A TALE OF TWO CACTI: OPTIMIZING NATIVE RESTORATION AND CONSERVATION IN A FUEL MODIFCATION ZONE

Michelle L. dela Cruz[1]

[1]University of California, Irvine

3108 Biological Sciences III, Irvine, CA 92697

e-mail: mldelac1@uci.edu

Key words: wildland-urban interface, fuel modification zone, wildfire, fire management, coastal sage scrub, cactus scrub

ABSTRACT

Wildfire risk management at the wildlife-urban interface (WUI) is ineffective when agencies and institutions seek solutions to their objectives in isolation. Mitigation policies like bulldozed fuel breaks or large-scale fuel removal negatively impact natural habitats at the WUI by destroying or displacing native flora and fauna that need conservation. In 2018, the Center for Environmental Biology at the University of California, Irvine, initiated its Defensible Space Demonstration Project on the campus Ecological Preserve to show how conservation and fire safety protocols can be compatible at fuel modification zones (FMZ). Experimental cactus planting sites were set up on the eastern WUI of the preserve to meet FMZ standards while assisting local conservation efforts. Large and small clumps of *C. prolifera* and *O. littoralis* were tested to determine optimal planting strategies at the FMZ. Cactus survival, growth, and vegetation cover data were collected and analyzed to see which planting arrangement best facilitates cactus establishment and whether groundcover also has an impact. Few large clumps resulted in better growth and survival for both cactus species, though not always statistically significant, while percent thatch cover negatively correlated with *C. prolifera* growth. These results first suggest that further investigation of other factors contributing to the positive trend in large clumps. Secondly, the negative impact of thatch on cactus establishment confirms the need for non-native vegetation removal when restoring native habitat in an FMZ. Long term monitoring and adaptive active management of this project will help create a solid integrated risk management framework to address future urban fire and wildland conservation issues in southern California.

I. INTRODUCTION

Wildfire frequency and severity have substantially increased in conjunction with human population growth and expansion into wildland-urban interfaces (WUI), especially in the twenty-first century in California, USA (Pausas and Keeley 2009, Keeley and Syphard 2019). There have been nearly ten thousand wildfire incidents, over four million estimated acres burned, over ten thousand structures damaged or destroyed, and 31 lives lost in the state of California for the year 2020 (Cal Fire 2020). These devastating impacts necessitate wildland fire management strategies that mitigate loss of human life and property. However, current strategies such as altered fire regimes and large-scale mechanical fuel reduction often have negative ecological consequences on native biodiversity (Syphard et al. 2011, Syphard et al. 2016, Smith et al. 2016, Rice 2016). The balance between fire safety and ecological conservation is particularly challenging in southern California, where coastal sage scrub is widespread with highly diverse and flammable native plant species (Pausas and Keeley 2009, Underwood et al. 2018). Integrating multiple perspectives and agendas concerning WUIs—from government agencies to academic institutions and public perception—is a crucial next step in addressing broader challenges of wildland fire management (Smith et al. 2016).

The University of California, Irvine (UCI) Defensible Space Demonstration Project at the UCI Ecological Preserve exemplifies the multidisciplinary effort needed for sustainable wildfire management strategies. In this project, partnerships between public, private, and academic entities result in an adaptable fuel treatment plan with compatible social and ecological objectives (Calkin et al. 2014, Smith et al. 2016, Syphard et al. 2016). UCI-Nature and the Center for Environmental Biology (CEB) collaborate with the Natural Communities Coalition to design a fuel modification zone that supports wildland conservation and improves residential fire safety awareness while meeting fuel management standards in Orange County (Coffey et al. 2019). Fuel modification zones (FMZ) are strips of land at WUIs where existing combustible vegetation (fuel) is gradually reduced from the wildland toward the urban edge. Fuel is replaced with interspersed fire-resistant plants and irrigation within a given distance from urban structures to provide a fuel break. Experimental plots at the eastern edge of the Preserve demonstrate how native plantings in FMZs can restore habitat and conserve biodiversity while meeting fuel modification standards.

The UCI Ecological Preserve spans 62 acres of open space with 31 acres of cactus scrub and a remaining mix of coastal sage scrub, non-native grassland, and highly disturbed areas (Griswold et al. 2010). The Preserve is included in the Natural Community Conservation Plan/Habitat Conservation Plan (NCCP/HCP) and Nature Reserve of Orange County (NROC), except for FMZs due to public access and use. Between 2011 and 2016, the NROC restored cactus scrub habitats in the Preserve to conserve coastal cactus wren (*Campylorhnychus brunneicapillus*) and California gnatcatcher (*Polioptila californica californica*) populations which rely on prickly pear (*Opuntia littoralis*) and coastal cholla (*Cylindropuntia prolifera*) for shelter. These native and fire-resistant cactus species were excellent candidates for the experimental plots in the Preserve FMZs which tested whether few large clumps or several small clumps impact cactus survivorship and growth. CEB interns harvested cactus in December 2018 and initiated baseline monitoring at the sites before planting early in 2019. The first group of UCI Masters students in the Conservation and Restoration Science program (MCRS) began assessing cactus survival later that year in October.

As a first year MCRS student, I shall contribute to the ongoing assessment. The overall focus of the study is to determine an efficient planting strategy of cacti that facilitates best practices in FMZ management. I will assess cactus survival and growth by answering each of the following three questions for coastal cholla and prickly pear. First, are survival rates significantly different between clump sizes (large/small)? Second, is cactus growth (in the combination of additional pad count per plant and maximum clump height) significantly different between clump sizes? Finally, is there a significant association between thatch percent cover and growth in terms of maximum clump height?

II. METHODS

Experimental design. The defensible space planting project consisted of three manipulated experiments on cactus establishment, native annual herb establishment, and irrigation regimes, and one observational study on ground/vegetation cover. Data were not yet available for the native annual herb and irrigation studies, so I focused my analyses on cactus establishment and ground cover surveys. Three study sites were located at the wildlife-urban interface between the eastern edge of the Preserve and the University Hills residential community (Figure 1). Baseline monitoring on biotic and abiotic conditions of the experimental plots began in January 2018. In this study, I analyzed cactus and cover data that my cohort and I (graduate students in the UCI Masters in Conservation and Restoration Science) collected at the Preserve in October 2020.

Cactus establishment. Cactus survival and growth were tested between two planting arrangements that met fuel modification standards: cacti were either planted together in a few large clumps or several small clumps. Cacti response was tested in a randomized block design: clump treatment (small, large) were divided into half block plots and replicated in eight blocks across the three sites. Single cactus pads were initially planted; small clumps were in groups of four of the same species, and large were in groups of 16 (four cholla and 12 prickly pear). There were six small cholla clumps, 18 small prickly pear clumps, and six large clumps per block replicate. We counted the number of rooted living cacti to determine survival and measured growth in terms of total pad count and the maximum clump height (cm) for each clump.

Native annual herb seeding. The native seeding experiment was designed to increase native biodiversity of vegetation cover and test interactions between cactus clump sizes and native annual seed establishment. Two additional treatments were incorporated into the randomized block design on cactus clump size. Each block was further divided into seeded and unseeded resulting in four plot types per block: small clump seeded (SS), small clump unseeded (SU), large clump seeded (LS), and large clump unseeded (LU) (Figure 2). Local native annual seeds were collected and cleaned by hand and weighed, but there were not enough seeds to sow and begin the experiment in the winter of 2019 as intended.

Percent cover transects. Percent cover data was collected to test interactions between cactus plantings, composition of vegetation/ground cover, and eventually native annual seed establishment. We surveyed ground and vegetation cover on each plot type with two point-intercept transects and 15 points per transect. Transects were 12 meters long for plots with small clumps and 7.5 meters long for plots with large clumps. We categorized observations into nine cover types (bare, rock, stem, litter, thatch, moss, coarse woody debris, fine woody debris, and cryptobiotic crust) and recorded the six-letter code for any native species that intercept the transects.

III. STATISTICAL ANALYSES

Cactus survival and growth data from block VB 1 were omitted from the analyses due to recording errors and several new metrics were computed. For question 1, survival rates were calculated by dividing the number of rooted living cacti by the initial plant count of cacti in each clump. For question 2, growth in terms of average pads per plant was calculated by dividing the total pad count by the initial plant count for each species and clump size. For question 3, percent thatch cover was calculated by dividing the number of thatch counts by the number of observations per plot. Cactus variable names were CYLPRO for coastal cholla and OPULIT for prickly pear in the analyses and resulting figures. All analyses and computations were conducted in R (RStudio Team 2020). All R packages used in the analyses were listed and cited in the code of conduct file in APPENDIX A.

Cactus survival and clump size. Differences in median survival rates between large and small clumps of each cactus species were compared with Wilcoxon tests due to non-normal data. Assumptions of normality were tested with Shapiro-Wilk tests and violated for both cacti. However, assumptions of homogeneity of variance were tested with Levene tests and met.

Cactus growth and clump size. Differences in growth between clump sizes for each species were compared with a MANOVA with the combination of average pads per plant and maximum clump height as the dependent variables. Univariate and multivariate outliers were present in both variables in both cactus species, with only one extreme univariate outlier in prickly pear pads per plant. Assumptions of univariate normality were reasonably met in quantile-quantile plots, but multivariate normality was violated in Shapiro-Wilk tests. Linearity and multicollinearity assumptions were tested and met with scatter plots and Pearson correlations. Assumptions of homogeneity of variance were tested with Levene tests and met for prickly pear data but violated in coastal cholla data. I determined a Welch ANOVA post-hoc test would be used for any significant differences detected in the coastal cholla MANOVA. Homogeneity of covariance assumptions were tested with Box M tests and violated in both variables of both cactus species, so I ran the MANOVA with a Pillai multivariate statistic.

Thatch cover and cactus height. Associations between percent thatch cover and maximum clump height across plot types were tested in each cactus species with a Spearman's Rank Correlation. Shapiro-Wilks tests showed that percent thatch data were non-normal, however maximum clump height was normal in both cacti. The assumption of homoscedasticity in the linear model was tested and met with a residuals vs. fitted plot.

IV. RESULTS

Wilcoxon tests showed no statistically significant differences in median survival rates between clump sizes neither coastal cholla, $W = 1112.5$, $p > .05$; nor prickly pear, $W = 3446.5$, $p > .05$ (Figure 3). The MANOVA showed significant difference in growth for prickly pear but not cholla (Table 1). A post-hoc Welch ANOVA test showed prickly pear only differed significantly in max clump height between clump size (Table 2, Figure 4, Figure 5). The Spearman's Rank test showed a statistically significant and moderately negative correlation between percent thatch and max clump heights of coastal cholla; but the association was insignificantly negative for prickly pear (Figure 6).

V. DISCUSSION

The cacti establishment experiment was designed to observe suitable planting strategy for cactus scrub in future fuel modification zones. Clump size did not impact survival for either species in this study, but overall survivorship was high for both species as confirmed in previous studies (Land IQ 2016, Coffey et al. 2009). Interestingly, average cholla survivorship improved from just under 80% (Coffey et al. 2019) to roughly 89% (Table 3) over 12 months since the last cactus survey. This indicates that new cholla have rooted across the experimental sites in the past year and cholla reproduction is successful in the FMZ Preserve environment. The Preserve FMZ is highly degraded and publicly accessible; the disturbance may facilitate cholla's habit of easily dislodging and re-rooting elsewhere (Baumann 2017).

Differences in cactus growth between clump sizes were generally small and insignificant. However, all cacti grew better in large clumps than in small clumps—another trend supported by the previous year's assessment (Coffey et al. 2019). Prickly pears were significantly taller in large clumps this year although the mechanism for that effect remains unclear. Coffey et al. (2019) suggest mutualistic effects between cacti, neighboring vegetation, and non-native competition suppression. These effects can be assessed with additional data on vegetation and ground cover, as well as the native herbal seeding experiment. In this case, Occam's razor beckons me to first consider the basic factors of plant growth—light, temperature, precipitation, soil, and other such data would make good covariates for future analyses on cactus growth. Surrounding ground and vegetation cover play a large part in increasing native biodiversity in FMZs though. Thus, I examine the influence of thatch cover on cactus growth in my last question.

Thatch is generally made of any matted accumulation of dead plant matter, though non-natives species tend to produce more thatch than native species (Coffey et al. 2019). As percent thatch increases in the Preserve FMZ, cactus growth declines. This effect is more pronounced cholla clumps; it would be a good place to start in the event thatch removal must be prioritized. The negative impact of thatch on cholla also suggests a negative impact on native annual seed establishment which has been demonstrated in coastal sage scrub habitat such as the Preserve (Martinson et al. 2008). In addition to helping cholla establishment and making room for annual native ground cover, thatch replacement also reduces the risk and amount of flashy dead fuel that often sustains wildland fires (Keeley & Syphard 2019).

Conclusion. We can now recognize new trends to continue monitoring in the UCI Defensible Space Demonstration Project. Coastal cholla and prickly pear seem to experience better survivorship and growth when planted in few large clumps, while thatch removal indicates positive benefits for cacti, native, and a reduction in fuel and fire risk. Upcoming experiments with native annuals and irrigation will present new opportunities for fire safety education and collaboration around the University Hills community and UCI Preserve FMZ. The framework for social and ecological integration in risk management will improve as the Defensible Space project develops. This integration is critical for effective mitigation of wildfire impacts in Orange County and the state of California.

LITERATURE CITED

Baumann, L. (2017). *Coast Cholla*. Santa Monica Mountains Trail Council. Retrieved December 19, 2020, from https://smmtc.org/plantofthemonth/Cholla.php

Cal Fire. (2020). *Incident archive*. Retrieved December 17, 2020, from https://www.fire.ca.gov/incidents/2020/

Calkin, D. E., Cohen, J. D., Finney, M. A., & Thompson, M. P. (2014). How risk management can prevent future wildfire disasters in the wildland-urban interface. *Proceedings of the National Academy of Sciences*, *111*(2), 746-751.

Coffey, J., Kimball, S., & Lulow, M. (2019). Wildfire safety and healthy habitats: UC Irvine defensible space demonstration project.

Griswold, M., Preston, K., & Bowler, P. (2010). Measure M cactus scrub restoration plan for the University of California Irvine Ecological Preserve.

Keeley, J. E., & Syphard, A. D. (2019). Twenty-first century California, USA, wildfires: fuel-dominated vs. wind-dominated fires. *Fire Ecology*, *15*(1), 24.

Land IQ. (2016). 2016 Performance monitoring report: Year 4 Measure M cactus scrub restoration for the University of California Irvine Ecological Preserve.

Martinson, E. J., Hunter, M. E., Freeman, J. P., & Omi, P. N. (2008). Effects of fuel and vegetation management activities on nonnative invasive plants. *In: Gen. Tech. Rep. RMRS-GTR-42-vol. 6.* US Department of Agriculture, Forest Service. https://www.fs.fed.us/rm/pubs/rmrs_gtr042_6/rmrs_gtr042_6_261_268.pdf

Pausas, J. G., & Keeley, J. E. (2009). A burning story: the role of fire in the history of life. *BioScience*, *59*(7), 593-601.

Rice, C. L. (2016). Stakeholder implementation guide: University of California, Irvine for the Natural Communities Coalition Wildland Fire Management Plan.

RStudio Team (2020). RStudio: Integrated development for R, Version 1.3.1093. RStudio, PBC, Boston, MA. Available from http://www.rstudio.com/.

Syphard, A. D., Keeley, J. E., & Brennan, T. J. (2011). Comparing the role of fuel breaks across southern California national forests. *Forest Ecology and Management*, *261*(11), 2038-2048.

Underwood, E. C., Franklin, J., Molinari, N. A., & Safford, H. D. (2018). Global Change and the Vulnerability of Chaparral Ecosystems. *Bulletin of the Ecological Society of America*, *99*(4), 1-10.

TABLES

Table 1. Clump size was the predictor variable and a combination of mean pads per plant and maximum clump height were the response variables for each cacti. Dashes indicate non-significance due to blocking. Asterisks indicate statistical significance at α = .05.

Type II MANOVA results

Species	Predictor	*df*	Pillai	$F_{approx.}$	df_{num}	df_{den}	η^2_p	*p*	
C. prolifera (coast cholla)	clump size	1	0.046	1.65	2	69	0.05	0.19	
	block	6	0.592	4.90	12	140	0.30	1.02e-06	-
O. littoralis (prickly pear)	clump size	1	0.225	22.44	2	155	0.22	2.75e-09	***
	block	6	0.504	8.76	12	312	0.25	2.02e-14	-

Table 2. Asterisks indicate statistical significance with a Bonferroni multiple testing correction and α = .025

Post-hoc Welch ANOVA results

Species	Variable	*n*	Statistic	df_{num}	df_{den}	*p*	
O. littoralis (prickly pear)	max clump height	164	29.79	1	52	1.35e-06	***
	mean pads per plant	164	1.83	1	79	0.18	

Table 3. Descriptive statistics on cactus survival.

2020 Cactus Percent Survivorship Summary Statistics

Species	Clump Size	Median	Mean	SD	SE	*n*
C. prolifera (coast cholla)	small	100	88	20.5	3.3	39
	large	75	90	38.3	6.1	39
O. littoralis (prickly pear)	small	100	98	11.1	1.0	123
	large	100	98	8.0	1.2	41

FIGURES

Figure 1. Map of the block design at the Fuel Modification sites at the UCI Ecological Preserve. The University Hills residential community is located on the bottom right side of the photo. The three sites and corresponding number of block replicates are Currie (1), Gibbs Ct. (3), and Vista Bonita (4).

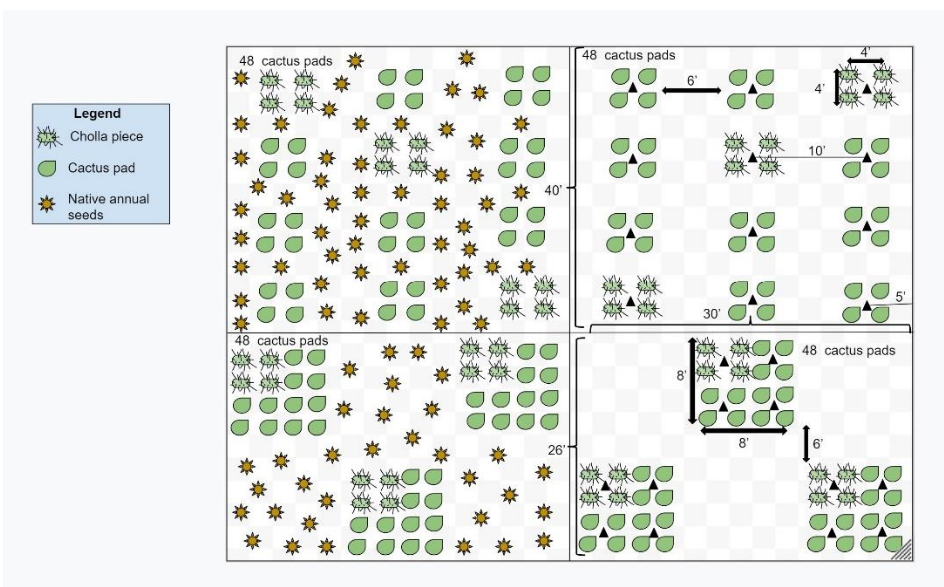

Figure 2. Diagram showing the treatment combinations and planting arrangements that were replicated in each block.

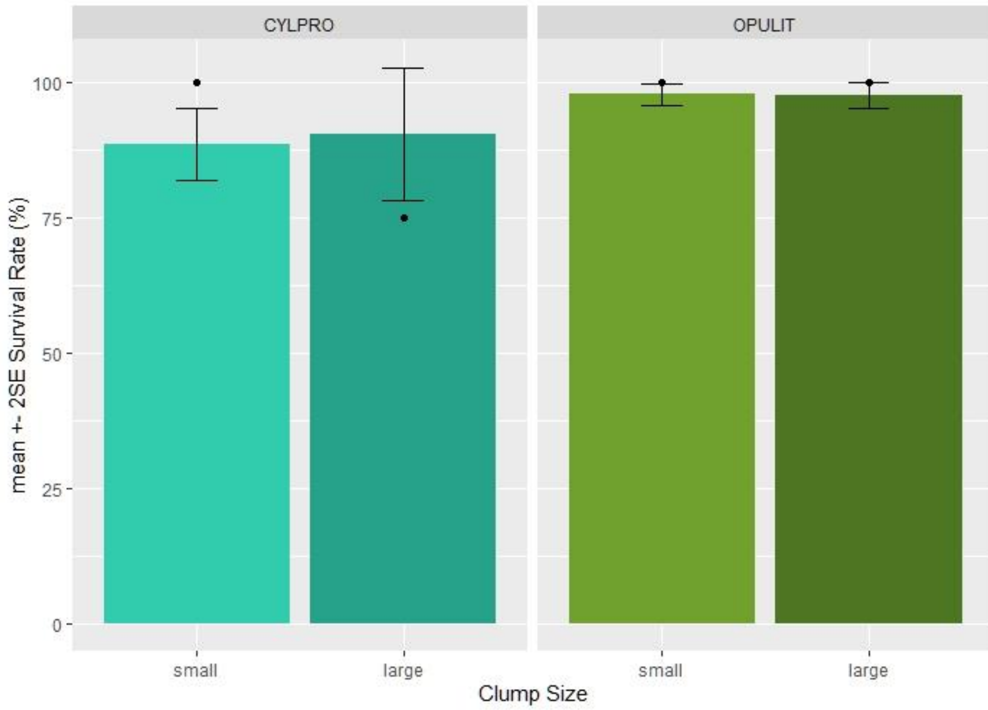

Figure 3. Bar graph showing the mean percent survival rate of each cactus species and planting arrangement. The dots represent the median survival percentage for each group, and the bars represent two times the standard error from the mean. Mean and medians were not significantly between clump sizes of each species.

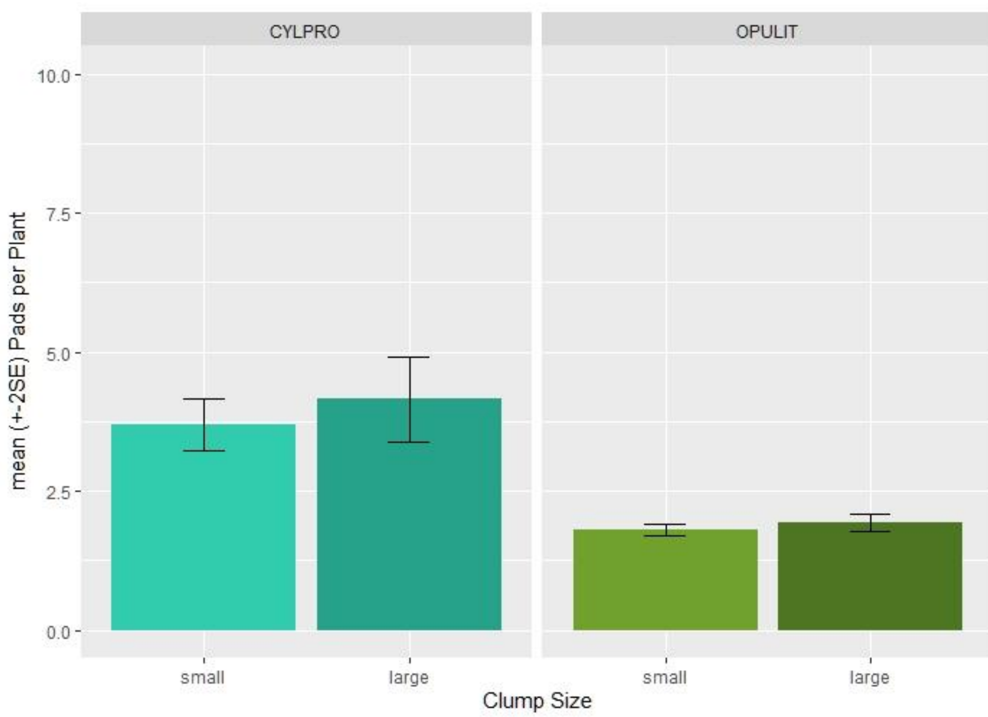

Figure 4. Bar graph showing the average number of pads per plant for each cactus species and planting arrangement. The bars represent two times the standard error from the mean. Difference in mean number of pads per plant were not statistically significantly different between clump sizes of each species.

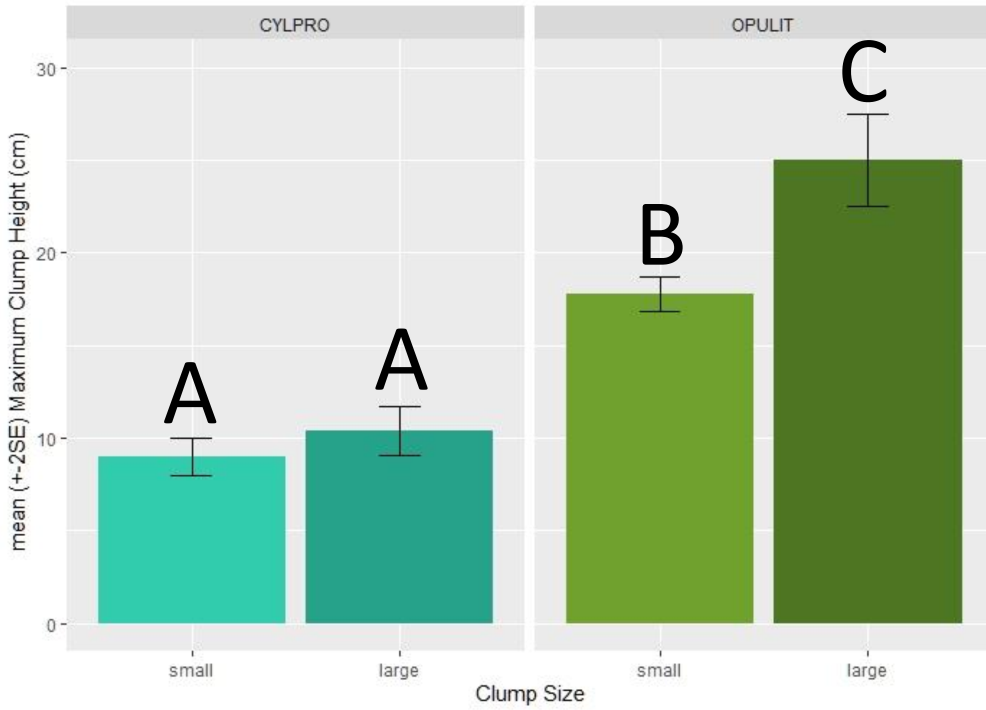

Figure 5. Bar graph showing the mean maximum clump height for each cactus species and planting arrangement. The bars represent two times the standard error from the mean. Cholla clump heights were not significantly different between clump sizes. Prickly pears were significantly taller in large clumps than in small clumps.

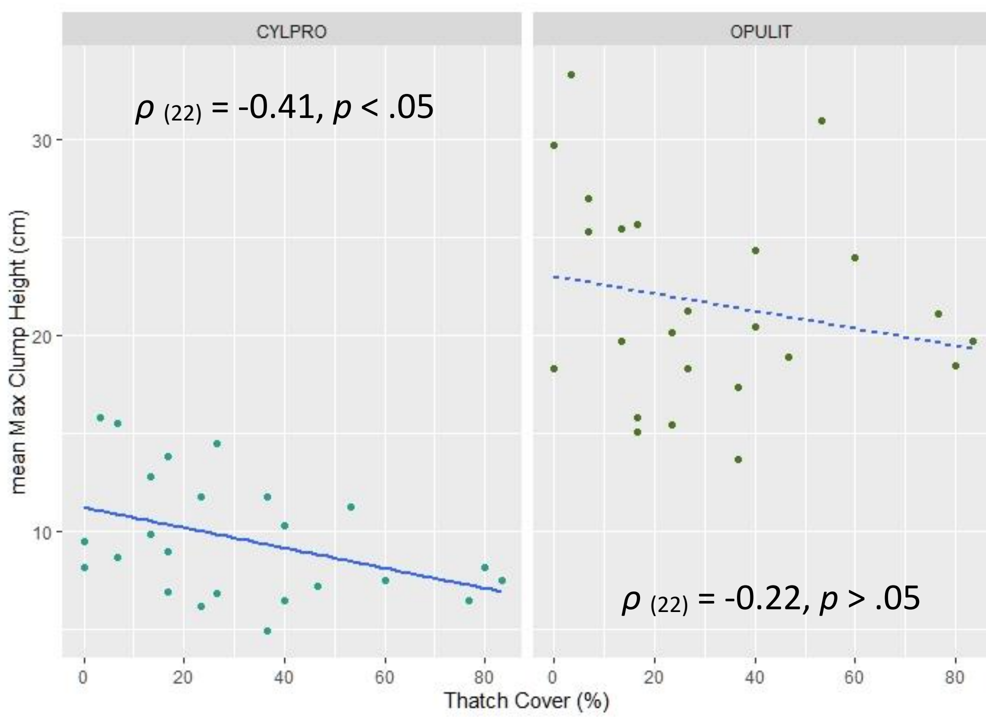

Figure 6. Scatter plot with best fit lines indicating the correlation between the mean max clump height of each cactus species and the percent thatch cover of their plot. The correlation was statistically significant for cholla (indicated by a solid line) and insignificant for prickly pear (indicated by a dashed line).

APPENDIX A: R Script

See attached PDF and RMD files:

MCRS_FA20_delaM_FM_CodeofConduct.Rmd
MCRS_FA20_delaM_FM_Rscript_PDF.pdf
MCRS_FA20_delaM_FM_Rscript_RMD.Rmd

APPENDIX B: Data Files

All original data files were preserved and modified in R:

2020_Veg_Cover_Data.csv
Fall 2020_Cactus_Size_Survival-Data.csv
Veg_Cover_Species List.csv