VARIABLES THAT INFLUENCE THE ENDANGERED PIMA PINEAPPLE CACTUS (*CORYPHANTHA SCHEERI* VAR. *ROBUSTISPINA*) MORTALITY AFTER TRANSPLANTING

By

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Professor

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Abstract

Coryphantha scheeri var. *robustispina* (Schott) L. Benson, the Pima pineapple cactus, herein referred to as *C. scheeri*, was declared an endangered species in 1993 and only occurs in a limited range in Arizona, USA and northern Sonora, Mexico between 2,300'-4,500' asl. Development within the range of *C. scheeri* threatens individuals, but transplanting to conserve them while allowing for development has been considered to be ineffective for conservation due to low post-transplant survival rates in past studies. The construction of a natural gas pipeline provided the opportunity to conduct a transplant experiment on 82 individual *C. scheeri* transplanted in July and August 2014. The plants were randomized into one of four transplant methods: bare-root with supplemental water, bare-root without supplemental water, soil-and-plant moved with supplemental water, and soil-and-plant moved without supplemental water. Higher than average precipitation occurred during the 2014 monsoon season including after transplanting. A subset of the transplanted *C. scheeri* (n=17) were transplanted back onto the pipeline after pipeline construction was completed. Survival rates were monitored through December 2016 and compared to undisturbed *C. scheeri* near the pipeline ROW and those on other sites. For the plants transplanted once, no significant effect of moving the plants with soil compared to no soil (X^2 = 2.9, p = 0.09), no significant effect of adding water at the time of transplant compared to not adding water (X^2 = 1.2, p = 0.26), and no significant interaction among treatments (X^2 = 0.06, p = 0.81) was observed. For plants transplanted twice, a significant effect of moving the plants with the soil compared to no soil (X^2 = 5.0, p = 0.02) was found, while due to the

random selection of plants to be transplanted twice there was too little data to adequately test other comparisons. There was no significant difference in mortality between the transplanted once (27% mortality) and the transplanted twice (31% mortality) treatments ($p = 0.78$), but there was a significant difference between transplanted and non-transplanted plants (2% mortality in non-transplanted plants; $p < 0.05$). Soil series did not appear correlated with mortality. Plants in good condition (scored 4 or 5 on scale of 0-5) at the time of transplanting had low mortality rates (16%) while plants scored 3 or lower had high mortality rates (60%) but deaths did not occur immediately after transplanting: 5 died after 8 or 9 months, 4 after 13-16 months, and 9 after 23 or 24 months. The majority of the deaths occurred after numerous months of declining in condition but six plants died suddenly. Good condition plants were more likely to flower than those in poor condition. Transplanting appears to conserve some of the *C. scheeri* population which would have otherwise been lost to development.

Introduction

Infrastructure development degrades habitat of all species but threatened and endangered species remain of special concern because 90% of imperiled plants in the United States have been found to be endangered through habitat degradation or loss (Wilcove, 1998). Although prevention of habitat loss prevails as the primary goal, conservation banks have been established by the US Fish and Wildlife Service (USFWS) to help mitigate the pressure on threatened and endangered species. Transplanting has also been a strategy for species protection, but arguably disregards the displacement of surrounding flora and fauna and increased on-going disturbance due to development. Transplanting has often proven ineffective or uncertain as a conservation measure (Fahset, 2007).

Nutrient availability and competition for resources (Wilson, 1991, 1993; Koutecka, 2013) can affect survivability of plants after transplanting. Data demonstrating these impacts can take many years to produce, can lack cause-and-effect links, and without a consistent long-term monitoring program can be biased or incomplete (Marino, 1997; Ballard, 2015). Compared with mesic systems, Xeric environments add an even greater challenge due to the extreme temperatures and highly variable precipitation patterns. A successful transplant in the complex desert ecosystem requires knowledge on plant life history, ecosystem functionality, and an understanding of the drivers behind survivorship for the species in question.

Other common factors that affect survivability include rainfall, availability of light or shade, and predation. For example, water stress has been proven to affect determinate root development of plants in the Sonoran Desert, which led to earlier termination of root growth when compared to roots with little to no water stress (Dubrovsky, 2003). Shading has been shown to impact the establishment of saguaro (*Carnegiea gigantea*) seedlings over a 15- month period in a study conducted at the Saguaro National Monument, Tucson, Arizona. In a group of 1200 transplanted saguaros, 100% mortality occurred in one year after being transplanted into an open area, compared with only a 65% mortality rate for shaded plants (Turner et al., 1966). Light availability may influence vegetative growth and reproductive output (Went, 1949), and facilitation may lead to competition for intra-and interspecific interactions (Leger, 2010; Lindsay, 2011; Garcia-Cervigon, 2013). Predation on *Coryphantha* species has also been discussed in multiple studies examining the affects of native *Gerstaeckeria* sp. (cactus weevil), *Moneilema* sp. (cactus beetle), and *Cactobrosis* sp (pyralid moth) on *C. scheeri* (SWCA, 1999; Schmalzel 2002) as well as the ecology of native jackrabbits and their impacts to *C. scheeri* in the southwestern United States (Vorhies and Taylor, 1993; Brown, 2014).

Coryphantha scheeri (Kuntz) L. Benson var. *robustispina* (Schott) L. Benson (1969), the Pima Pineapple Cactus, herein referred to as *C. scheeri*, is a hemispherical globose cactus, found within a limited range in Pima and Santa Cruz counties, Arizona and northern Sonora, Mexico (USFWS, 1993). *Coryphantha scheeri* may grow as a solitary individual (a single stem), as a group with multiple stems and up to 10 sprouts, or as a cluster with primary stems being difficult to identify and 20 or more sprouts (pups) emerging from a single root system. C*oryphantha scheeri* have been known to sprout lateral fibrous roots, as well as tuberous roots that may act as an extension to the aboveground portion of the plant (Schmalzel, 2004: Dicht

& Lüthy, 2005; Baker, 2013). *Coryphantha scheeri* typically grow in alluvial basins with a preference for shallow to deep, and silty to rocky soils in semidesert grasslands and Sonoran desertscrub communities with a gentle (<10%) slope (USFWS, 1993; Brabander, 1998; Schmalzel, 2004; Kidder, 2015). The US Fish and Wildlife Service classified the Pima Pineapple Cactus as federally endangered in October of 1993 (USFWS, 1993).

Development sites offer a unique venue for assessing transplanting methodology because they allow for the entire disturbed area to be monitored throughout the revegetation process. In 2012, pre-construction planning began on a pipeline that would transfer natural gas into Mexico through the Altar Valley, southwest of Tucson, Arizona. The approximately 60-mile, 36-inch diameter pipe is a lateral shoot from Kinder Morgan, Inc.'s main gas line that runs from El Paso, Texas. The new addition extends to the United States-Mexico Border in Sasabe, Arizona (Figure 1) where the ownership is then transferred to Mexican authorities, moving approximately 200,846 dekatherms of natural gas per day (Dth/d) (www.kindermorgan.com) to customers in Mexico. The need for understanding the impacts and repercussions of infrastructure development such as a pipeline installation on native species is important, and scientific research is necessary in order to identify best practices for future development projects. A cause for concern is the lack of follow up monitoring on transplanted *C. scheeri* populations. Four other transplanting events involving the taxon were found, two of which had some level of follow up monitoring (SWCA, 2000; McIntosh & Baldwin, 2001; Powell and Rice, 2015). Of these, some success was noted, particularly by McIntosh and Baldwin

(2001) during their study in the Santa Cruz Valley, Arizona where transplanted individuals were separated into three different sites. The first two sites had relatively few deaths, while all (24) individuals had perished in the third site. All mortalities were attributed to being moved bare-root (without soil) and hardened off under shade (Schmalzel, 2000).

The Sierrita pipeline project (the experimental site) evaluated in this study passes through roughly 61.9 miles of *C. scheeri* habitat and required the relocation of 82 individuals. The experimental site provided an opportunity to extend the scope of inference with the new construction-related transplants by comparing the data with past efforts. The primary objectives of this study were to use current and historical transplant data on *C. scheeri* to help 1) determine the impact of transplant methodology on survival rates, and 2) identify variables influential to *C. scheeri* mortality after transplanting. The study focused on the efficacy of moving *C. scheeri* with soil from the source location versus moving it bare rooted and adding versus not adding supplemental water. The movement of soil as well as the addition of supplemental water were expected to prove beneficial to the plant.

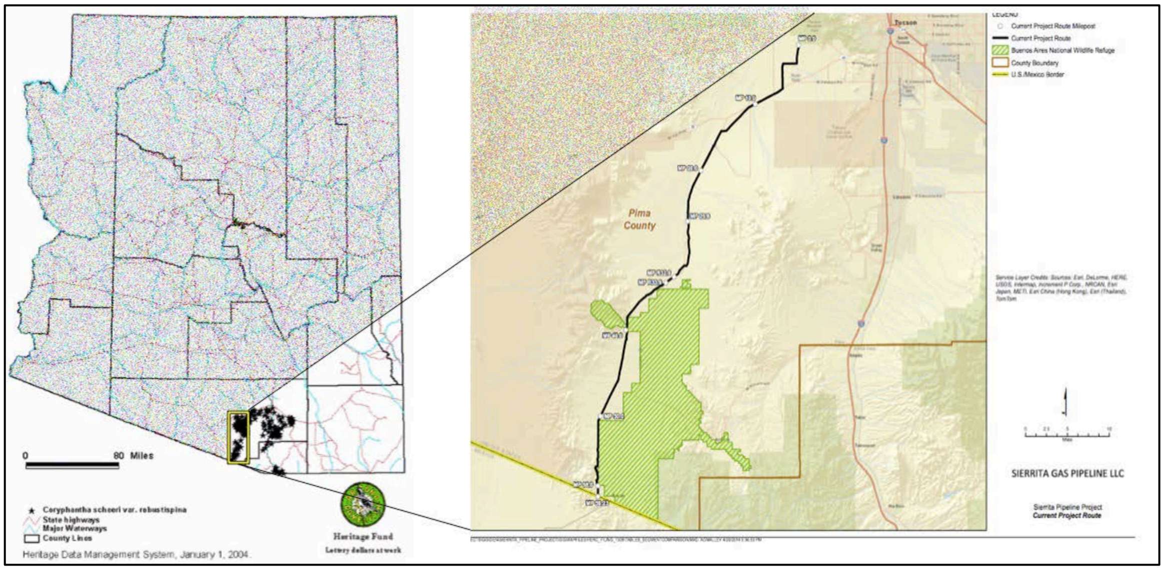
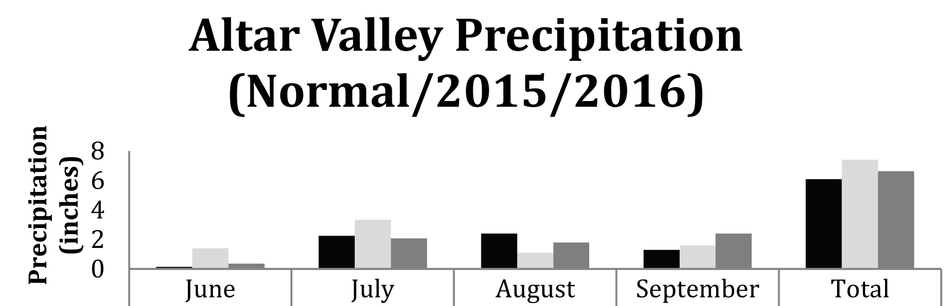


Figure 1. Map showing PPC distribution in southeast Arizona and the pipeline study site in Arizona, USA.

Materials and methods

Description of study sites:

The experimental study site was in the Altar Valley of the Sonoran Desert, located southwest of Tucson, Arizona (32° 7'-31° 48' N, 111° 12'- 111° 28') between 2451’-3303’ asl (747-1007 m). The Altar Valley reaches temperature extremes over 115°F in the summer months to below freezing in the winter months with a mean high of 83.5° F and a mean low of 48.9°F. A strong bimodal precipitation pattern exhibits the majority of its 11.42” annual precipitation in the summer monsoonal months of July and August (Figure 2, wrcc.dri.edu).



	June	July	August	September	Total
Normal	0.15	2.25	2.39	1.29	6.08
2016	1.39	3.32	1.09	1.6	7.4
2015	0.35	2.08	1.8	2.4	6.63

Figure 2. Precipitation totals from monsoonal rains in the Altar Valley, Arizona taken from the King Anvil weather station. 'Normal' values are averaged precipitation values from 1945-2005 (wrcc.dri.edu)

The site occurs in the Arizona Upland subdivision of Sonoran Desert scrub community, transitioning to semi-desert grassland south towards the Mexican border (Brown, 1994). The site transitions from historical grassland into exotic dominated grassland due to the abundance of the invasive Lehmann lovegrass (*Eragrostis lehmanniana*) (Gori & Enquist, 2003). Soils were generally sandy and loamy (Table 1).

Table 1. Ecological site description names for soil series as associated with the *C. scheeri* locations

Soil Series	Ecological Site Description
Anthony fine sandy loam	Sandy Wash 10-13" p.z. (R040XA115AZ)
Bucklebar-Sahuarita complex	Sandy Loam Upland 10-13" p.z. (R040XA118AZ)
Diaspar sandy loam	Sandy Loam Upland 12-16" p.z. (R041XC319AZ)
Hayhook-Sahuarita complex	Sandy Loam Upland 10-13" p.z. Deep (R040XA117AZ)
Palos Verdes-Sahuarita complex	Loamy Upland 10-13" p.z. (R040XA114AZ)
Pinaleno-Stagecoach complex	Loamy Upland 10-13" p.z. (R040XA114AZ)
Tubac gravelly loam	Loamy Upland 10-13" p.z. (R040XA114AZ)
Tubac sandy loam	Sandy Loam Upland 10-13" p.z. (R040XA118AZ)

Two additional sites also located in the Altar Valley, just east of the experimental site, were visited and reinvestigated to determine *C. scheeri* transplant success. The 107-acre Sycamore Canyon (SC) development site (31°56'59.6"N 110°46'55.3"W) was undeveloped and considered natural open space, as was the 115-acre Diablo Village (DV) Estates property (32°07'22.6"N 111°07'37.2"W).

Common perennial trees and shrubs on all three sites included velvet mesquite (*Prosopis velutina*), whitethorn acacia (*Acacia constricta*), catclaw acacia (*A. greggii*), littleleaf palo verde (*Cercidium microphyllum*), triangle-leaf bursage (*Ambrosia deltoidea*), creosotebush (*Larrea tridentata*), and desert zinnia (*Zinnia acerosa*). Also abundant were cactus species, including fishhook barrel cactus (*Ferrocactus wisilizenii*), several species of prickly pear cactus and cholla (*Opuntia spp*.), pincushion (*Mammillaria spp*.), hedgehog (*Echinocereus fasciculatus*), and saguaro (*Carnegiea gigantea*).

Experimental field methods:

From March to May, and July to September 2012, a pre-construction survey located 82 individual *C. scheeri* along the proposed pipeline right-of-way (ROW) and throughout the staging areas proposed for construction (R. Waldron, personal communication). The surveying method was adopted from Roller (1996), in which observers spaced 4-6 meters apart walked belt transects along the entire pipeline ROW (~60.9 miles). GPS coordinates, plant size (stem diameter), growth form, general health, and photographs were collected for each cactus with a survey beginning on July 9th and ending on August 8th, 2014. A south facing centroid spine for each cactus was marked on the tip with white out to maintain solar orientation through the transplant process. *C. scheeri* were then moved onto the adjacent 25' buffer zone on July 9, 10, 11, 14, 15, 16, 17, 18, 23 and August 8, 2014. One of four transplant methods was used: bare-root with supplemental water, bare-root without supplemental water, soil-and-plant moved with supplemental water, and soil-and-plant moved without supplemental water. The bare-root treatment moved plants with only the soil that adhered naturally to the roots, while the soil-and-plant method transferred 7 L. of soil with a 5-gallon bucket from the original location to the transplant location. Supplemental water meant the addition of 2 L. of water into the excavated hole for transplanting, and another 2 L. of water once the plant had been transplanted (SWCA, Appendix K). After construction and reclamation activities were completed, 17 randomly selected individuals of the original 82 plants were then transplanted back onto an adjacent area within the ROW on 12/15/2014 of 12/16/2014 using their respective transplant method. All *C. scheeri* were visited monthly from October 2014 to December 2016 to monitor survivorship (Table 2). The following morphological and microhabitat variables were measured at the initial location of each cactus from October 2014 to December 2016 within a 1-m circular plot. Photosynthetically active radiation (PAR) was estimated using a Field Scout quantum light meter (Spectrum Technologies, Inc., Bridgend, United Kingdom) with an accuracy of ±5% at 15 cm from the soil surface. Three measurements were taken per plant and then averaged. Volumetric water content (VWC%) of the soil was measured near the base of each plant (≤ 20 cm) using 10-cm probes on a Field Scout TDR 100 model (Spectrum Technologies, Inc., Bridgend, United Kingdom) with an accuracy of ±3%.

2014	
October	20
November	14, 21
December	12, 14
2015	
January	10, 13, 23
February	14, 20
March	13, 27
April	19
May	3, 4
June	3, 4, 7
July	28
August	4, 11
September	11
October	16, 31
November	20
December	2
2016	
January	12, 23
February	27
March	21, 22
April	12, 15
May	25
September	2, 24
October	7
November	11, 12
December	2

Table 2. Dates when *C. scheeri* were visited from October 2014- December 2014

Height and width measurements did not include spine length (Baker, 2013). Height was measured from the soil surface to the apex of each cactus. Width was measured differently depending on growth form, (i.e. solitary cacti were measured at their widest point; groups and clusters were measured twice, once with pups included and once without pups included). Aboveground soil temperatures were taken with a non-contact infrared thermometer (Cen-Tech, Camarillo, CA) within 5 cm of the base of each plant at the four cardinal directions and then averaged for the statistical analysis. Belowground temperatures were taken with a Taylor 9840N digital instant read thermometer (Taylor Precision Products, Oak Brook, IL) on the same sides of each cactus and also averaged for statistical analysis. Slope aspect was determined with a Suunto A-10 NH compass (Suunto, Vantaa, Finland) using secondary intercardinal directions, but collapsed to intercardinal directions to improve the CART analysis. After determining slope aspect with a simple visual inspection slope percentages were measured with a Suunto clinometer (model PM-5/360 PC, Suunto, Vantaa, Finland).

It was crucial to monitor a set of control plants, as well as the experimental plants. For this reason, an additional population of *C. scheeri* plants (n=51) located near, but not disturbed by the pipeline were monitored for survival to allow estimation of overall transplant mortality.

Diablo Village and Sycamore Canyon site field methods:

Survivorship was assessed for two additional transplanted *C. scheeri* populations to allow for comparison among the historical sites and the experimental site. The first site, Diablo Village Estates (DV), had 34 *C. scheeri* transplanted sometime before 2005 (exact dates are unknown). All live plants were transplanted onto appropriate habitat within Pima County-owned land that wouldn't be developed on as a conservation measure by the county for preserving this endangered species. Follow up surveys from April 2005 to January 2006 found 63 *C. scheeri* (53 live, 10 dead) on the 191-acre property (WestLand BA, 2005). Nearly forgotten until a decade later, multiple reports (WestLand BA, 2005; USFWS BO, 2006; Powell and Rice, 2015) confirmed high levels of surface disturbance including illegal dumping, off-road vehicle recreation, extensive channel cutting, and sheet flow erosion leading to an overall decrease in population for *C. scheeri.*

The second site, Sycamore Canyon (SC), had 81 *C. scheeri* transplanted in 2004. In 2008, only 43 live transplanted individuals were identified, and in 2012, just 28 transplanted individuals persisted (WestLand Resources Monitoring Report 2014). Reasons for such a decline could be due to transplant failure or any kind of undocumented disturbance on the property. After 2008, WestLand Resources Inc. surveyed the property every four years (Table 3). Data discrepancies are consistent with the Diablo Village site in that a lack of consistent monitoring provides some uncertainties with respect to transplant methodology and actual mortalities due to transplanting.

Table 3. *C. scheeri* survey results reproduced with permission from the Annual Monitoring Report (WestLand Resources Inc. 2014) on the Sycamore Canyon development site.

Year	Start		Additions and <Mortalities> Since the Previous Monitoring			End		
	Transplant	*In Situ*	Transplant	*In Situ*	Mortality	Transplant	*In Situ*	Total
2004	0	2	23	-	-	23	2	25
2005	23	2	57	39	<5>	75	41	116
2006	75	41	0	0	<33>	50	33	83
2007	50	33	1	0	<7>	47	30	77
2008	47	30	0	0	<11[a,b]>	44[b]	23	67[b,c]
2012	43	23	0	0	<25[d]>	28	14	42
2016	24[e]	20	0	1	<15>	15	13	28

a: Three plants not found, all transplants, are considered among the mortalities

b: One transplanted *C. scheeri* reported dead in 2008 was found alive in 2012, affecting this total

c: Total *C. scheeri* was reported as 65 instead of 66 in the 2008 *C. scheeri* monitoring report and subsequent annual conservation lands reports through 2011, due to miscount

d: Seven plants not found, all transplants are considered among the mortalities

e: Found three reported missing from the 2012 report, affecting total

Using *C. scheeri* locations from the most recent (2014) monitoring report, some coordinates led to tag identifiers for *C. scheeri*, which allowed certainty that a plant was located in that particular spot at one point. Other identifiers for whether or not a plant ever existed at a particular location included *C. scheeri* flesh and scattered spines. In the absence of any of these identifiers, measurements were not taken because of the uncertainty around what happened to the plant, or the possibility of having received inaccurate coordinates. These plants were documented as presumed dead and left out of the statistical analyses.

In January 2016, both sites were visited to update the figures on live versus dead *C. scheeri,* and document PAR, slope aspect, current health condition, and growth form data for each cactus using the same condition classes and methodology as for the experimental site (above).

Statistical Analysis:

Chi-square analyses were used to determine the differential mortality of transplanting versus not transplanting, single and twice-transplanted plants, and uniquely twice-transplanted plants. Post-hoc testing was done using logistic regression and the equivalent of a Tukey test. Three phases of classification and regression tree (CART) analyses were used to determine the important predictors for *C. scheeri* survival on the experimental site and then again for all the combined data. The Random Forest procedure was used to assess the CART models and eliminate variables that appeared to hold little importance on the target variables. CART models have been a widely used tool in ecological research and Random Forests create a highly accurate model for gauging accuracy (Cutler, 2007).

Results

Transplanting techniques:

Transplanted plants were associated with higher death rates when compared with undisturbed plants. For the plants only transplanted once on the experimental site, there was no significant effect of survival of transplants with soil compared to no soil (X^2 = 2.96, p = 0.086; Table 4). There was also no significant effect of adding water at the time of transplant compared to not adding water (X^2 = 1.25, p = 0.264) and no significant interaction among treatments (X^2 = 0.057, p = 0.812). For plants transplanted twice, there was a significant effect of moving the plants with soil compared to no soil ($X^2 = 5.03$, $p = 0.025$; Table 5), while due to the random selection of plants to be transplanted twice there was too little data to adequately test other comparisons.

No significant difference in mortality between the transplanted once (27%) and the transplanted twice (31%) treatments ($p = 0.982$) was found, but there was a significant difference between transplanted and non-transplanted plants ($p = 0.032$ between once and non-transplanted, $p = 0.046$ between twice and non-transplanted; Table 6).

Table 4. Summary of the mortality (mortality/number of plants in treatment) for *C. scheeri* transplanted once in the randomized, replicated treatments. No significant differences were found ($p > 0.05$)

		Soil Treatment		
		No soil	**Soil**	
Water Treatment	**No water**	1/10	4/19	5/29
	Water	3/20	6/16	9/36
		4/30	10/35	

Table 5. Summary of the mortality (mortality/number of plants in treatment) for *C. scheeri* transplanted twice in the randomized, replicated treatments. The soil treatment was significant ($p = 0.02$) and the rest of the comparisons had too little data to test.

		Soil Treatment		
		No soil	**Soil**	
Water Treatment	**No water**	4/9	0/6	4/15
	Water	0/1	0/1	0/2
		4/10	0/7	

Table 6. Summary of the transplant data. Transplant treatments with different superscript letters were significantly different ($p < 0.05$)

	Transplanted		
	Not[a]	**Once[b]**	**Twice[b]**
Dead	1	14	4
Alive	50	51	13

Classification and Regression Tree (CART) analysis of the Pipeline field site

For the CART analysis to correctly associate environmental variables with mortality, the mortality must be distributed uniformly across the population otherwise the correlation between sampling dates and environmental variables will mask any real result. For this reason, before the CART analysis, the mortality data was evaluated for geographic clustering. The mortality was concentrated in the northern part of the *C. scheeri* distribution (Figure 3) with 9 of the 24 *C. scheeri* in that area dying. This group was sampled across two dates and the *C. scheeri* overall were sampled across five dates. The plants transplanted once had both fewer complications with environmental variables and their transplanting most closely matched a common transplant procedure. Thus, the focus of the CART analysis was the cacti transplanted once. Neither a correction for ambient air temperature nor time elapsed since sunrise took the date effect out of the temperature (soil surface as well as below ground), PAR, and volumetric water content so these data were not used for the CART analysis. An analysis of mapped soil type showed no relationship between soils and *C. scheeri* mortality (Table 7).

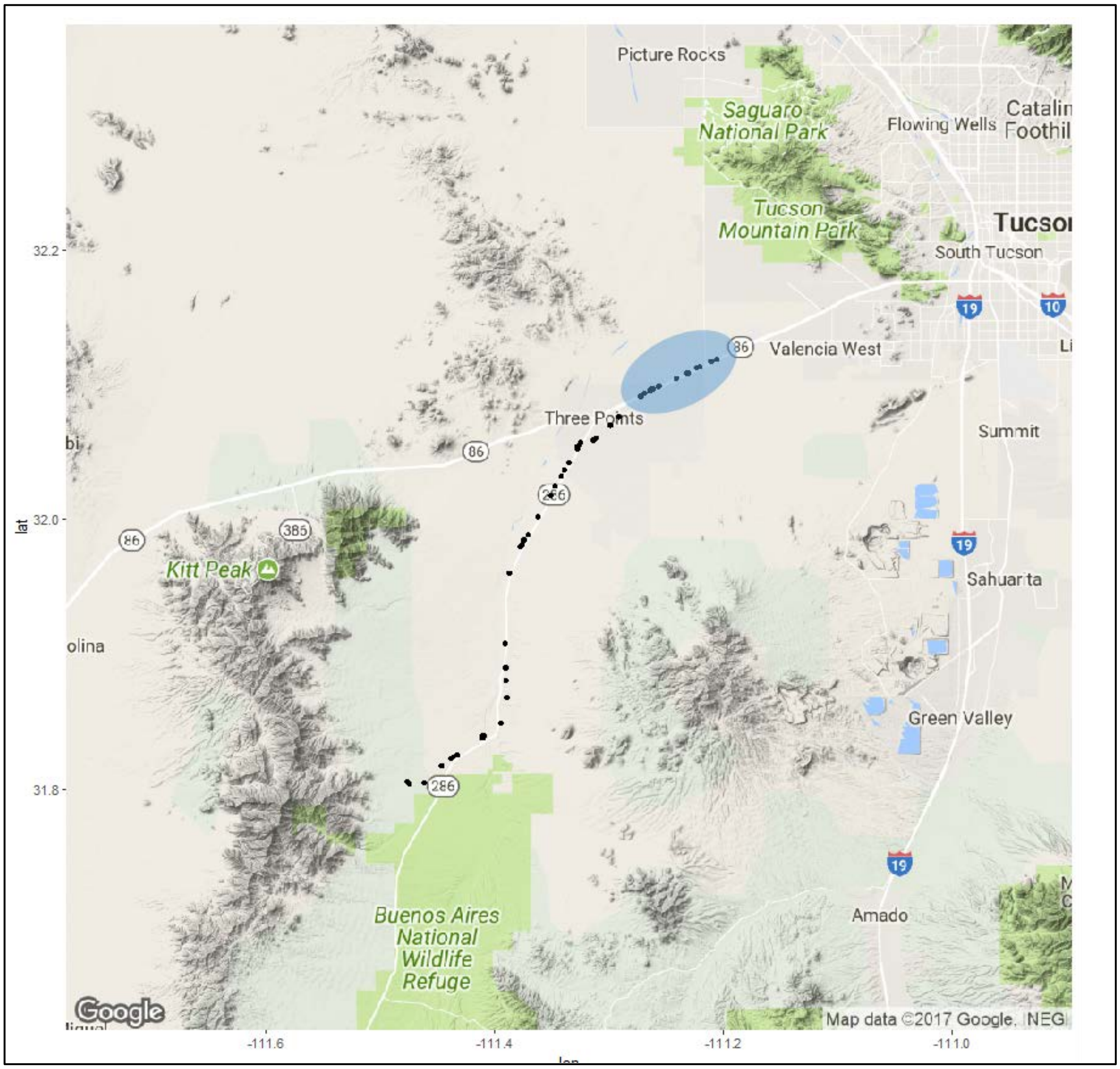


Figure 3. Map of the *C. scheeri* points along the pipeline corridor. The blue circle encloses 24 plants of which 9 died. The rest of the mortality – 5 plants – was more randomly distributed. This aggregation describes most of the variability in the environmental data.

Table 7. *C. scheeri* occurrences and condition scores with mapped soil series. Soil maps from https://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx. Evaluating the four series with sufficient data showed no significant differences between them (X^2 = 8.39, p = 0.30).

	Condition score							
Soil Series	**0**	**1**	**2**	**3**	**4**	**5**	**Total**	**Mortality**
Anthony fine sandy loam	0	0	0	0	0	1	1	0.00%
Bucklebar-Sahuarita complex	7	1	3	1	3	10	25	28.00%
Diaspar sandy loam	0	0	0	1	2	1	4	0.00%
Hayhook-Sahuarita complex	1	0	0	2	6	3	12	8.30%
Palos Verdes-Sahuarita complex	0	0	0	0	0	4	4	0.00%
Pinaleno-Stagecoach complex	3	0	0	2	4	1	10	30.00%
Tubac gravelly loam	0	0	0	0	1	0	1	0.00%
Tubac sandy loam	3	0	0	1	2	2	8	37.50%

The aggregation of mortality might imply a single event but analysis of the monthly plant observations for both the transplanted once and transplanted twice plants from September 2014 to December 2016 showed that 5 died 8 or 9 months after transplanting, 4 after 13 to 16 months, and 9 after 23 or 24 months. Evaluating condition scores (Table 8), only 10 plants were scored below 4 at the time of first observation – six of them died (60%) versus 12/72 (16%) of the plants with higher condition scores at the time of transplanting. Plants did not generally increase in condition score and the majority of the deaths occurred after numerous months of declining condition. Six plants died suddenly (i.e. died without a previously noted decline in condition) which can be attributed to flooding, predation, or unknown reasons such as anonymous or illegal excavation of the plant, or disappearance with the presence of vehicle tracks nearby implying it may have been run over by an off-road vehicles. Mortality within this set of individuals across time was sporadic, one each at 9, 15, and 16 months after transplanting and three in month 24.

Table 8. Condition score for both transplanted once and transplanted twice plants from September 2014 to December 2016

		Score at last observation					
		0	**1**	**2**	**3**	**4**	**5**
Score at first observation	**2**	2	1	-	-	-	-
	3	4	-	-	3	-	-
	4	8	-	1	4	17	-
	5	4	-	2	1	9	26

The CART analysis for the *C. scheeri* transplanted once (Figure 4, n=65) showed that the slope followed by the aspect as the best predictors of survivorship although it must be noted that the aspect applies to a smaller subset of the data. The differences between transplanting techniques did not show up as an important predictor of mortality in the CART analysis for these data. The random forest analysis (Table 9) analysis shows that the elements of the CART model, slope and aspect, were the best for predicting mortality (e.g. slope of <2.25 coupled with an aspect of E, N, no, NW, S, or W experienced greatest mortality) but that distance to the nearest neighbor and the two treatments may have some explanatory power.

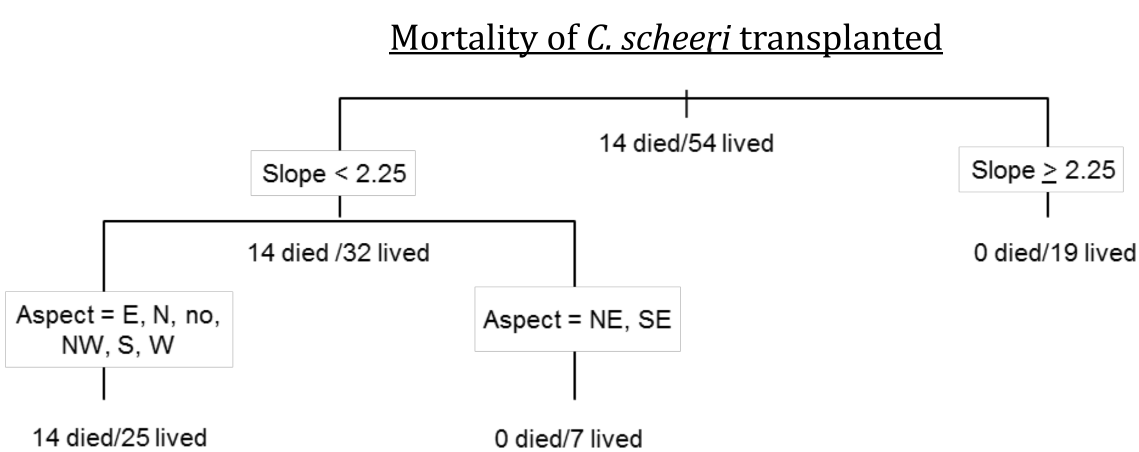


Figure 4. Classification tree analysis of the variables slope, aspect, *C. scheeri* group, soil treatment, water treatment, species adjacent, and distance to nearest neighboring species (Table 8) at the time of *C. scheeri* transplant vs. survival after two years. “No” indicates a level surface with no particular aspect

Table 9. The random forest analysis shows the relative importance for each variable used in the CART analysis based on 500 iterations of building trees with randomly selected variables. Variables included 'Aspect'- the slope aspect at the location of each plant, 'Slope' – angle of the ground at which the plant sits expressed as a percentage, 'NND' – distance to the nearest neighbor after *C. scheeri* was transplanted, 'NN after' - nearest neighboring functional group after C. scheeri was transplanted (tree, succulent, grass), 'Growth form'- whether each cactus grew as a solitary individual, in a group, or as a cluster, 'Water' – the supplemental water treatment and 'Soil' – the supplemental soil treatment

	Mean Decrease Accuracy (Type 1 Error Reduction)	**Mean Decrease Gini (Type 2 Error Reduction)**
Aspect	0.956	4.973
Slope	9.998	4.489
NND	0.886	4.366
Growth Form	2.246	1.552
Water	3.011	1.251
Soil	-3.922	1.107
NN after	-1.131	1.735

Predictions of flowering

Of the 65 plants transplanted once, flowering was largely based on the initial score at the time of transplanting, 23/35 plants with the initial score of 5 flowering, 11/21 with an initial score of 4, and 1/6 with the initial score of 3. Based on the 58 plants transplanted once with available data, a CART analysis was run to determine factors important for flower production in the first year after transplanting based on measurements of *C. scheeri* at the time of transplant. Results from this analysis, similar to the mortality analysis, showed that slope of <4.75 and aspect of northeast, north west, and South were important environmental predictors of higher flower production in the first year (Figure 5). The random forest analysis (Table 10) showed continued importance to variables relating to slope and aspect but also indication that again the status of the plant at the time of transplanting (height, condition, width, volume) were also important for predicting flowering.

Flowering of *C. scheeri* transplanted once

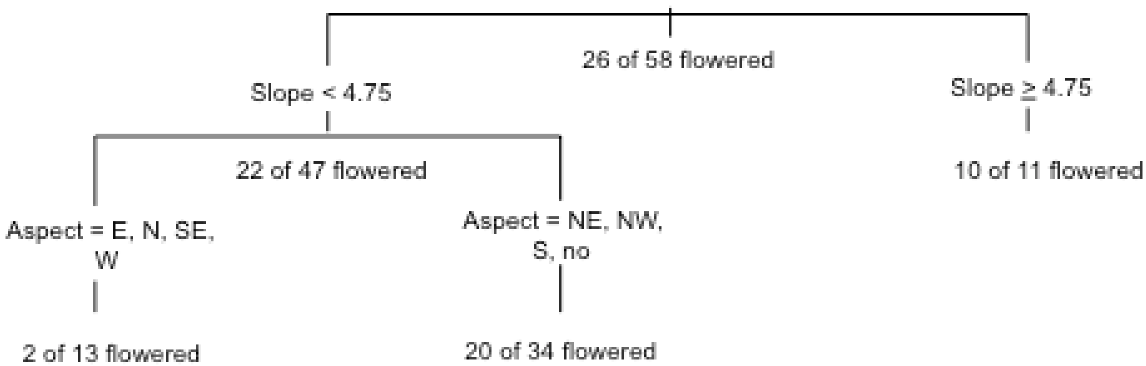


Figure 5. Classification tree analysis of the variables: slope, aspect, group, soil, water, nnd, height, width, volume, firstscore (Table 9) at the time of *C. scheeri* transplant on whether or not flower production occurred in the first year after transplant.

Table 10. Variable importance table shows the relative importance for each variable used in the random forest algorithm. Variables included 'Aspect'- the slope aspect at the location of each plant, 'Width' – the width of each cactus at the time of transplanting (mm), 'Height'- The height of each plant from the soil surface to the body apex excluding apical spines (cm), 'Slope'- angle of the ground at which the plant sits expressed as a percentage, 'Volume' – calculated as area of a circle times height, 'NND' – the distance to the nearest neighboring plant, 'Firstscore'- the condition score at the time of the initial observations, 'Growth form'- whether each cactus grew as a solitary individual, in a group, or as a cluster, 'Soil' – the supplemental soil treatment , and 'Water' – the supplemental water treatment.

	Mean Decrease Accuracy (Type 1 Error Reduction)	Mean Decrease Gini (Type 2 Error Reduction)
Aspect	0.359	5.296
Width	0.072	3.804
Height	2.188	3.531
Slope	4.944	3.517
Volume	-0.512	3.358
NND	0.02	3.153
Firstscore	5.633	2.614
Growth Form	2.808	1.063
Soil	-3.048	0.446
Water	-2.784	0.439

Diablo Village and Sycamore Canyon field sites:

Twenty-four *C. scheeri* individuals (6 of them dead) were located on the DV property of the 53 live plants live plants last observed in 2006. This implies a mortality rate at the high end of 66% or, assuming the search for plants was ineffective, a low of 25% over 10 years or an annual rate of 6.6 to 2.5%. For the SC site, 27 *C. scheeri* individuals were located (6 of them dead) of the 43 live transplanted plants last observed in 2012. This implies a mortality rate with a range of 49 to 22% or an annual rate of 12.3 to 5.5%.

Discussion

While transplanting was associated with higher death rates compared with undisturbed plants, the role of environmental conditions and transplanting methods at the time of transplanting did not have a clear impact on mortality. This could have been due in part to above average monsoonal rains after transplanting (Figure

2) but the lack of difference among transplant methods in the *C. scheeri* plants results align with the conclusions made by Ballard et. al. (2015) in western Colorado on a sandy salt desert at an elevation of 1472 meters. Their study monitored survivorship in transplanted *Sclerocactus parviflorus* (a genus of cactus similar in size to *Coryphanthas*) for 8 years and found no difference in cactus survival among the 3 transplanting techniques used in that experiment.

The *C. scheeri* that were transplanted twice, once off the right of way and again back on after construction was complete showed some advantage of being transplanted along with soil (0 of 7 died) compared to plants that were transplanted without soil (4 of 10 died). The small sample size (17 plants) along with imbalance between treatments make the significance less convincing than with a larger and more balanced sample. However, the finding makes sense because the highly disturbed right of way possibly lacked soil structure and beneficial mycorrhizae which would have been present in the soil that was moved.

The variables associated with mortality in the transplanted once plants in the CART analysis were slope followed by the aspect. For slope, the Altar Valley terrain appears relatively flat from a distance but on a local scale it is crisscrossed with hundreds of washes and rills that create a highly variable topographical landscape. It was not uncommon to find *C. scheeri* growing on the banks of small washes that appeared less healthy than their flatland-growing neighbors, but despite their appearance, the mortality of plants on slopes steeper than 2.25% was lower. This may be due to an interaction between the topography and disturbance or water availability when monsoonal rains fill the washes after a heavy precipitation event.

This is in contrast to a study by Parker (1991) on vegetation patterns in the Sonoran Desert where increased heat stress and lower soil moisture availability were linked to plants growing on steeper slopes in bajada sequences not uncommon to *C. scheeri* habitat within my study site.

The next most important predictor of *C. scheeri* mortality was the aspect with the analysis picking out the NE and SE aspect as better for survival. *C. scheeri* were consistently found on slight inclines facing all directions, but most often on north and west-facing slopes (45%) or no slope at all (42%). This effect appears largely due to the low numbers of plants in other aspects. Nonetheless, aspect seems likely to be important given other studies on the effects of slope aspect on plant growth in the southwestern United States. Van de Water (2002) conducted a study on isotopic variation in C3 and C4 plants along an elevation gradient in Utah and New Mexico. His findings suggested lower heat loads and potential evapotranspiration were reasons for plants to grow on north-facing slopes in semi-arid environments as opposed to south-facing slopes.

Determining the environmental variables associated with mortality was greatly complicated by the higher mortality within the northern and eastern group of *C. scheeri*. With the mortality in a small geographic area, the environmental variables were all similar to one another and the plants being in relatively close proximity the sampling of variables associated with these plants tended to be sampled in the same day. The tight correlation between this mortality cluster and sampling day made many of the variables (PAR, aboveground and belowground temperatures, and volumetric water content) not useful for predicting mortality.

There was the suggestion that the distance to the nearest neighboring plant was associated with mortality and digging into the data it appears that neighbors more than 17 feet away reduced mortality. This implies that minimizing temperature and soil evaporation was less of an issue than avoiding competition. More commonly, plants do better with some neighbors to get a balance of sun and shade similar to findings of McBride et. al. (2014) who conducted a study on *Adenium* spp. in Apopka, Florida to assess the effects of light intensity on growth form and flowering, and found the healthiest plants growing under 30% shade. This was also consistent with ideal growth conditions described by Cervera (2006) who suggests that a certain amount of shade provides optimal temperatures for plant success in *Cactaceae* species and Herce et al.'s (2013) study on radiation acquisition and temperature control by plant tilting. Herce analyzed the importance for plants growing in hot environments to maximize PAR interception for photosynthesis, while minimizing temperatures at the hottest time of day in order to optimize soil moisture availability. Similarly, Turner et al's study (1966) on *Carnegiea gigantea* transplants showed that shading significantly decreased mortality of seedlings. For *C. scheeri,* the difference in heat may not be as important despite Sonoran Desert cacti generally having relatively shallow roots, growing at an average depth of 7 to 11 cm for various species (Nobel 2009). An unpublished report by Florides (2004) examined the relationships of ground temperature at various depths with soil texture and found dry, sandier soils similar to those found in the Altar Valley, to have the least thermal diffusivity of all soil types sampled, and the shallowest heat penetration.

Growth form was documented for each cactus because it was not known whether a larger surface area will impact the plant's health negatively or positively, or if any conflict occurs between the parental plant and its offspring. Haferkamp (1988), in a study done on rangelands in Montana, notes that increased surface area can be beneficial for optimal light reception, but can also be detrimental for potential water loss. Similarly, plants in the desert have not typically been deficient of sunlight, but rather develop strategies to decrease the amount of light reception, such as spinal growth instead of broad leaf development. Shaanker and Ganeshaia (1997) conducted a study in India to prove that plants, like animals, are prone to conflict between parents and offspring. Further research would need to be done to assess if this is this case with *C. scheeri,* but it's notable that the majority of the transplanted *C. scheeri* mortalities (~71%) in my study were growing as a solitary individual, without any offspring present which would argue that there was benefit to clustered or clumped growth forms.

In this study along a pipeline ROW, a 10% mortality rate per year was found for transplanted plants compared to 1% in undisturbed plants. In contrast, the transplanted *Sclerocactus parviflorus* cacti in Ballard et. al. (2015) had a mortality rate of 1.9% per year which compares well to Roth (2008) who calculated an average mortality of 4% per year of transplanted *Sclerocactus mesae-verde* over a 6-year period. While the recruitment rate would be needed for a complete assessment of the mortality rate, the rate of 10% per year found here will need to greatly decrease for long term survival of transplanted plants. The higher mortality in the poorer condition transplants implies that mortality will level off but the continued high mortality rates at the Sycamore Canyon and Diablo Village sites at least implies that a relatively high mortality rate can continue many years into the future, possibly due to increased disturbance. Although it must be noted that the continued presence of transplanted *C. scheeri* at Sycamore Canyon and Diablo Village also supports that transplanting can offer long-term conservation for at least some of the plants in the path of development. More permanent conservation banks could also be considered a viable long-term solution.

Conclusion

Transplant methodology did not play a significant role in success for transplanted *C. scheeri* when followed by two above average rainfall years, however bare rooted plants had the highest rates of mortality. To understand the effects in low precipitation years, mesocosm or greenhouse studies will be needed because it seems unlikely that development will both coincide with a representative range of rainfall years and have enough consistency to sort out the effects. Overall, the control group (undisturbed plants) had highest survival rate, indicating avoidance is the best conservation measure for this species. For environmental variables, the primary underlying factor of the slope and slope aspect seems most likely to have been soil water content, resulting from eastern slope exposures and variable heat loads. Given that shade does not appear important but slope and aspect were important, competition from plants may be an important factor for future study although a reasonable alternative hypothesis would be that these factors instead affect disturbance. The disturbance may be greatly increased by the development itself and transplant mortality due to environmental variables, transplant shock may also play a limited role. A larger data set and a longer period of observation due to the extended time it takes for mortality to occur in *C. scheeri* may both be able to better verify which environmental variables are important as well as their direct or indirect mechanism on mortality.

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