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Soil crust does not have an effect on the health of *Cylindropuntia echinocarpa*

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In desert regions, soil crust serves a vital role in the survival of many plants. During drought conditions, desert plants experience elongated periods of water stress, increasing competition with other plants. Previous research has shown a symbiotic relationship between plants and soil crust as it prevents evaporation. However, there is little knowledge of the effect of soil crust on golden cholla. We surveyed areas surrounding golden cholla, *Cylindropuntia echinocarpa,* near Sweeney Granite Mountain Research Center in the Mojave Desert. We measured the health and size of golden cholla, accounting for human disturbance and surrounding plants, and taking into consideration current drought conditions. Our study found that soil crust does not have an effect on golden cholla health or size. We did find that higher coverage of small plants decreased golden cholla size, whereas higher rock coverage increased golden cholla size. This provides further evidence that the presence of small plants inhibits golden cholla growth.

Keywords: *Cylindropuntia echinocarpa,* desiccate, human disturbance, Mojave Desert, soil crust

INTRODUCTION

The Mojave Desert is a beautiful and diverse place filled with specialized flora and fauna. The uniqueness of this ecosystem makes it a popular camping and hiking destination. As tourism in the Mojave Desert increases, concerns for plant life are raised by possible effects of human disturbance. Desert plants are some of the most resilient as they can survive the arid environment with extreme weather conditions. Some of these are: creosote (*Larrea tridentata)*, juniper trees (*Juniperus osteosperma)*, mesquite *(Prosopis glandulosa)*, yucca (*Yucca schidigera),* several cholla species (*Cylindropuntia spp.*), along with small woody shrubs and invasive annuals, mostly bromus grasses (*Bromus diandrus*) (granit.ucnrs.org). However, many cacti are drying up in the Mojave Desert despite specialized adaptations such as water holding capacities and slower growth (Gremer et al. 2013). The Mojave Desert has been experiencing drought since 2011 with a decrease of 1.22 cm from average precipitation (drought.gov). Extended drought periods raise further concerns for plant life as human disturbance breaks soil crusts.

Soil crusts in arid regions are known to have a positive impact on vegetation (Zhang

2016). Soil crusts vary based on location, precipitation and level of disturbance. For example, light-algal/cyanobacteria, cyanolichen, green-algal/lichen, smooth-moss, and rough-moss are found on different soil compositions and geographies (Pombubpa et al. 2020). In the Mojave Desert, Rugose crust is the most common type (Belnap 2006). These crusts play a role in nitrogen fixing, soil stabilization, erosion prevention and help prevent invasive species from establishing (Johansen 1993). When it rains crust are also known to swell with water which helps hold it nearer to the surface for longer periods, helping to feed the surrounding plants (Carle 2010). Despite their importance and ubiquity in desert regions, soil crusts are surprisingly fragile. One of the biggest threats to biological soil crust in arid regions in southwestern United States are mechanical disturbance, such as vehicle traffic (USDA). When soil crust is broken or "disturbed" the structural integrity of the crust is destroyed.

One common Mojave Desert plant that may be affected by soil crust disturbance and competition is *Cylindropuntia echinocarpa* or golden cholla (referred to hereafter as golden cholla). Chollas (*Cylindropuntia* spp.) have a smaller volume of water-storage tissues, but have higher surface area to volume ratio, compared to other cacti such as barrel and columnar. This adaptation allows chollas to have cooler stem temperatures in hot environments but are more likely to experience higher mortality during extreme long-term droughts (Bobich et. al 2014). As golden cholla's root system is known to be 2 to 5 times as wide as the height of the cacti itself, sprawling under 2.5 inches of topsoil, there may be harmful impacts with less abundance of soil crust due to water loss (Pavlik 2008, Barger et al. 2006).

With decreased precipitation, competition among desert plants can be a growing factor in cacti desiccation. Generally it is found that plants closer together are smaller and more likely to die. Additionally, the survival and growth rate of shrub seedlings was lower when planted closer to adult shrubs than with those further away. With this in mind, we expected water stress to increase competition between plants that are experiencing severe droughts (Fowler 1986). Cacti use the Crassulacean acid metabolism or CAM cycle photosynthesis, which limits water loss during the day by opening stomata at night. When cacti are under persistently dry conditions, they keep their stomata closed, which eventually leads to desiccation (Pavlik 2008). These are a few of the adaptations golden cholla have to combat the harsh dry conditions of the Mojave Desert.

Insight on the interactions among disturbance, soil crust, and plants can display how desert organisms persist in prolonged dry conditions. We speculated that 1) an increase in soil crust would increase health and size of golden chollas; 2) more disturbance would cause decline in golden cholla health; 3) areas with more disturbance would have less soil crust; and 4) increased plant coverage would decrease health and size of golden chollas.

METHODS

2.1 Research

Research was conducted from February 24th-29th, 2021 at Sweeney Granite Mountain Research Center on the eastern slope of Granite Mountains of the Mojave Desert in San Bernardino county, California (elevation: 150-2,100 meters) where golden cholla are abundant. Additionally, golden cholla compared to other cacti species, are experiencing some signs of mortality due to current drought conditions. The topography of the rugged Granite mountains consisted of vast open space of high plateaus and ridges dominated by plant communities of pinyon-juniper woodland and mixed desert scrubs, with creosote and yucca as some of the dominant plant species (granite.ucnrs.org).

We chose 2 types of sites: more or less disturbed by human activity. More disturbed sites included campsites in the unregulated, frequently used, BLM (Bureau Land Management) land, and less disturbed sites included restricted access reserve land. We observed golden cholla adjacent to BLM campsites because we expected to find the highest possible disturbance; on the reserve, we expected to observe the least amount of disturbances.

Since golden cholla roots typically grow from 2 to 5 times the height of the plant, we assumed that at least 5 meters would be an appropriate minimum length to observe from the base of the plant (Pavlik 2008). Upon observing the golden cholla, we found an approximated average height of 2 meters. Thus, a 5-meter transect was placed along each cardinal direction (north, south, east, and west) from its base.

After golden cholla were chosen, the plant health was rated 0 to 5. **0** was assigned to plants that completely lack any living stems and leaves. No formation of new shoots or leaf growth were found; **1** was less than 12.5% of the entire plant living; **2** = 12-25% alive; **3** = 25-50% alive; **4** = 50-75% alive; **5** was more than 75% alive. Individual golden cholla health was visually estimated and categorized by a health index based on McAuliffe's and Hamerlynk's study (2000). Additionally, as a proxy for golden cholla size, radius and height was measured and used to calculate volume. For each golden cholla, a line-transect was used to measure surrounding ground cover. We accounted for soil crust, annual grasses, large plants, small woody shrubs, and rocks. We considered mesquite, juniper, creosote, yucca, and other chollas as large plants because they are of similar or larger size than golden chollas. Presence of soil crust was found by lightly applying pressure to the dirt under the transect tape line. If the top layer of the ground was sturdy and broke in flat, slab-like pieces, soil crust was present. Given their size, we can expect these plants to have large enough root systems to pose competitive threats towards golden chollas (Austin 1987). Small woody shrubs were plant species that are smaller in size compared to golden chollas.

2.2 Statistical Tests

All statistical tests were conducted using JMP ver. 15.0.0. Non-normal data was transformed for statistical analysis. The Anderson-Darling test was used to test for normality. Non-normal distributions were transformed using: Transformed value = log(X+(Y/2)), where X is the original variable, and Y is the smallest value greater than 0. Non-normal data included soil crust, large plants, and rock coverages.

A t-test was used to measure the difference of soil crust coverage between more disturbed sites and less disturbed sites. A X^2 test was used to test the effects of less and more disturbed sites on golden cholla health. Logistic regression was used to test for relationships between golden cholla size and golden cholla health. Logistic regression was also used to test for the effect of coverages of soil crust, larger plants, smaller plants, annuals, and rocks on golden cholla health. Linear regression was used to test for effects of coverages of soil crust, larger plants, smaller plants, annuals, and rocks on golden cholla size.

RESULTS

3.1 Disturbance

In total, data on 104 individuals of golden cholla were collected equally between more disturbed and less disturbed sites. There was a higher proportion of soil crust coverage in less disturbed than more disturbed sites (N=52, t=2.10, p=0.0386, Fig. 1). There were no differences in golden cholla health between less disturbed and more disturbed sites (N=104, X^2=5.88, p=0.318).

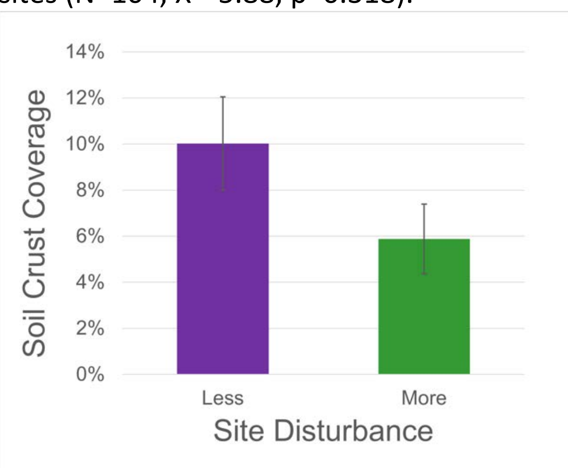

Figure 1. Difference in proportion of soil crust in disturbed and undisturbed sites. Less disturbed sites were located in unregulated campsite lands, and less disturbed sites were located in access-restricted reserve land. Ground cover was measured at 52 locations at each type of site. The x-axis represents the two categories of sites tested: less disturbed and more disturbed. The y-axis represents the percent ground cover of soil crust around an individual golden cholla (*Cylindropuntia echinocarpa).* There was a higher proportion of soil crust coverage at less disturbed sites (N=52, t=2.10, p=0.0386). Bars represent + 1 S.E.

3.2 Cholla Heath

There was no effect from the proportion of soil crust coverage on golden cholla health (N=104, X^2=7.43, p=0.190). There was no effect of the proportion of larger plant coverage on golden cholla health (N=104, X^2=6.19, p=0.289). There was no effect from the proportion of smaller plant coverage on golden cholla health (N=104, X^2=0.0121, p=0.604). There was a negative effect from the proportion of annuals coverage on golden cholla health (N=104, X^2=8.08, p=0.15). There was no effect from the proportion of rock coverage on golden cholla health (N=104, X^2=6.50, p=0.261).

3.3 Cholla Size

There was no effect from the proportion of soil crust coverage on golden cholla size (N=104, r^2=0.00441, p=0.503). There was no effect from the proportion of large plant coverage on golden cholla size (N=104, r^2=0.000673, p=0.79). There was a negative effect from the proportion of small plant coverage on golden cholla size (N=104, r^2=0.0550, p=0.0166). There was no effect from the proportion of annuals coverage on golden cholla size (N=104, r^2=0.00849, p=0.352). There was a positive effect from the proportion of rock coverage on golden cholla size (N=104, r^2=0.0732, p=0.0055).

DISCUSSION

Overall, our results did not support our hypothesis that soil crust would increase the health of the golden cholla. There was more soil crust coverage in less disturbed areas (Figure 1), however, golden cholla health was not impacted in either more or less disturbed sites. Since soil crust is a group of biotic life forms bonding together, it is easy to conclude it is more fragile, compared to other ground covers such as soil, gravel or rock. It follows that human interaction would cause disturbance and have a greater effect on soil crust. It has been shown how important soil crust is in a desert environment, and plays an important role in the ecosystem. It would be interesting to see why it does not have an effect on golden cholla and how much of an effect it has on the other plants in the desert community especially since disturbance does have an effect on soil crust.

While there was no observed effect of soil crust on golden cholla health or size, it was found that they were smaller in size when there was a greater presence of small woody shrubs (Fig. 2). This may be an indication of nurse plant relationships. It is possible that golden chollas use small woody shrubs as nurse plants, and thus are frequently found among small woody shrubs. This is backed up by a study conducted by Martin L. Cody (1991), to which they had also found that nurse plants may contribute to root competition, helping golden cholla survival early in life. Longer term studies can be conducted to observe how nurse plants can potentially stunt golden cholla growth past its early life stages.

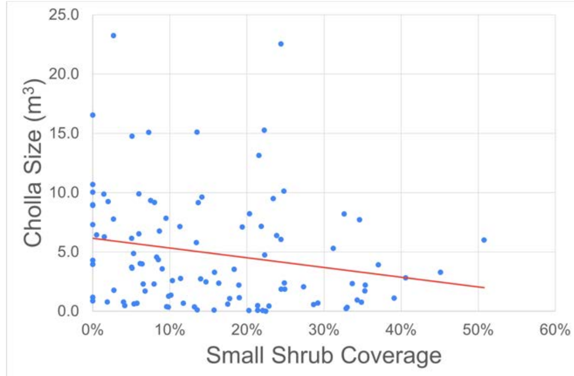

Figure 2. Negative effect of small shrub coverage on golden cholla size. This study was conducted at Sweeney Granite Mountain Reserve Center in the Mojave Desert. Data on 104 golden cholla and surrounding ground cover were measured. The x-axis represents the percent cover of small woody shrubs by an individual golden cholla (*Cylindropuntia echinocarpa).* The y-axis represents the size of golden cholla as approximated by volume. It was found that when small woody shrub coverage was greater, golden cholla size was smaller ($N=104$, $r^2=0.0550$, $p=0.0166$).

Furthermore, golden chollas were larger when found with higher rock coverage (Fig. 3). This may provide further evidence of root competition. The coverage of rock that was measured in our study was large enough to prevent other plants from effectively taking root and thus, most of the time, no plants were present where rock was measured. This could allow golden chollas to have less competition and potentially grow larger. McAuliffe and Hamerlynck's (2010) study supports the idea that large rocks slow the evaporation of water. This implies that golden chollas growing near rocks may have a better chance of survival as evaporation is decreased by rocks and competition from other plants is decreased. Gremer et al. (2013) also conducted a study that shows desert plants do better alone during wetter years. These studies support our findings that golden cholla would grow larger with higher rock coverage.

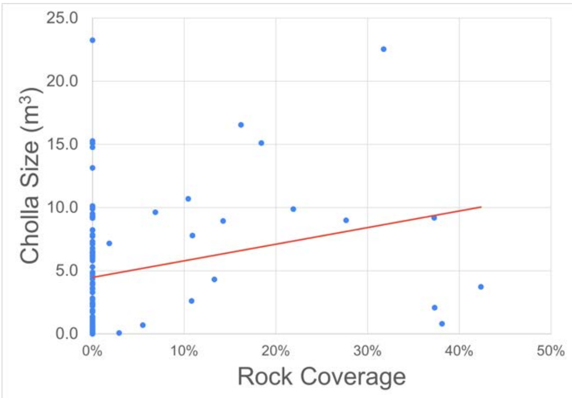

Figure 3. Positive effect of rock coverage on golden cholla size. This study was conducted at Sweeney Granite Mountain Reserve Center in the Mojave Desert. (N=104, r^2=0.0732, p=0.0055). Data on 104 golden cholla and surrounding ground cover were measured. The x-axis represents the percent cover of rocks by an individual golden cholla (*Cylindropuntia echinocarpa).* The y-axis represents the size of golden cholla as approximated by volume. It was found that when rock coverage was greater, golden cholla size was greater (N=104, r^2=0.0732, p=0.0055).

From our findings, larger golden chollas had relatively intermediate health whereas smaller golden chollas had more variable health (Fig. 4). With larger golden chollas, it is possible that they are more established and thus are less susceptible to environmental stress and could produce the low amounts of die-off that are expected of their general morphology (Bobich and Nobel 2014). Smaller golden chollas may be more susceptible to general golden cholla mortality rates, environmental stressors like competition and water loss, and incomplete root establishment.

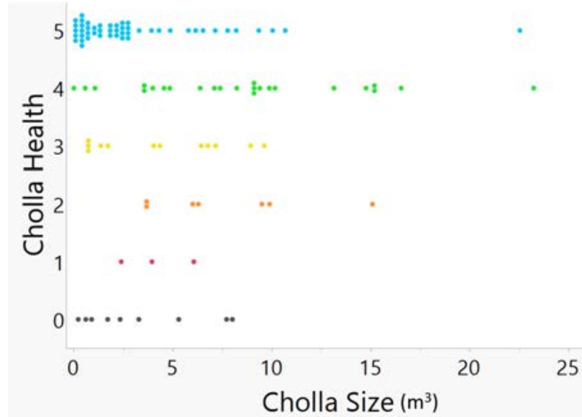

Figure 4. Golden cholla size by golden cholla health. This study was conducted at Sweeney Granite Mountain Reserve Center in the Mojave Desert. Data on 104 golden cholla (*Cylindropuntia echinocarpa)* were collected and categorized by the following visual health estimate index: **0** = 0%; **1** = 0-12.5% **2** = 12.5-25% **3** = 25-50% **4** = 50-75% **5** = 75-100%. The x-axis represents the size of golden cholla as approximated by volume. The y-axis represents the health of golden cholla as rated by the health index. Golden cholla that were smaller had more variable health, whereas larger cholla had more intermediate health (N=104, X^2=32.7, p<0.001).

Since our studies focus on visual health, we believe future studies should be done focusing on root systems. Cacti roots reach as far as possible in search of water, occupying much superficial space, competing for space rather than water (Gilbert, M. pers. com.). Additionally, Schenk (2006) claims that soil organisms have an important role in root interactions. However, we found no observed effect of soil crust on golden cholla health which contradicts this study. Further studies are needed on golden cholla interactions, as well as studies on the effect of rock on desert plants effect on the survival in different locations/geographies.

As our findings show golden cholla were not impacted by soil crust absence, it further supports studies that they are hardy desert plants (McAuliffe 2010). However, our experiment can be applied to any plants that are associated or have unknown association with biological soil crust. For example, blackbrush (*Coleogyne ramosissima*) are found in the western United states in hot and cold deserts. For the blackbrush community, soil crust was shown to improve growth, reduce energy investment in fine roots, enhance mineral uptake, and reduce competition from exotic annuals (Pendleton et al. 1999).

Additionally, desert plant's association with symbiotic fungi can be further examined. Specifically, cacti's association with mycorrhizal fungi. A study done in southern Illinois indicated that eastern prickly pear (*Opuntia humifusa*) showed higher levels of recruitment in association with higher density of mycorrhizal fungi compared to other areas states (Whitcomb 2000). Further work should be done to get a better picture if there is a correlation between golden cholla and mycorrhizal fungi.

Studies of how long cholla can survive without water have not been published. Cacti use the Crassulacean acid metabolism (CAM) cycle photosynthesis which limits water loss during the day by opening stomata at night. They stop opening stomata when there is no water available. To combat this, they drop their feeder roots but retain their anchor roots, and seal them until rain comes again. After precipitation, regrowth of feeder roots occurs within a short period of time (Pavlik 2008). When a cactus goes through this process, it will eventually desiccate if dry conditions persist. An observational study could be done by cutting a piece off of the main cacti to mimic the lack of root function and record how long it takes for desiccation to occur (Gilbert, M. pers. com.) Information of this kind could be useful in comparing cholla's water potential in drought conditions.

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