

Studying the Ecological Relationship Between Elevation and *Carnegiea gigantea* Branching Patterns in Saguaro National Park West

INTRODUCTION

The Saguaro, also known as *Carnegiea gigantea*, as defined by the Merriam Webster Dictionary is “a tall columnar usually sparsely-branched cactus (*Carnegiea gigantea*) of dry areas of the southwestern U.S. and Mexico that bears white flowers and a scaly reddish edible fruit and that may attain a height of up to 50 feet (16 meters).” It is the staple of the Sonoran Desert and Southern United States and provides essential environmental support for plants and animals native to such areas. Saguaros play a keystone role in their ecosystems, meaning that the health of the local wildlife and plants would drastically decrease if the health of the Saguaro population were to decline as well. As a keystone species, Saguaros provide food and shelter for many desert organisms. For example, the moist fruit of the Saguaro only grows in early summer, when other foods are scarce to most birds, rodents, insects, and bats. Additionally, these great cacti are great nesting sites for owls and birds because they are cool and provide shade from the unforgiving desert sun. After a Saguaro falls, its ribs become the new housing sites for insects and rodents as well and allows the entire ecosystem to flourish. Similarly, the arms, or branches, of these colossal cacti are just as fit for reproduction as the main stem and in many studies, the main stem is counted as a branch for data related to the reproductive ability of the Saguaro species.

Research on Saguaros has been conducted for decades in Saguaro National Park from the 30’s through the present. Such research has covered all aspects of the life of a Saguaro from reproduction to development as well as the relationships between the Saguaro and other organisms and the effects that changes in weather have on them. The National Park Service

(NPS) has public databases in which there are records on all of the censuses and other research done on Saguaro. For example, in an article titled “A History of Saguaro Cactus Monitoring in Saguaro National Park, 1939-2007,” Don E. Swann and Eric B. Ahnmark, both who are biologists in Saguaro National Park, discuss the past censuses done in the park as well as the past and present state of Saguaro growth. On a similar note, research has been done by universities and independent researchers and cover similar topics but are more directed at a specific detail of Saguaro life than what may be possible through a government agency such as the NPS or the United States Forest Service. Taly Dawn Drezner is a prime example of such a researcher. Drezner is an associate professor in the Department of Geography at York University whose research consists of biological study and mainly involves Saguaro. For example, in a study named “A Test of the Relationship between Seasonal Rainfall and Saguaro Cacti Branching Patterns,” Drezner discusses that the rarity of branching studies is primarily due to the fact that researchers study branching where rainfall is abundant and thus is claimed as the sole influencer on Saguaro branching.

There exists a gap however, where Saguaro branching meets environmental factors. In particular, the factor of interest is elevation. While there have been few studies on branching, there have been even less directly studying the relationship between the number of arms a Saguaro grows and changes in elevation. Saguaro are biologically heat dependent. Simply observing the mountain ranges surrounding Tucson, Arizona, it can be noted that Saguaro growth declines and stops at higher elevations. This is due to higher stagnant moisture at lower elevations with flatter slopes. Additionally, and not so easily noted is the relationship between Saguaro branch development and elevation. This is the primary focus of my study. Studying the branch development of Saguaro and how it relates to the environment around them can add to

existing research such as Drezner's research on rainfall and branch development and further the understanding of how Saguaro grow and interact with their ecosystems as well as their reproductive behaviors.

Literature Review

In this literature review, many of the major works listed discuss the complex relationships between many different environmental factors and the resulting growth patterns of the Saguaro, *Carnegiea gigantea* across the Sonoran desert of the Southwestern United States. To begin, Taly Dawn Drezner discusses in "A Comparison of Saguaro Regeneration on Slopes and Flats in Saguaro National Park and in South Mountain, Arizona" that saguaro regeneration, which is the growth of new Saguaros, commonly occurred on flatter slopes rather than mountainous slopes, regardless of north or south orientation in South Mountain (Drezner 65). However, Saguaro regeneration occurred at nearly the same percentage on flat slopes and South-facing slopes in Saguaro National Park and Drezner hypothesizes that any percent difference would be theoretically caused by the climate (Drezner 65). Additionally, it needs to be mentioned that saguaro regeneration is subject to other environmental conditions needed to be perfect in order for regeneration to occur. Such factors would include ample summer rainfall, dry and hot weather, and freezing temperatures.

Similarly, in "Morphological Growth Patterns of Saguaro (*Carnegiea Gigantea*: Cactaceae) on Flats and Slopes in Organ Pipe Cactus National Monument, Arizona," Richard I. Yeaten, et al study the differences in saguaros on two slope extremes in local moisture gradient in Organ Pipe Cactus National Monument in Arizona (Yeaten et al. 339). The researchers found that the most prominent difference in the two subpopulations was the prevalence of branching in the Saguaro group that had increased levels of surrounding moisture which were located on the flatter slope and that this was the driving force behind Saguaro regeneration (Yeaten et al. 341) The saguaros on the inclined slope faced more moisture stress, meaning that there were lower levels of water in the air, however and it is theorized that this lack of

branching is an adaptation to reduced water losses and increase individual survivorship (Yeaten et al. 341). While Drezner discusses how slope affects saguaro regeneration, Yeaten's study can be branched off Drezner because Yeaten studies the effect of climate and moisture levels on saguaro populations at different slopes which is what Drezner theorized. The two slopes were described to be flat and inclined, and from there he explains that the branching patterns are a result of the different climate levels.

Combined, these studies present an important connection and exemplify the complex relationships between the environment and its effect on saguaro growth and branching. The studies of Taly Drezner and Yeaten et al, agree that slope and incline are important factors in saguaro growth, development, and branching due to the other environmental factors such as climate that result from differing slopes. The results of these studies will be used as notes to find a study plot that has enough difference in slope to analyze the difference that slope has in saguaro growth and branching in Saguaro National Park East in Tucson Arizona.

On another branch, Lance S. Evans discusses in "Predicting Morbidity and Mortality for a Saguaro Cactus (*Carnegiea Gigantea*) Population," that saguaros that are taller, which generally translates to increased age, suffer more from scaling and barking, which is the process of the skin of the saguaro becoming hard and rigid, such as the bark on a tree (Evans 247). This is typically caused by the intense heat that the sun causes along the equatorial line of the saguaro. This is where the link between sunlight and branching exists. The study did not mention branching on saguaros or how it may relate to the barking that the cacti are falling victim to in the study. However, this data can be built upon with the data I collect and further, more specialized research in order to establish the relationship between barking and branching.

While the study that Evans et al. conducted may have not been directly relate to branching, the study fits in with the scholarly work surrounding the topic due to its study of how sunlight affects the skin of the saguaro and allows room for additional study such as mine that might attempt to find a link between barking on a saguaro and branching on saguaros.

Similarly and not directly related to branching, Taly Drezner discovers in “Saguaro (*Carnegiea Gigantea*, *Cactaceae*) Age-Height Relationships and Growth: The Development of a General Growth Curve” that a age-height curve can be made to fit every saguaro population across the Sonoran desert (Drezner 911). Drezner took many saguaro populations from Saguaro National Park East and Organ Pipe Cactus National Park among other sites and from there took height-growth data as well as rigorous in-field measurements in order to create an age-height growth curve, which is a scientific tool that generally plots the age of a Saguaro using height measurements, for each population (Drezner 911). Each curve was very similar to the next in that age affects the height of a Saguaro similarly across the Sonoran Desert but differs in microclimates from region to region. Generally all that is needed to fit it to a specific population is a few site specific measurements (Drezner 913). This can be a useful tool for analyzing the correlation between age and branching in saguaros.

Lastly, Taly Dawn Drezner discusses in “A Test of the Relationship between Seasonal Rainfall and Saguaro Cacti Branching Patterns” that branching studies are relatively scarce due to the summer precipitation bias in which the studies are conducted primarily in geographical locales that receive abundant amounts of summer rainfall, and is thus attributed the sole influencer for saguaro branching (Drezner 393). Drezner’s study found that among 30 saguaro populations across the Southwestern United States, winter precipitation is a more accurate estimator for branching and saguaros may primarily boost their fitness and branching patterns during the winter season which in turn balances their previously believed ecological patterns (Drezner 397). This agrees with the previous studies discussing slope and branching because the flatter the slope, the more moisture there is allowing saguaros to take advantage of branching opportunities. Additionally, looking at precipitation levels may also help me find a correlation between rainfall and branching.

Studying the relationship between elevation and Saguaro branching will fill in the gaps and provide insight as well as a base for further research. Drezner and Yeaten et al. provide very insightful research but fail to relate branching explicitly to elevation which is where my research will form the bridge between the two. Additionally, Drezner and Evans works compliment eachother but there is

nothing bridging the gap between age and branching. While my work does not explicitly deal with age, further research could tie my data between branching and elevation to those of the above by discussing how branching occurs on older or younger saguaros more frequently and from there associations can be made tying elevation to the age of a Saguaro.

METHOD

The method for my research contains four primary components in addition to comparative discussions on why options were picked over others. The first of these components was determining which environmental factor would be chosen to study. The second was finding a suitable study plot in Saguaro National Park West (SNPW). The third and final component was determining how to collect data and how it will be organized.

Elevation

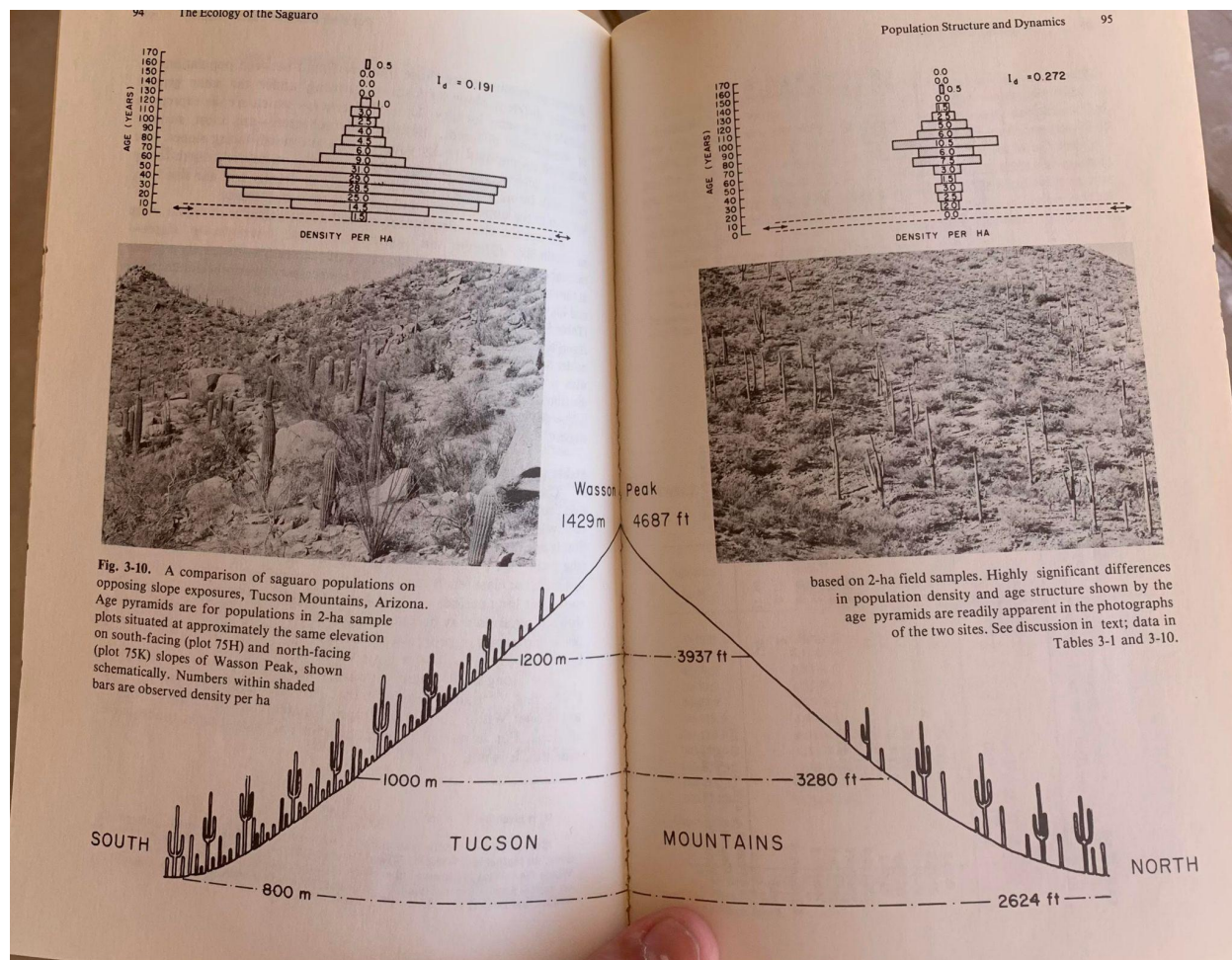
Deciding which factors to study that may or may not have an affect on Saguaro branching is complicated. Saguaro branching is a term used by scientists to refer to the extensions a saguaro grows from the main stem. Saguaro branching could be affected by any number of environmental influences such as precipitation, sunshine, height, nurse trees, elevation and more. Elevation was chosen as a potential factor affecting Saguaro branching in Saguaro National Park West. As Yeaten explains in his study on Saguaro growth in the Organ Pipe National Park, elevation may be a critical factor for branching because higher elevation correlates with steeper slopes which results in less stagnant water and less water absorbed into the ground on those slopes (Yeaten et al. 339). While precipitation may be directly related to saguaro branching, it would be near impossible to look at historical records of precipitation in SNPE and tell where the most water fell and study that area specifically. This skews off of Drezner's study on Saguaro branching and

seasonal rainfall which shows that such data can be taken but it must be done broadly and not specifically (Drezner 393), unlike the study this paper explains. Additionally, elevation was chosen as the environmental factor of study due to its reliability. Compared to other factors such as, but not limited to, precipitation, hours of sunlight daily, or height, elevation data is simple to collect due to the fact that any specific geological point in the study area will not change over long periods of time and can be measured accurately using a Global Positioning System (GPS). On the other hand, other factors like the ones listed above are difficult to measure as they require more equipment and can change daily, skewing data and creating more unreliable datasets.

Study Area

A study area, as defined by the geographic information system software, arcGIS, is “a geographic boundary created to define the extent of an analysis.” A very selective study area is crucial for this project for many reasons. To start, if there is not enough change in elevation in the study area, a correlation between elevation and Saguaro branching may not present itself, if existent at all. Additionally, the study area has to cover enough space in order to capture a reasonable number of saguaros in order for the data to be statistically sound. Thus, as a result, I decided to choose a trail in SNPW rather than open land with no trail intersecting it because a trail would allow ease of access up and down the mountain which is crucial for measuring elevation. This trail is named King Canyon Trail and winds up the South face of Wasson Peak and ends at the apex of the peak. Trails serve as great study areas due to their ease of access as well as their clear view of the vegetation surrounding the area which makes for a perfect observational study. Similarly, trails provide room away from the natural wildlife and act as a barrier in order to protect the local plants and animals in the region. Additionally, I chose SNPW

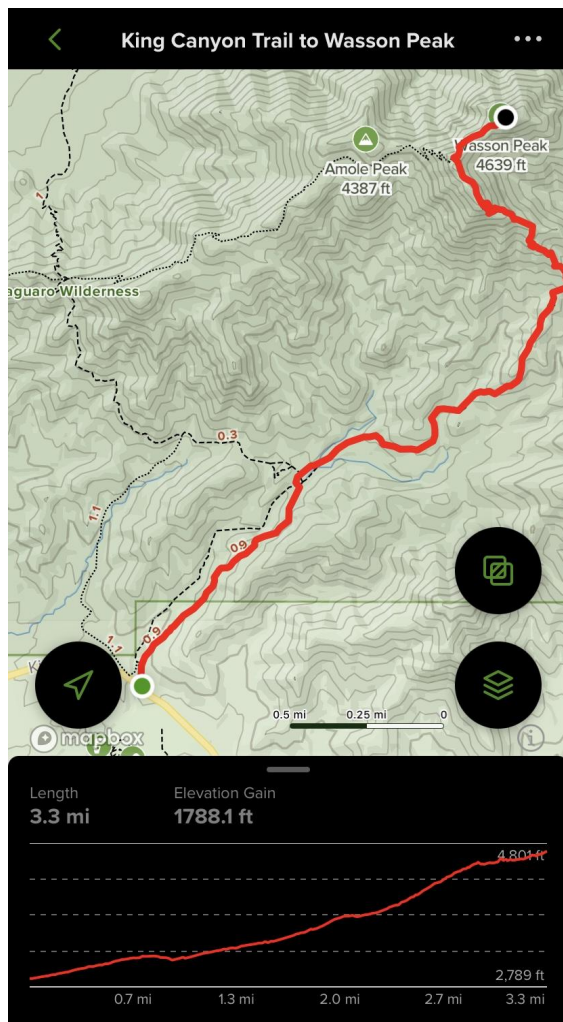
for many reasons. First, Saguaro National Park West had multiple mountains that provided adequate elevation gain. Second, SNPW has never, on record, sustained any sort of fire damage to the mountain range and would provide the most reliable data. Third, Wasson Peak has a phenomenon where the South face has Saguaro growth at higher elevations than the North Faces where there appears to be a cap (Steenbergh et al. 94)



Shown above are pages from a journal titled "The Ecology of the Saguaro" depicting Saguaro growth on the South and North face of Wasson Peak (Steenbergh et al. 94)

On the contrary, while Coronado national park provides great elevation gain, there are less hiking trails that go up the ridges of the Santa Catalina mountains and this mountain range has suffered multiple fires and burnings over the past few decades which may result in unreliable

data when attempting to determine if Saguaro branching has an elevational cap, being the point at which Saguaros either stop growing, or if the arms stop growing. Saguaro National Park East on the other hand would have been another great option to study due to the soaring mountains as well as an abundance of trails that lead to the tops of the range as is supported in Drezner's study on the Saguaro age-height relationship (Drezner 393). However, Saguaro National Park East was not chosen for the study due to the fire damage that the range had seen over the past years which, yet again, may have provided unreliable data and would not have allowed me to study any possible correlations.



Shown above is a screenshot from my Smartphone depicting the King Canyon Trail to Wasson Peak trail as well as Elevational data in Saguaro National Park West.

Disturbing local wildlife is an ethical problem I had to greatly take into consideration and was the reason I chose a trail over open land. There was too much low-lying vegetation on the desert floor for me to comfortably move around and observe as I had intended. The trail I chose was named “King Canyon Trail,” as mentioned above. This trail in particular is 3.3 miles long and heads north through one of the canyons in the Tucson Mountains. I chose this trail because it provided ample elevation gains for my study whereas the other ridges and trails were either inaccessible or there was not enough change in elevation to provide a significant correlation. After the trail was chosen, it had to be decided how far up the trail would be the starting and stopping points for the study area. The map of the trail at the trailhead served as the starting point of my data collection and the highest point of Wasson Peak served as my stopping point for data collection. I then had to decide how far off the trail I would go in order to capture a reasonable number of Saguaros.

Data Collection

The data that was collected on Saguaros was only the number of arms each Saguaro grew, excluding the main stem. Mentioned by a Biologist at Saguaro National Park, Don Swann, other researchers such as the National Park Service (NPS) include the main stem as an arm in their studies due to the arms having the exact same reproductive potential as the main stem. For example, if a Saguaro had four branches off its main stem, I would record it as having four branches whereas the NPS would record it as having five arms. Additionally, the fashion in which data was collected on Saguaros in King Canyon Trail was strictly observational and there

was no physical contact with the cacti in order to preserve the validity of the data and the protection of the species.

Elevational data was collected on a GPS and was measured in feet from sea level.



Shown above is the GPS unit used in the study with the display on. Once enough satellites have been acquired, speed, elevation, and accuracy will be displayed in their respective units. Elevation and accuracy were the measurements taken for this study.

The first data point was the elevation of the trail map at the start of the trailhead of King Canyon trail and the last data point of elevation was at the highest point of Wasson Peak. Additionally, elevation was recorded on every saguaro within 10 meters of either side of the trail in order to produce a large enough sample size for the study. 10 meters seemed the optimal distance as it provided enough space to include a large sample size but was short enough to still collect accurate data. Lastly, elevational data on Saguaros was not collected at the base of each saguaro, but rather from the trail at a point perpendicular to the saguaro. This ensured the safety of the local plants and animals as well as provided satisfactory information in order to study a correlation between branching and elevation. The data did not need to come from the base of the saguaro as the subject of the study was to observe general trends.

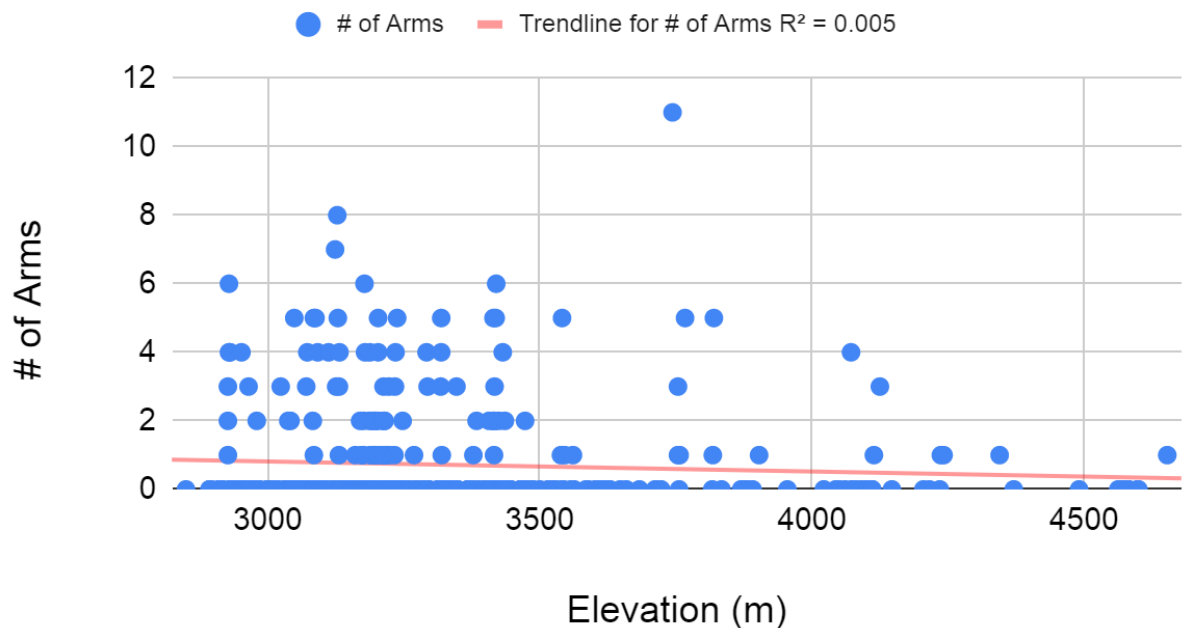


Shown above is an image taken from the King Canyon to Wasson Peak trail consisting of two Saguaros. The one on the left is further than ten meters from the trail and the one on the right is within ten meters from the trail. This is an example of subjective vision in assuming what is greater than ten meters from the trail.

DATA ANALYSIS

Over the course of the study, 412 Saguaros were studied and data consisting of elevation as well as the number of arms grown was recorded. The original hypothesis was that which Saguaro branching would decrease as elevation increased. The reasoning for this was as follows: Saguaros are climate dependent and will grow and reproduce best in warmer temperatures and Saguaro branching follows similar patterns and is expected to be in greater abundance at lower elevations due to the higher temperatures. Additionally, Saguaro growth follows stagnant water and with greater elevation comes greater slopes which in turn means less stagnant water.

of Arms vs. Elevation (m)

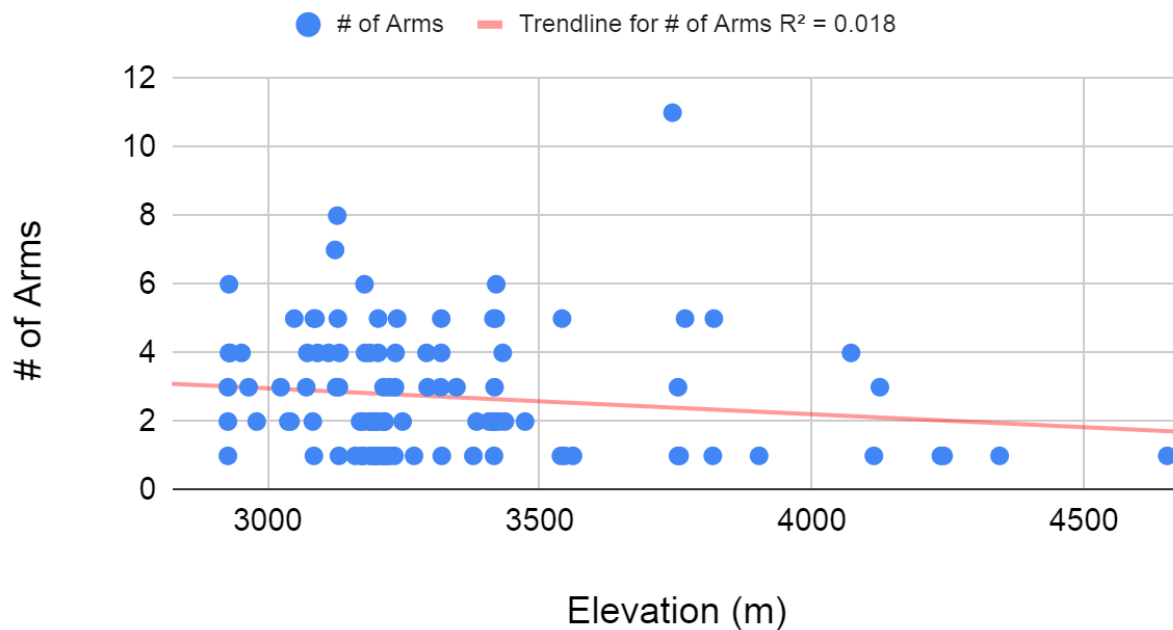


Shown above is the unedited graph with all 412 data points.

The trendline for the data shows a R-squared value of roughly 0.005, meaning that 0.5% of the variability in the predicted number of arms is accounted for by elevation. When the square root of 0.005, as mentioned above, is taken, this will yield “r,” or the correlation coefficient. Since $r = -0.07$, there is a very weak, negative association between the observed number of arms and elevation. Two conclusions come from this: The number of arms decreases as elevation increases and there may be a model that fits the data better, but the linear model is not appropriate. This coincides with claims in the study conducted by Yeaten et al. that Saguaros grow less arms at higher elevations (Yeaten et al.) The majority of the Saguaros tested, 73.79% or 304, had zero branches off the main stem while 8.5% or 35 had one branch, 5.83% or 24 had two branches, 3.88% or 16 had three branches, 3.64% or 15 had four branches, 2.91% or 12 had five branches, 0.73% or two had six branches. The remaining three Saguaros had seven, eight, and 11 branches, respectively, and each accounted for 0.24% of the datapool.

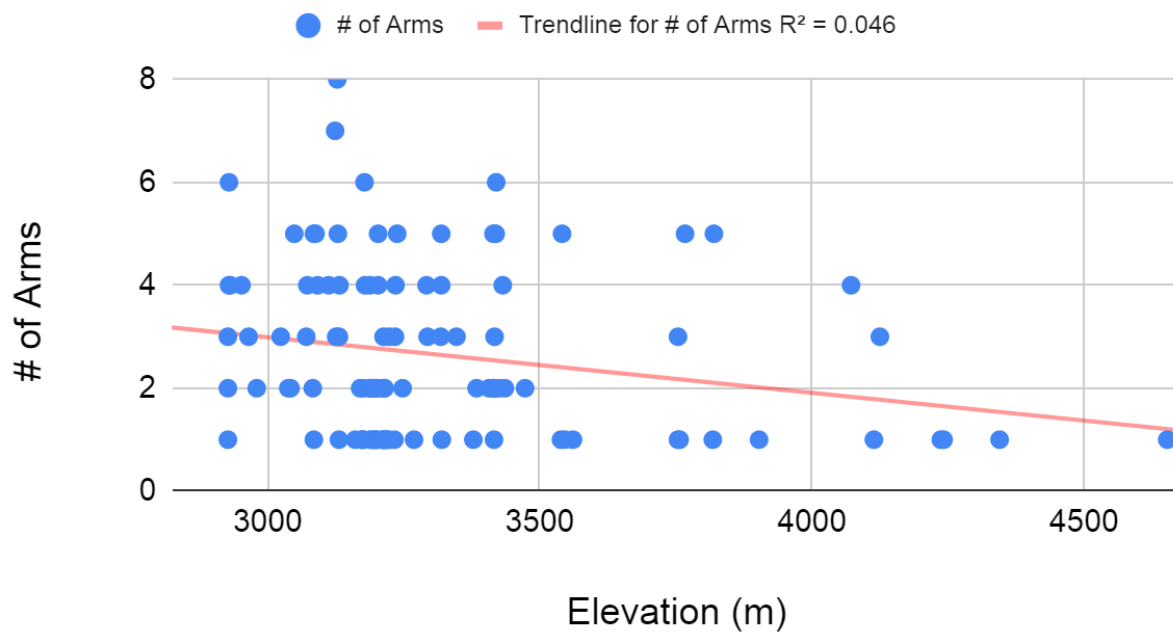
On the topic of Saguaro growth, cacti were growing in plenty around lower elevations between 2,850 feet and 3,500 feet, with the majority of the data points within this range being Saguaros with zero arms off of the main stem. Cactus growth seemed to begin to thin out starting at 3,500 feet and, generally speaking, the change in elevation began to increase between each Saguaro recorded. The dataset, overall, created a bell-curve that depicts an a-symmetrical distribution that is skewed to right as shown above. The distribution is centered at an elevation of 3347.17ft. The minimum elevation of the dataset occurs at 2850ft and has a maximum elevation occurring at 4653ft. As a result of the data, it can not be determined that there is an elevation barrier on Saguaro growth and development as well as branching behaviors. There is enough data, however, to suggest a correlation that Saguaro growth and, more importantly, the number of arms grown off a main stem decreases as altitude increases.

of Arms vs. Elevation (m)



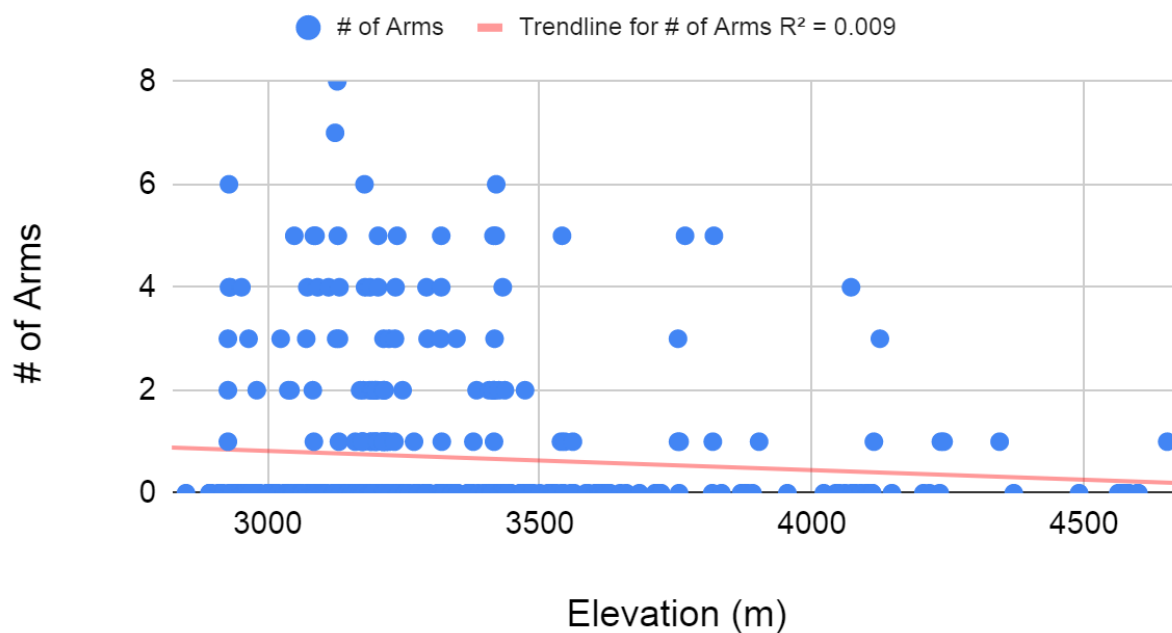
Shown above is the graph with each "0 number of arms" data point removed to show how the trend is set using strictly Saguaros that did grow arms.

of Arms vs. Elevation (m)



Shown above is the graph with each “0 number of arms” data point removed as well as the single data point which contained 11 arms removed to emphasize how such an outlier can skew data. Compare with the graph above this one.

of Arms vs. Elevation (m)



Shown above is the graph with only the single 11 number of arms data point removed to show how such an outlier can skew data. Compare with the first graph.

Number of arms	1	2	3	4	5	6	7	8	9	10	11	12	Total
Number of Saguaros	304	35	24	16	15	12	3	1	1	0	0	1	412

Shown above is the data table depicting the number of Saguaros that were observed to have grown each number of arms.

Discussing branching, or the process of a Saguaro growing arms off of the main stem (excluding the main stem), the dataset shows that the majority of the Saguaros did not grow any arms at all, while a handful grew arms but climaxed at 11. The data table above depicts that branching occurs in a pyramidal structure. This means that zero arms will be the greatest observed number of arms and as the number of arms grown increases, the frequency for those numbers will decrease with each additional arm. Additionally, branching was observed to decrease as elevation increases. That is, there was a greater number of arms observed more frequently at lower elevations and as elevation increases, branching becomes less frequent and the number of arms grown decreases as well.

Further research is required in order to elaborate and create possible correlations between Saguaro branching and changes in elevation. While the relationship between branching and changes in elevation is shown to be inversely related, as shown by the dataset in the graph above, the sample size collected was only a small portion of the Saguaro population in Saguaro National Park West as well as a small portion of the Saguaro population that exists across changing elevations. Research should be conducted across other peaks throughout the park and other mountainous locations across southern Arizona and possibly across the sonoran desert in order to come to any certain correlations regarding the matter. Additionally, data was collected on a subjective basis in the interest of time management and allows room for bias in collection. Bias is introduced when determining the distance of a Saguaro off of the trail and whether or not it should be included in the dataset. Further research and more time allotted would allow for more accurate data collection and a more defined dataset. Bias is also introduced in determining the

trail used for the study, as the South face of Wasson Peak has been observed to have more Saguaro growth in higher elevations than the North face. A study in Saguaro National Park East or Coronado National Park would be of great interest as the mountains are of greater elevations compared to Wasson Peak and may provide more accurate information in determining the barrier, if any, on Saguaro growth and branching development.

CONCLUSION

To briefly summarize all of the above, Saguaro branching research is a lightly touched upon area of study under the grand umbrella of Saguaro scholarly work. What work has been done, especially by Drezner and other scientists, has shown primarily the relationship between branching and precipitation levels with an underlying theme on elevation. That is, as elevation increases, it is expected that stagnant waters and humidity would decrease. On the other hand with my study, I am studying the direct relationship between Saguaro branching and elevational changes at a specific area in Saguaro National Park West, being Wasson Peak. Wasson Peak is one of the highest peaks in SNPW and also has sustained no fire damage like her sister parks to the North and East. This has made King Canyon Trail to Wasson Peak a prime subject of study as well as it provides extensive elevational changes that may not be found commonly around Tucson, Arizona unless you are in one of the other National Parks in the surrounding area.

The branching data was collected over a 2 day period and consisted of rough elevation levels at each Saguaro data point. Additionally, the number of arms each Saguaro has was recorded in order to observe how branching changes over large differences in elevation. Over the course of 3.3 miles, 412 data points (Saguaros) were recorded and their elevational and branching data was recorded as well. There was a 1,803 ft change in elevation from the starting

point of the hike to the top at Wasson Peak. The data trends showed that overall, Saguaro branching became not only less common in higher elevations but also the number of arms growing on Saguaros became less frequent at higher elevations. There are many reasons for these observations but they are not limited to; Saguaro climate dependency, decreased precipitation and standing water at higher elevations and decreased humidity at higher elevations. The goal of this study was strictly to observe and theorize on the relationship between elevation change and the frequencies of Saguaro branching.

Saguaro branching is a result of reproductive fitness. This is because each arm on the cactus has the same reproductive abilities as the main stem and in some studies, the main stem is counted as one of the branches. Having more branches may be a result of increased humidity and/or precipitation or other causes and will result in a greater fitness, or the increased likelihood of passing on their genes to their offspring than those with fewer branches. Additionally, as elevation increases, temperatures decrease and Saguaros are temperature sensitive as they thrive in warmer climates. These lower temperatures are most likely the reason for decreased Saguaro growth and less frequent branching at higher elevations. On the other hand, Saguaro growth has been theorized to increase on slopes as the earth slowly becomes warmer but over the past decades there has been no supporting research or observations to validate these claims. In order to make any claims on these trends in the dataset, more research is required in studying the complex relationships between Saguaros and the environment in which they live.

Further research is necessary in order to establish any correlations with statistical significance. For instance, the linear statistical model was not appropriate as it resulted in a negative, weak association and looking forward it would be encouraged to look at other models that could appropriately handle datasets with exponential trends. Additionally, using larger

datasets encompassing a multitude of varying slopes and trails in each of the four mountain ranges surrounding Tucson, Arizona would aid in making such claims.

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