For summer transects, triangle-leaf bursage again had the highest average cover (10.3%) followed by foothill palo verde, the ephemeral grass six weeks needle grama (*Bouteloua aristidoides*), and resurrection plant.

The highest total average cover for a species in single season was combbur in spring 2005 in both districts (16.5% at RMD and 32.5% at TMD). Two grasses had the highest total cover for summer monitoring, both in 1999: bush muhly with 9.15% cover at RMD and six weeks needle grama with 19.5% cover at TMD.

Non-Native Species

Long-term vegetation monitoring transects were added to saguaro monitoring plots to measure the influx of invasive non-native species into the park. We calculated the number of non-native species encountered on transects, and the composition of these species with respect to total species diversity on monitoring transects.

At RMD, non-native plant species were encountered in all spring and summer monitoring periods. On average, non-native species were encountered on 6 transects per season, with non-native species on as few as 2 out of 15 transects in summer 2003, and as many as 10 out of 14 transects in spring 2004. On average, non-native species were encountered on twice as many transects in the spring than summer (an average of 8 versus 4 transects).

At RMD, non-native plant species made up an average of 3.5% of the total spring transect species diversity (ranging from 1.4% in 2003 to 7.2% in 2004), and an average of 3.2% of the summer transect species diversity (ranging from 0.3% in 2003 to 7.1% in 2004). At RMD, a total of 16 non-native plant species were encountered on monitoring transects; Lehmann lovegrass (*Eragrostis lehmanniana*) was encountered in all 12 monitoring periods, and natal grass (*Rhynchelytrum repens*) was encountered in 11.

At TMD, non-native plant species were encountered in 4 of the 6 total spring monitoring periods, and only one out of six summer monitoring seasons. On average, non-native species were encountered on 7 transects per spring monitoring season, ranging from no non-native species in 2000 and 2002, to 9 out of 12 transects in spring 2005. For summer monitoring at TMD, a single non-native species was encountered on one transect in 2003.

At TMD, non-native plant species made up an average of 5.4% of the total spring transect plant species diversity, ranging from none in 2000 and 2002, 2.5% in 2001, to 10.0% in 2005. Non-native species diversity was 0.3% for the single summer season when non-native species were intercepted at TMD. A total of 5 non-native species were intercepted on transects; red stem filaree (*Erodium cicutarium*) and Mediterranean grass were both intercepted the most at TMD, in 4 of the total 12 monitoring periods.

See Appendix A for all non-native species encountered.

Mortality

Dead plants were tallied as part of the vegetation monitoring. The species of dead vegetation could often be identified through plant characteristics or by comparison with surrounding plants; unidentifiable dead plants were listed as “unknown.” The total percent cover of dead plants on transects across all seasons was 3.5% at RMD and 5.3% at TMD. However there was a great deal of variability in the amount of dead vegetation encountered: percent cover of dead vegetation in summer 2002 was 6.9% at RMD and 22.1% at TMD (the second-highest at RMD and highest at TMD), and 0% at RMD and 0.3% at TMD (the lowest for both districts) in spring 2005.

Some species were encountered regularly as dead plants. At RMD, dead foothill palo verde had the highest average cover in both spring (0.79%) and summer (0.90%), as well

as the highest single season cover in one spring monitoring period and in 5 of all six summer monitoring periods. Unknown plants (shrubs and grasses) also contributed to dead vegetation at RMD, having the highest single seasonal cover in two spring and one summer monitoring seasons, as well as the highest cover for any monitoring period for both seasons (2.62% in spring 2001 and 2.36% in summer 2001). Other regularly-encountered dead species at RMD included brittlebush, turpentine bush (*Ericameria laricifolia*), burroweed (*Isocoma tenuisecta*) and prickly pear.

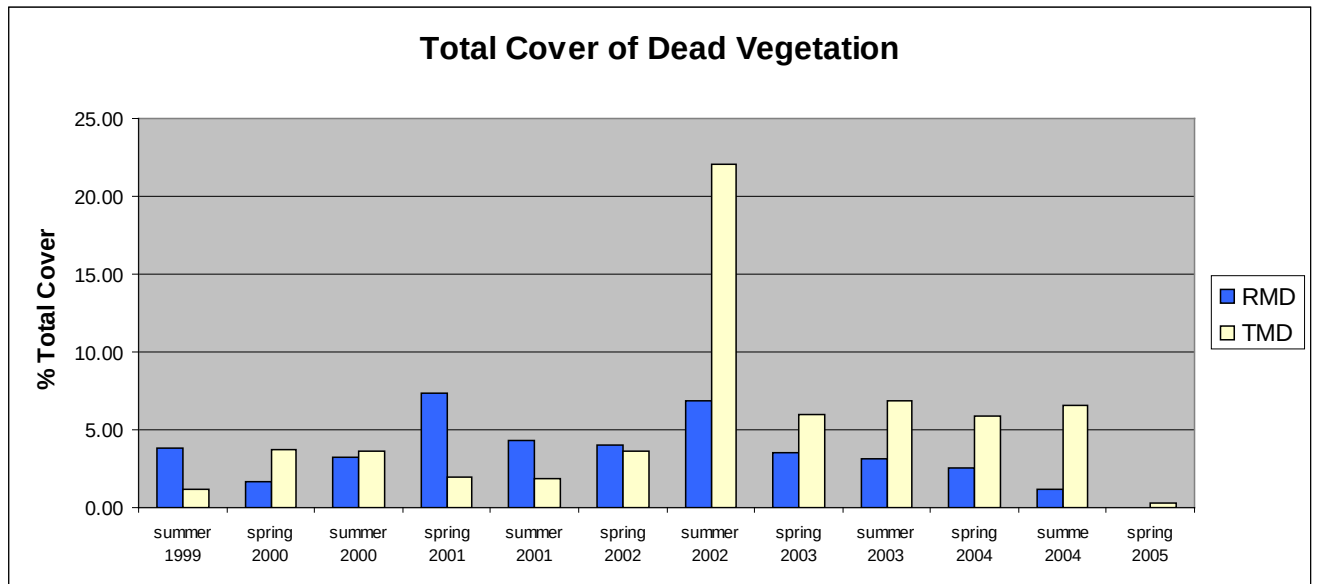


Diagram 4: Cover of Dead Plants on Vegetation Monitoring Transects, summer 1999-spring 2005

At TMD, dead triangle-leaf bursage had the highest average percent cover in both spring (1.32%) and summer (4.16%); the highest single season cover in 5 of six monitoring periods for both spring and summer; and highest cover of all spring seasons (2.4%) and all summer seasons (15.6%). Other regular dead species at TMD included foothill palo verde, brittlebush and buckhorn cholla.

Discussion

District Differences in Vegetation

In comparing the characteristics of vegetation between both districts, RMD had consistently higher plant species diversity on transects and with added plot species than TMD. RMD also had higher plant canopy cover and total cover than TMD, with the exception of spring 2005. Also, a greater variety of non-native species were encountered on transects at RMD compared to TMD.

The differences in vegetation by district are also indicated by the plant species frequency and cover for both districts. At RMD, bush muhly had the highest frequency and cover; at TMD, triangle-leaf bursage had the highest species and cover. With the exception of the ephemeral plants of the *Cryptantha* and *Pectocarya* genus, the list of most frequently encountered species and species with greatest canopy cover were different for each district.

Saguaro National Monument was created from lands in the Coronado National Forest and some private holdings. Grazing lease-holders on the Forest Service lands were allowed to continue to graze on the Monument. Historic reports indicate that the Monument was severely over-grazed for decades, which led to the eventual non-renewal of all grazing leases by the 1970s (Clemensen 1987). The grazing impact to vegetation in the Monument's lower elevations was thought to be one of the causes of the lack of saguaro recruitment (Steenbergh and Lowe).

Over-grazing and the slow attrition of the famous Cactus Forest on the east district were part of the impetus for the establishment of Saguaro's west district in 1961. The Tucson Mountains were never heavily grazed due to a lack of water sources, and because of the intact stands of saguaro cacti, the west district has enjoyed a reputation for possessing 'less disturbed' plant communities when compared to the east district. Transect monitoring results, as well as saguaro population studies that documented increases in saguaro seedlings in the east district, suggest that the east district's vegetation may have recovered from decades of over-grazing.

Elevation

RMD has a greater elevation range overall when compared to TMD (1,850m at RMD and 770m at TMD). Vegetation monitoring under this study was concentrated within the lower elevation Sonoran Upland. Monitoring transects at RMD range from 811m to 1207m in elevation; transects at TMD range from 676m to 1274m in elevation, so the TMD transects have about 200 meters of greater elevation range than those at RMD. Still, the greater range of elevation of transects at TMD in general seemed to not have increased plant species diversity or cover when compared to RMD.

Transect elevation appeared to have little influence on average total cover of vegetation on transects. Average total cover for each transect across all seasons was correlated to the elevation of each transect; the correlation was 0.17 at RMD and was 0.41 at TMD. However, elevation seemed to have more influence on total cover in the summer than

spring: at RMD, correlation of average total cover for each transect by monitoring season versus its elevation was 0.04 in spring and 0.32 for summer; the correlation was 0.17 for the spring and 0.63 in the summer at TMD.

Results were similar for average species diversity on transects. Average species diversity for each transect across all seasons, when correlated to each transects' elevation, was 0.28 at RMD and 0.53 at TMD. Average species diversity by transect for each season correlated to elevation by transect was 0.19 for spring and 0.35 for summer at RMD, and 0.41 for spring and 0.62 for summer at TMD.

The influence of elevation on transect vegetation may need to be examined within the context of transects' larger landscapes. From the correlation coefficients, transect elevation may have had a greater effect on transect species diversity and total cover at TMD than RMD. However, the RMD transects are at the base of a much higher mountain range – the climatic effects of the Rincon Mountains (orographic lifting and cool air drainage) may have influenced transect conditions more than their discrete elevation within the range. The Tucson Mountains are not as high, and each transects' elevation may have been more important at TMD.

Precipitation

One of the greatest influences on desert vegetation is precipitation. Precipitation in the Sonoran Desert is characterized by a bi-modal rainfall pattern: winter rains are associated with passing weather fronts that tend to cover a broader geographic area, and are longer and gentler, allowing moisture to soak into soil; summer rains (or 'monsoons') tend to build on a daily basis, and produce localized, torrential downpours that sheet quickly off the land. There are generally pronounced dry periods in the late spring and fall.

One limitation to investigating the effect of precipitation on the transect vegetation is that transects in both districts cover a broad geographic extent, and we have not collected precipitation data for each transect. The most complete precipitation data is collected at fixed sites, usually far from transects. Diagram 5 (below) shows the inter-seasonal differences in rainfall between park districts and official National Weather Service site at Tucson International Airport (TIA). However, we compare species diversity, total plant cover and plant mortality district seasonal averages to district seasonal precipitation, which helps reduce some of the potential single-site differences in precipitation.

Seasonal precipitation totals for each monitoring season were summed for the months prior to the monitoring. For spring transects, winter precipitation was considered all rainfall from September to April inclusive prior to monitoring; for summer transects, the monsoon season was considered to be May to August inclusive prior to monitoring.

Precipitation records were collected at a rain gauge at the RMD Visitor Center starting in mid-July of 1999 (rainfall data from TIA was used to fill in additional months for correlation analysis, from May 1998 to mid-July 1999). Total precipitation for the May 1999 to April 2005 monitoring period at RMD was 69.17 inches; 27.98 in. fell during the summer monsoon and 41.19 in. fell in the winter. RMD rainfall averaged 4.66 in. (± 1.72

in.) in summer monsoons between 1999 and 2004, and averaged 6.87 in. (± 3.83 in.) during winter storms between 2000 and 2005.

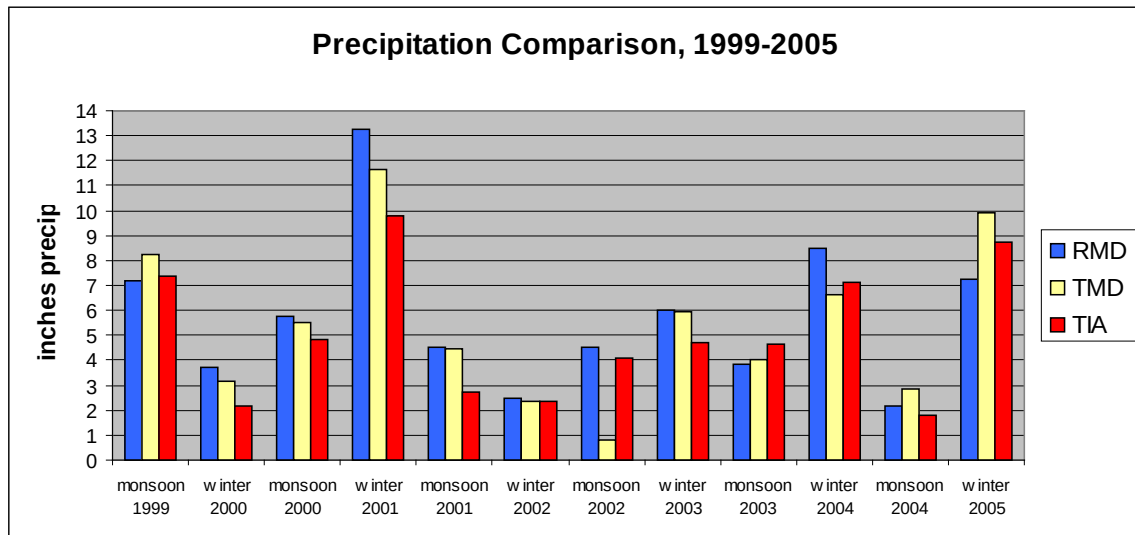


Diagram 5: Comparison of seasonal precipitation at Saguaro NP and Tucson International Airport

Climate data, including precipitation records, are collected at the Red Hills Visitor Center at TMD, on the west side of the Tucson Mountains, and was used for the west district transects. Total precipitation for the May 1999 to April 2005 monitoring period at TMD was 65.49 inches; 25.84 in. fell in the summer monsoon and 39.65 in. fell in the winter. TMD rainfall averaged 4.31 in. (± 2.50 in.) in summer monsoons between 1999 and 2004, and averaged 6.61 in. (± 3.64 in.) during winter storms between 2000 and 2005.

Average seasonal district species diversity and total plant cover were strongly correlated to precipitation in both districts. The correlation coefficient was 0.70 for species diversity and 0.85 for total cover at RMD, and 0.83 for species diversity and 0.84 for total cover at TMD. As precipitation increases, we would expect a greater flush of ephemeral species, with an increase in diversity and cover.

We expect an inverse relationship between plant mortality and precipitation: with more rain, there should be less mortality. However, there were very different results in each district when comparing the effect of precipitation on mortality. There was a negative relationship between for seasonal plant mortality versus precipitation at TMD (correlation coefficient = -0.62), albeit weaker than the relationship between precipitation and species diversity or cover. However, when the previous season's precipitation was summed with the current season, the correlation coefficient between seasonal mortality and rainfall decreased to -0.72, and decreased again to -0.78 when two prior season's rainfall was added to each season. This suggests the effect of precipitation on plant mortality takes a number of seasons to manifest.

However, the results were very different at RMD. The correlation coefficient between precipitation and seasonal plant mortality was 0.39, a rather weak relationship. This

reduced further when additional seasons of precipitation were added, dropping to 0.32 when two seasons were summed, and down to 0.11 when three seasons were summed, suggesting a lack of a longer-term relationship between precipitation and mortality.

Invasive Plants

One of the objectives of the long-term monitoring transects were to detect the influx of invasive non-native plants into the park. A total of 16 non-native species were encountered at RMD and a total of 5 non-native species encountered at TMD during all monitoring between 1999 and 2005. However, invasive species monitoring in the park has identified around 80 non-native species in the park. Also, only the RMD transects encountered one of the two most problematic invasive species in the park, buffel grass (*Pennisetum ciliare*), and completely missed a second, fountain grass (*Pennisetum ciliare*); neither species was encountered at TMD.

The transects tell us that at randomly chosen spots in the park, there may be little probability of encountering some of the park's most troublesome species. However, we know that these species form dense populations, and prefer to establish on disturbed areas and south-facing slopes. Therefore, establishing randomly-located transects may not be the best method to monitor for these species, although personnel are able to spot and record populations of these species in the backcountry as they travel to transects.

APPENDIX A: Non-Native Species Encountered on Vegetation Monitoring Transects

RMD Non-Native Plant Specie

<u>Scientific Name</u>	<u>Common Name</u>	<u># Seasons Encountered</u>
Bromus rubens	red brome	7
Centaurea melitensis	starthistle	1
Echinochloa colonum	jungle ricegrass	2
Eragrostis cilianensis	stink grass	1
Eragrostis echinochloidea	lovegrass	1
Eragrostis lehmanniana	Lehmann lovegrass	12
Erodium cicutarium	red stem filaree	4
Galium aparine	goosegrass	5
Herniaria cinerea	burstwort	2
Pennisetum ciliare	buffel grass	3
Phalaris caroliniana	Carolina canary grass	1
Polypogon monspeliensis	rabbit foot grass	1
Rhynchelytrum repens	natal grass	11
Schismus barbatus	Mediterranean grass	3
Sisymbrium irio	London rocket	2
Sonchus species	sow thistle	1

TMD Non-Native Plant Species

<u>Scientific Name</u>	<u>Common Name</u>	<u># Seasons Encountered</u>
Erodium cicutarium	redstem filaree	4
Herniaria cinerea	burstwort	2
Mollugo cerviana	threadstem carpet weed	1
Rhynchelytrum repens	natal grass	1
Schismus barbatus	Mediterranean grass	4

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