Saving saguaro cacti at Saguaro High School

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Introduction

A few years ago, the Saguaro Environmental Club (Fig. 1) formed at Saguaro High School, in Scottsdale, Arizona, USA, as a place for like-minded students to engage with each other and explore the intricacies of sustainable living in the desert landscape. Students participating in the club have a shared goal of learning more about the Sonoran Desert and how they can directly contribute to conservation, restoration, and research efforts in their local environment. The Environmental Club has tackled issues related to sustainability on campus, recycling, and general environmental awareness. However, this story shares the opportunity that we have had to work with scientific partners around the Phoenix Valley area to conduct a large-scale project on our campus that addresses real-world and pressing ecological problems.

Forming our vision

In recent decades, Arizona has experienced the drastic effects of increased urbanization and habitat change, including the rapid expansion of invasive species, like the highly flammable red brome (*Bromus madritensis)* and schismus (*Schismus arabicus)*, which we have observed in Scottsdale's McDowell Sonoran Preserve. Stresses like invasive plants, and others, may be causing possible alterations in soil nutrient levels and microbial functioning in desert communities (Hall et al. 2009), and changes in environmental stability have led to warmer temperatures and more heat stress for plants and animals (Baker et al. 2004). It is possible that these changes also correlate to a higher potential for wildfires, exacerbated by the arid climate and decreased barriers between wild and urban areas, and therefore an increased need for effective desert restoration methods. Many of the natural defenses of the desert, especially its strong, native flora species, such as the saguaro cactus (*Carnegiea gigantea* Britton & Rose*)*, have been damaged because of these changes. Specifically, 270 saguaro-populated acres of what became our field study site, the McDowell Sonoran Preserve, were moderately damaged during the Diamond Fire in the summer of 2023 (Fig. 2).

While this fire gave us a "blank slate," so to speak, to conduct restoration experiments and learn more about the biotic connectivity of the desert, it also clearly demonstrated the need for effective restoration techniques and the importance of ecological awareness throughout the local community that interacts with this landscape. As such, students in the Saguaro Environmental Club worked closely with staff and stewards at the McDowell Sonoran Conservancy and faculty at colleges throughout Arizona to bring these issues to light, spread awareness throughout the community, and contribute scientifically to solving problems like land degradation in the desert.

When approaching this project, we felt empowered to conduct relevant research in the company of like-minded peers. The component of collaboration was key in our mission, and only fueled our passion for spreading awareness about environmental stewardship. In early 2023, while partnering with McDowell Sonoran Conservancy staff and stewards, local community leaders, and faculty from local colleges, our club quickly went to work developing ideas for our project and mapping out how we wanted to convert our campus grounds into a place for ecological research: a "living laboratory." We were able to define our vision by creating a graphic roadmap (Fig. 3), alongside our partners, of what we wanted this project to represent and how we wanted it to impact our school, the students, community, and landscape around us. This enhanced presentation of our ideas was beyond motivating for us in the weeks leading up to our restoration projects and allowed for the larger "Living Labs" vision to be displayed in an easily understood way. Overall, we found that our graphic roadmap laid the perfect foundation for our journey and our goals.

1. Environmental Club student members and McDowell Sonoran Conservancy stewards examining moss and lichen samples during our first ever field trip to the preserve (left). Students and stewards on our campus creating "seed balls" containing native pollinator seeds as a restoration effort in response to the Diamond Fire (right).

That spring, we completed the first labor-intensive phase of our vision, converting our campus into a sanctuary for native pollinator species. This phase involved removing many bushes of an invasive fountain grass species (*Pennisetum setaceum* (Forssk.) Chiov.) from long-time untouched planters on our campus. As we learned, seeds of these non-native grasses are easily spread by wind and can outcompete many native plants for resources. Additionally, the overabundance of grasses like these and other invasives in the desert may be leading to increased severity and intensity of fires (Wilder et al. 2021, McDermott 2024) and are reducing the resources for our native pollinators like hummingbirds, bats, and butterflies. In place of these grasses, we planted over a dozen native Arizonan pollinator species that are specially adapted to attract and retain the many pollinators living in our area. These species include the fairy duster (*Calliandra eriophylla* Benth.), desert marigold (*Baileya multiradiata* Harv. & A.Gray), and desert willow (*Chilopsis linearis* (Cav.)Sweet) (Fig. 4).

Our goals with this part of our project were to promote biodiversity on campus, beautify the campus, and simultaneously address a major issue that the Sonoran ecosystem is currently facing: loss of its pollinators. Since planting our pollinator garden, students have been periodically collecting biodiversity data using iNaturalist (www.inaturalist.org), by splitting our campus into several survey areas (Fig. 5). So far, we have observed successful plant growth and an increased presence of pollinators like butterflies and hummingbirds.

2. McDowell Sonoran Conservancy Steward, John Parente, and Saguaro Environmental Club students discussing their observations during a walk-through of the site of the Diamond Fire on the McDowell Sonoran Preserve.

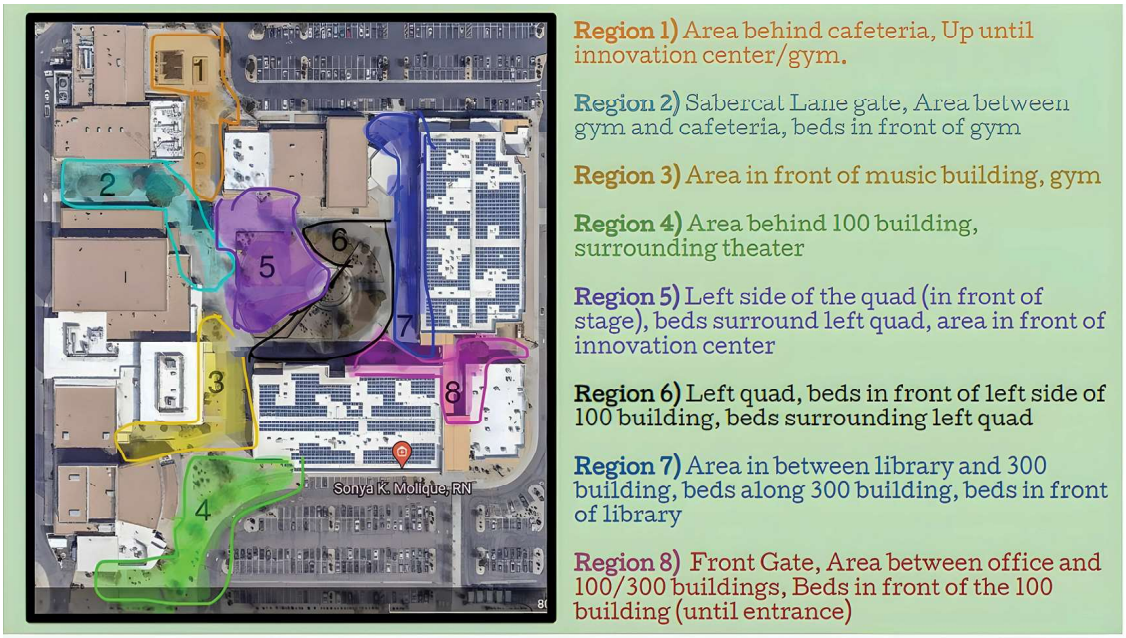
Time for some "real science"

Once the pollinator garden was established, we focused more heavily on our opportunity to conduct an experiment focused on saguaro cacti growth and nurse conditions. Initially, this study was intended to simply explore the impacts of nurse conditions on the growth of saguaros, but as it evolved, and after the Diamond Fire, it became a way for us to contribute to understanding paths toward saguaro restoration after a disturbance.

We attended a series of field trips and in-classroom workshops with our partners from the McDowell

3. Image of our graphic roadmap. The map provided us with a vision for our project and our goals for the future. Some of our ideas included the saguaro nurse condition project, researching biocrust, and increasing the presence of native species on campus. Taryl Hansen from Scottsdale's Frame the Message Ink generously donated her time and resources to us and drew this image for us, live, as we sat down with our many partners (logos on bottom of image) to brainstorm what we all wanted to achieve in creating our district's first "living laboratory".

4. A before and after shot of the removal of invasive grasses and replacement with native pollinator species in one of the main planters on our school campus. Students worked with SUSD facilities, community members from the Scottsdale Leadership Group, staff and stewards from the McDowell Sonoran Conservancy and faculty at Scottsdale Community College and Northern Arizona University to complete this first phase of our campus transformation. A schematic of the plant species included in the planter is displayed in the bottom right of the image.



5. Our study areas for our campus. To collect initial biodiversity data, the campus was split into eight relatively similarly sized study areas. Pairs of students walked each study area and collected opportunistic data on all species observed in that study area. Initially, we did not observe much biodiversity on campus. Since our planting of the pollinator garden and saguaro planter, however, we have observed noticeably more species (mainly insects and birds).

Sonoran Conservancy and faculty from Northern Arizona University. We learned that, along with other native plants, saguaros have been threatened by extreme temperatures, wildfire damage, and illegal poaching (Hultine et al. 2023). We also learned that, despite threats to them, saguaro cacti are a vital part of arid ecosystems, providing nutrients, water, shelter, and energy to many desert consumers while helping to support a diverse network of native pollinators (Winterbottom 2021). However, while the saguaro is widely known as an icon of the Sonoran Desert, and their importance for the survival of many other species is commonly observed, it is not entirely clear what conditions are best for the survival of the saguaro itself.

Being from Saguaro High School, we were the perfect place to house an experiment focused on saguaro cactus growth, so we accepted the opportunity to conduct a research project exploring methods to hasten their growth using various nurse conditions. Nursing, we learned, occurs when a human-placed or natural object or plant in the microhabitat of a subject species enables it to grow faster and healthier (Soliveres et al. 2012). Different species of cactus have variations in their nurse requirements, with some preferring objects over biotic nurses and some preferring specific trees and shrubs over others (Drezner 2006). Most commonly, nurse conditions are plants, which facilitate the growth of a differing plant species by creating microhabitats under a protective canopy, providing shade and other benefits to their establishment and survival (Valientebanuet and Ezcurra 1991). Many existing studies focus on nurse conditions and their impact on saguaros in their first stages of development, arguing that the establishment of saguaro pups near nurse plants positively influences their microclimate, protects seeds and seedlings, and aids in survivorship during the early stages of growth (Drezner and Garritty 2003; Drezner 2006). Others state that nurse rocks may play an equally important role in modifying local conditions and providing shade in a harsh environment (Peters et al. 2008). In fact, some studies argue that, while nurse plants are highly beneficial during seedling establishment, it may be abiotic nurse objects, such as rocks, that are of the most benefit during the first few years of growth. This is thought to be because nurse plant associations likely cause issues with resource allocation between plants and saguaros, while nurse objects still provide the necessary heat relief or insulation from cold, moisture retention, and protection without introducing competition for nutrients (Munguia-Rosas and Sosa 2008). In our research, however, we noticed relatively few studies that investigated these

6. Transformation of our study area by Environmental Club Students, Scottsdale Leadership Group Members, Scottsdale Community College faculty and McDowell Sonoran Conservancy staff and stewards. Converting this planter took us 20+ hours of work in the heat and dirt, but at the end we had a leveled, irrigated and sectioned out research area for our saguaro pups.

topics in controlled experimental plots rather than in the field through observations of associations. Therefore, we found the setting of our experiment, our high school campus, to be unique in the sense that it allowed for a more stable environment, with minimal disturbances, in which we were able to experimentally change nurse conditions while creating a space for a meaningful research project.

Our partnerships with Northern Arizona University's Dr. Helen Rowe and the McDowell Sonoran Conservancy granted us the opportunity to experiment with various nurse conditions, including shade

cloth, rocks, and plants, and study their effects on the establishment of 40 saguaro cactus pups. Our subject cacti, we planned, would be provided with combinations of the following conditions: shade cloth, a concrete paving nurse stone, and a native nurse plant, the triangle leaf bursage (*Ambrosia deltoidea* (Torr.) W.W.Payne). This is a species that both our students and McDowell Sonoran Conservancy stewards had observed as a potential natural nurse plant, as on the McDowell Sonoran Preserve they were commonly growing alongside, and possibly providing shade and other benefits to, saguaros and other desert plants. Though we personally observed these associations, other studies have previously found that the triangle leaf bursage is a preferential nurse plant for saguaro seedling and pup establishment as it provides high quality nutrients and microclimate amelioration (Franco and Nobel 1989, Drezner and Garrity 2003). Based on what we had learned from our partners and the research that we had done, we hoped to observe growth trends related to nurse associations in our cacti and were excited to get things started.

Setting up our saguaros

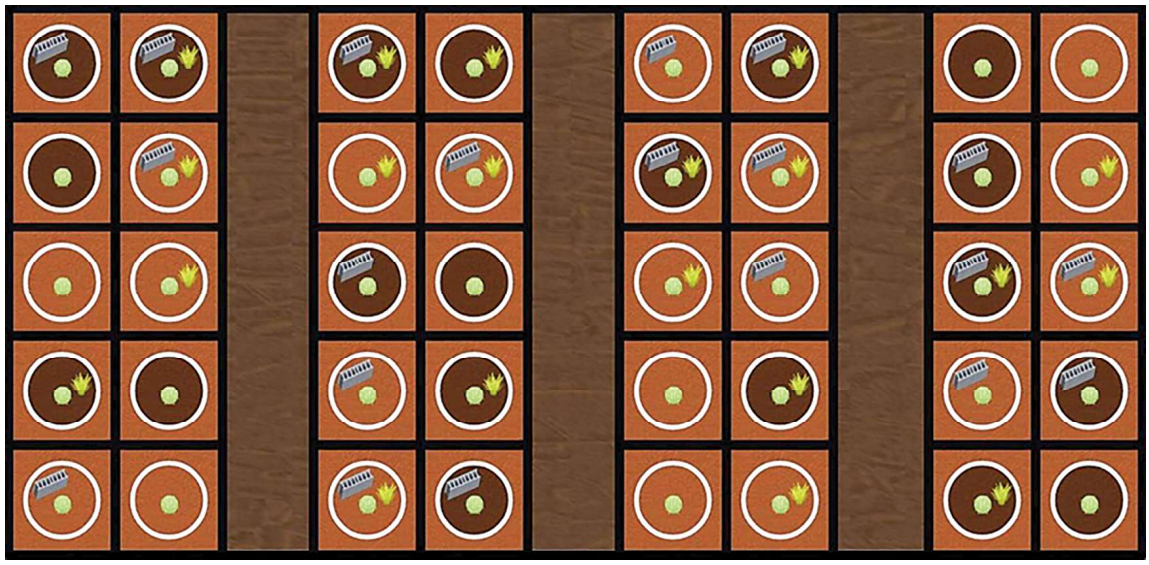
After working with the Conservancy and Dr. Rowe to define the conditions of the experiment, we began preparing the dusty, untouched planter that would become home to our "living lab." We worked alongside the Scottsdale Unified School District's facilities team to re-till the dry, compact soil in the planter, reinforce its concrete foundation, run irrigation lines, and create sections for our soon-to-be research plots. After a large group effort of digging, measuring, and laying pipes and hoses, the planter was finally ready for use and our saguaro-nurse conditions experiment was established on April 16th, 2023 (Fig. 6).

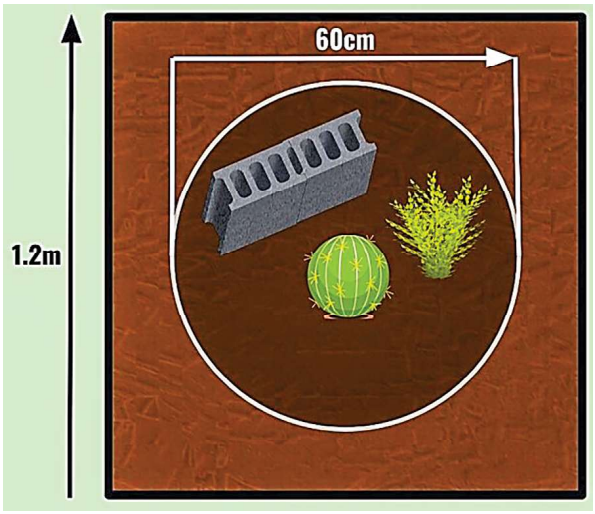
We divided 40 plots into 5 replicate blocks of treatments, with each plot measuring 1.2 meters long and 1 meter wide. In the center of each plot, we dug a 15-centimeter-deep basin with a diameter of 60 centimeters. The exact center of each basin was then marked as the planting location for each saguaro pup. Each cactus was initially grown under the same greenhouse conditions, then were planted in their basins on our campus along with randomized combinations of shade, a nurse triangle leaf bursage, a nurse rock, or nothing. Plots were initially "watered in" with 3.8 liters of water, 1.9 liters the following day, and 1 liter every other day for the next month. Since then, plots have been on a tapered watering schedule, receiving 1 liter of water every other day from 5/22/23 to 12/6/23, moving to 1 liter of water every Tuesday/Friday from 12/6/23 to 1/16/24, then receiving 1 liter of water every Tuesday from 1/16/24 to 2/13/24. Since 2/13/24 the irrigation lines to the plots have been turned off and all plots are currently receiving only natural water. Watering regimes were determined based on observations of plant growth and health, infiltration of soil in the basins, and trends in precipitation since the planting of the cacti. Supplementing the watering system was initially a way for us to ensure growth of our nurse plants, while also ensuring saguaro success before the heat of the summer and controlling the water each plot initially received. Their watering schedule will continue to be modified as needed as observations are made.

Shade treatments were placed on the southeast side of the saguaros, providing maximum shade cover according to solar trends and the location of the planter on our campus. Shade coverage consisted of a 50.8 cm x 43.1 cm square of 50% shade cloth attached to protective caging in the basin of the plots, for plots containing this treatment. Initially, all basins were encircled with 1" x 1" chicken wire, and for the plots receiving a shade treatment shade cloth was attached. Since the original planting, the chicken wire cages have been removed and, for those applicable, shade cloth remained attached to a section of the cage matching the size of the cloth. For the plots that received a nurse rock as part of their treatment, a 41.3 cm x 21.6 cm x 9.5 cm concrete paving stone was used for uniformity in size and shape. Nurse rocks were placed on the northwest side of the cacti (Fig. 7).

Gathering data

Once the saguaro plots were established, we took preliminary measurements of each juvenile cactus and the nurse plants we had planted (Fig. 8). Our initial procedure included measuring the height, width, number of ribs, and number of areoles per rib for each cactus. However, we encountered early problems with our original data collection protocol and learned a swift lesson in experimental design. With our initial measurement procedure, we noticed that it was difficult to keep our height measurement consistent between each cactus and between each data collection period. We also deemed that our measurement of the cactus base width was difficult to take accurately. These issues were exacerbated by the large number of club members collecting data simultaneously. Guided by the McDowell Sonoran Conservancy and





7. Illustrated and actual representations of our experimental plots. Each of the 40 plots received a saguaro pup and a randomized combination of shade, a paving stone, and a triangle leaf bursage. Plot sizes are 1.2 m X 1 m and basins are 15 cm deep X 60 cm in diameter. Each cactus was placed in the exact center of each basin and "watered in" using irrigation lines running to each individual plot.

Dr. Rowe, we modified our methods and established a simpler and more reliable protocol.

Many of the initial difficulties were eliminated by creating a set height from the level ground at which we inserted three clothes pins, shallowly, into each cactus. Pins were placed 18 mm up the body of the cactus from leveled ground, using a uniform height bracket for each plot, at the north, southeast, and southwest sides of the cactus. Using these pins as uniform base markers, height measurements are taken by carefully sliding a metal landscaping flag through the crown of the cactus, leveling the flag with a handheld level, and measuring the distance between each of the three pins and the level flag using a pair of calipers. In our first few rounds of data collection, we also measured the width of the base of the cactus from pin marker to pin marker, for three different measurements. Due to continued difficulties in reliability and potential damage to the cacti when setting the calipers, we have since fully eliminated the base width measurement. Ribs for each cactus are still counted as a method of tracking cactus width, as well as three

8. Demonstrations of our data collection methods. Environmental Club members getting dirty during our initial round of baseline data collection. Since our original procedure, our methods have changed to make data collection simpler and more reliable. Cacti have 3 sewing pins placed 18 mm from base height and a leveled landscaping flag woven through the crown of the cactus is used as a marker for the top. A caliper is then placed above the flag and under each of the 3 pins to measure height. Note the green/white paint visible on the crown and areoles of the cacti and the plot number and code located on the labelled popsicle stick.

counts of areoles, on the ribs to the right of each pin marker. Additionally, the main grouping of spines in the crown of each cactus has been painted with green, weather resistant paint to track growth. We intend to measure the spread of this paint from the crown to the body of the cactus as growth progresses. General notes on health and color of each cactus are also recorded during each round of data collection and opportunistically in between rounds of data collection (Fig. 8).

Along with measuring changes in our saguaros, we have collected data on the growth of the triangle leaf bursage in the plots that include them. Students are recording the height of each plant at the three tallest points, the width of each plant at the three widest points, general health, and an estimate of the percent of coverage in each 60 cm basin.

What we are seeing so far

Though we have not yet conducted a full analysis of our data and have much more data to collect, we have seen several changes in our planter that excite us. Despite losing three cacti to mishaps in their irrigation, an overwhelming majority of our experimental plots are thriving. We have noticed qualitative patterns in their growth that may indicate that the saguaros are benefitting from their nurse treatments. We have seen that, in the presence of shade and nurse rocks, cacti seem to grow larger and display a healthier

9. Students and McDowell Sonoran Conservancy Stewards collecting data and helping with the installation of the nurse experiment plots in the field, at the site of the Diamond Burn fire. These plots have slightly different experimental conditions than what we installed on our campus. With data collected from our saguaro planter, we hope to be able to add to what is being learned from these plots on the preserve.

appearance. Interestingly, some cacti in the presence of the triangle leaf bursage have seen low amounts of growth, while others seem to have greatly benefited from their placement. We hypothesize that some of the bushes have been consuming large amounts of the water that we provide to each plot and may be dominating the root systems of the cacti. We have been further drawn to this conclusion, as some of the bursage have grown so large that they have extended outside of their 60 cm basin; in these plots the cacti have not grown substantially since planting. To minimize potential effects of the bursage extending beyond their plots, such as providing uncontrolled shade to other plots, we have begun trimming them to fit within their plots' basins. A clear trend about the impact of the bursage is hard to identify, as some cacti have flourished healthily alongside them. The results that we are observing so far are certainly raising future questions for us to explore and are providing insights to answer previous ones.

In addition to collecting data on our campus, we have traveled to the burned area in the McDowell Sonoran Preserve multiple times to participate in a sister study in the field. We recently helped install study plots on the Preserve which nearly mirror those on campus. In the next few years, as the cacti on our campus and in the Preserve grow, we hope to discover what consistencies and differences exist between the two locations (Fig. 9). In addition to the nurse conditions that we are studying on campus, McDowell Sonoran Conservancy stewards are investigating how nursing with palo verde trees (*Parkinsonia aculeata* L.) benefits the saguaros. They are also taking sun exposure measurements with a photosynthetically active radiation (PAR) meter, which may provide deeper insight into how sunlight levels impact cactus growth. As our study on campus is more controlled and less susceptible to natural interference, it will likely give insights into which nurse conditions prove most successful in fostering the saguaros, while those in the preserve may reveal limitations to nursing.

Thoughts toward the future

Working on the Saguaro High School "Living Labs" project has given the entire Environmental Club the unique opportunity to conduct relevant research on our own campus. The research skills that we have gained from "Living Labs" have given us a solid foundation to continue pursuing scientific fields in the future. None of us had research experience before; through this project we came to understand its importance to solving crucial issues that face our community and environment. It has also been an excellent opportunity for all of us within the Saguaro Environmental Club to collaborate with community members and experts in environmental fields to create progress in desert restoration efforts. In addition to continuing the projects discussed in this article, we also have plans to establish a biocrust research project, investigating the impact of soil substrates on biocrust growth. We have even had the opportunity to present the project's development to a group of over 70 volunteers and ecologists at the Parson's Field Institute Ecological Symposium in May of 2023. Through our efforts on campus, we hope that we can be a model for our peers and other schools who are seeking to get involved in research and restoration.

Acknowledgements

Though we are still a long way from completing this project, at this stage there are already many people who we would like to acknowledge for their contributions. Without the help of the individuals and groups below, we would still be simply digging in the dirt.

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