Mesa Verde Cactus
(*Sclerocactus mesae-verdae*)
Monitoring Report

El Malpais Monitoring Site
2008-2013

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ABSTRACT

Because of its federal status as "threatened," it is important to maintain long term monitoring programs for the Mesa Verde Cactus. Five years of demographic and threats monitoring of a Mesa Verde Cactus population in the *El Malpais* Conservation Area near Shiprock, NM revealed a decline in total numbers, driven by mortality outpacing germination most years. The primary cause of mortality could not be determined, and is hypothesized to be drought. Cacti were also lost to erosion, trampling by horses, and off-road vehicle use. Population reproductive effort was related to winter precipitation, contrary to findings of another long term study of the species. Annual growth rate appeared to also correlate with winter precipitation, but the relationship was not statistically significant. The time span of monitoring was much too short to extrapolate trends, especially considering that a germination event did not occur during the study. Monitoring will continue in the future, with the ultimate goal of providing information to support delisting.

INTRODUCTION

Mesa Verde Cactus (*Sclerocactus mesae-verdae*) is a federally threatened, NESL-G2 species that is endemic to San Juan County, New Mexico and neighboring Montezuma County, Colorado. It is restricted to clay-rich soils derived from the Mancos, Menefee, and Fruitland shale. The Mesa Verde Cactus is a small, globose cactus that produces cream to yellow or occasionally pink flowers in the springtime. It is notoriously difficult to find outside its flowering season because of its small size and the fact that many Mesa Verde Cacti contract into the ground in response to drought or cold conditions. The Navajo Natural Heritage Program has been tracking this rare cactus since the program came into existence in the mid-1980s. In 1979 when the cactus was added to the federal Endangered Species List, the U.S. Fish and Wildlife Service (USFWS) identified its primary threats to be poaching; highway and transmission line construction; and off-highway vehicle activity (USFWS 1979). The Mesa Verde Cactus Recovery Plan identifies additional threats, all related to the "destruction or modification of its habitat:" coal mining; oil and gas exploration and development; commercial and residential development; livestock grazing and trampling; pesticide use; and natural causes such as erosion and interspecific competition. (Heil 1984) The most recent 5-year review of the species' status also discusses climate change and insect predation as threats (USFWS 2011).

The *El Malpais* monitoring site is located within the 7,416 acre *El Malpais* Conservation Area, located northwest of Shiprock, New Mexico. This Conservation Area, along with three others, totaling 13,287 acres, was created in coordination with the U.S. Fish and Wildlife Service as mitigation for designating 9,780 acres for community development in Shiprock, Gadii'ahi (Cudei), and Hogback Chapters (Murphy 2007). The Mesa Verde Cactus Conservation Plan (NNDFW 2007) outlines management goals and prescriptions for the Conservation Areas. One of the management prescriptions outlined in the document is to monitor the Conservation Areas on a regular basis.

The *El Malpais* monitoring site was established to monitor population demographics and to measure the effect of certain threats to the cactus population. The monitoring plots are located beneath a 230-Kv transmission line that is operated and maintained by the Western Area Power Administration (WAPA). One of the plots is directly adjacent to the transmission line access road, a dirt 2-track that is occasionally graded or otherwise maintained by WAPA. The placement of the monitoring plots in a location that sees occasional activity allows the effect of those activities to be recorded.

This is the first report prepared from the monitoring data from this site; it will address short term demographic trends and their relationship with drought and other measurable threats from 2008 to 2013.

METHODS

On April 22, 2008, three rectangular monitoring plots, each approximately 500m^2 in area, were established beneath the Kayenta-Shiprock 230-kV transmission line northwest of Shiprock, NM. The plot corners were marked with rebar and GPS coordinates recorded. Within each plot, all Mesa Verde Cacti were located and individually tagged. The tagging method consisted of a nail, placed approximately 10 cm from each cactus or cluster of cacti, with a numbered metal tag wired to it. Each cactus or cluster of cacti was mapped based on the cactus's distance from the two closest plot corners, as measured with meter tapes attached to the rebar at the plot corners. Data recorded for each cactus were stem diameter, a qualitative assessment of vigor, and number and type of reproductive structures. The vigor assessment consisted of a four point system (Table 1). Any unusual or noteworthy characteristics of the cacti and habitat were recorded as well.

During subsequent years (2009, 2011, 2012, 2013) the plots were resurveyed in late April. Tagged cacti were re-located, and plots were thoroughly resurveyed for untagged cacti, including seedlings. Any new untagged cacti were tagged and mapped. Data were collected for all cacti as was done in 2008. Data was not collected in 2010 because there was no botanist in the Navajo Natural Heritage Program that year.

Weather and climate data are reported for New Mexico State University Farmington Agricultural Science Center (Farmington Ag C), the closest weather station with data available for the duration of the study. At the time of writing, data is not yet available for April 2013. The weather station is located south of Fruitland, New Mexico, about 25 miles southeast of the monitoring plots. Data were downloaded from the Western Regional Climate Center <http://www.wrcc.dri.edu/summary/Climsmnm.html>. Annual precipitation for the purposes of this study was calculated as the total precipitation for the 12 months preceding each monitoring visit. As monitoring is done in late April, annual precipitation was calculated as total precipitation from May of the preceding year through April of the sampling year. Winter precipitation was calculated as the total precipitation for the December through April immediately preceding the monitoring visit.

Annual cactus growth rate was calculated for each interval between sampling visits as d_f-d_i / t_f-t_i where d_f= final stem diameter, d_i = initial stem diameter, t_f = final year of growth interval, and t_i = initial year of growth interval. Only stems that were present and measured during both the initial and final year of the growth interval were included in each calculation. Population reproductive effort was calculated for each sampling visit as the mean number of reproductive structures (flowers and fruits, including any that aborted) produced per live stem.

Simple linear regression was used to test for the ability of winter precipitation to predict cactus growth rate, mean vigor score, and population reproductive effort. Regression was performed using R statistical software (R Core Team, 2013).

Table 1. Examples of cactus status corresponding to each vigor score. See fig. 9 for example photos.

Vigor Score	Vigor Assessment	Description of Status
1	Excellent	Fully turgid, dark green, with no physical damage.
2	Good	Slightly less turgid; slight yellowing of tubercules.
3	Fair	Major discoloring; stems shrunken; or minor physical damage.
4	Poor	Cactus appears as though it will not survive until next year or there is uncertainty as to whether the cactus is currently still alive. This includes major physical damage.

RESULTS

Population Size

Mesa Verde Cacti sometimes grow in clusters of adjacent stems (Fig. 1). These clusters may represent a single multi-stemmed cactus, a cohort of related but genetically distinct cacti, or a mother cactus and seedlings. Without excavating the roots, it is not always possible to tell whether a cluster of cacti is a single cactus or several separate cacti. For total population size, birth/ new observations, and mortality, data are reported for individual, genetically distinct cacti, based on "best guesses" as to what constituted individual cacti. The remainder of the demographics (diameter, vigor, and reproduction) are reported on a per-stem basis.

Fig. 1. Cluster of Mesa Verde Cacti. These likely represent 3 separate cacti from one cohort.

The first five years of this monitoring study have shown a modest decline in cactus numbers, due to mortality outpacing the discovery of new seedlings (Fig. 2).

In 2008, a total of 87 cacti were found in the three plots. In 2009, that number rose to 91; 4 new cacti were found and none died (Fig X). Of the 4 new cacti, 2 had diameters less than 2cm, indicating that they were likely seedlings in 2008 and extremely difficult to spot. The other two cacti had diameters greater than 2cm, making them overlooked adults in 2008.

The next sampling year was 2011, when the total count was 86 cacti. This reduction in numbers was due to mortality in 7 cacti, combined with the discovery of 2 new cacti. The cause of mortality was not clear for most of the dead cacti. However, cause of mortality was attributed to erosion for one of the dead cacti (Table 2). The 2 new cacti had diameters of 2.5 cm and 3 cm, suggesting that they had been adults but simply overlooked in previous years.

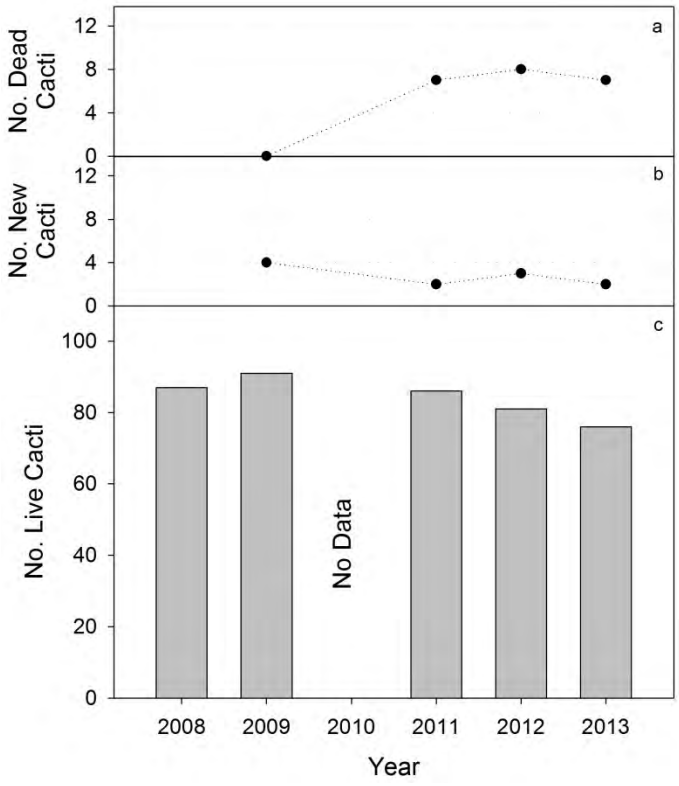


Fig. 2. (a) Number of cacti considered newly dead in 3 permanent monitoring plots for each year from 2009 to 2013 (b) Number of new cacti found in 3 plots from 2009 to 2013 (c) Total number of Mesa Verde Cacti observed in the 3 plots from 2008 to 2013.

In 2012, 81 cacti were censused, with 3 new cacti discovered and 8 deceased (Fig. 2). Two of the new cacti represented a recent cohort, with diameters of 1.2 cm and 1.7cm. The third new cactus was larger, at 3cm. During the April 2012 data collection, it was clear that the plots had quite recently been visited feral horses. Abundant fresh horse tracks were observed in the plots, and 6 cacti had been stepped on by horses. Of these, one was already dead at the time of the 2012 data collection. Two others took more time to die and were recorded as dead in 2013. Three of the cacti recovered from the damage and survived until 2013 (Fig. 3). There were also several "near-misses": 5 cacti were recorded as being located immediately adjacent to a horse track (Fig. 4).

Table 2. Causes of Mesa Verde Cactus mortality and number of deaths attributed to each.

	Year Declared Dead			
Cause of Death	2011	2012	2013	Total
Not Apparent	6	5	4	15
Erosion	1	2	0	3
Stepped on by Horse	0	1	2	3
Run Over by a Vehicle	0	0	1	1
Total	7	8	7	22

Fig. 4. Mesa Verde Cactus directly adjacent to a fresh horse track. Photo taken in April 2012.

Fig. 3. Mesa Verde Cactus that was stepped on by a horse in April 2012. Photo taken in April 2013. Cactus has healed the physical damage (visible on the right side of the cactus). Flower buds, which are normally borne on the tips of stems in this species, emerge from the side of this cactus.

In 2013, 76 live cacti were recorded within the plots. Of these, 2 were newly observed. Both new cacti represented a new cohort, with diameters less than 1 cm. In 2013, 7 cacti were considered dead. Besides the 2 mortalities attributed to feral horses, 1 cactus was likely run over by a vehicle (Table 2). This cactus was missing from plot 1, and its location had been recorded as the north part of the plot near the dirt road, where there were obvious tracks of a vehicle pulling off the road to turn around (Fig. 5)

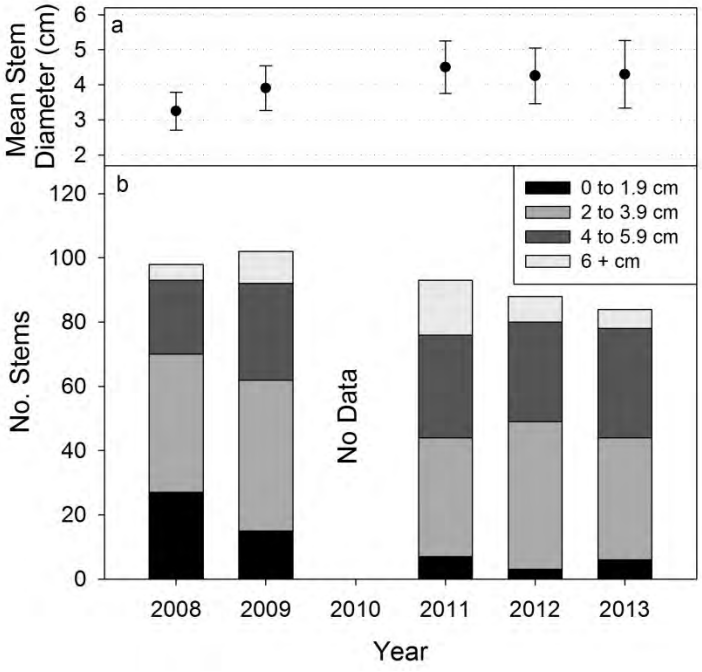
Fig. 5 (right). Looking west across north edge of monitoring plot #1. Pin flags mark the plot corners and edges. The red flag next to the pile of equipment in the foreground is the plot NE corner. The four pink flags near the transmission line tower mark the plot west edge. The white flag near the west edge is the approximate location of the missing cactus. Note the fresh tire tracts within the plot. Photo taken in April 2013.

Size Class and Annual Growth Rate

Mean stem diameter fluctuated from year to year throughout the study (Fig. 6). Annual cactus stem growth rate was positive during 3 of the time intervals between sampling visits, and negative during one time interval (Fig. 7). On average, stem diameter increased from the first year of the study until 2011, the year when there were also the highest number of stems in the 6 cm and larger size class (Fig. 6). This diameter increase was due to cactus growth (average growth rate of 0.4 cm per year from 2008 to 2011; *see* Fig. 7), combined with the scarcity of new seedlings (Fig. 6b).

Mean stem diameter decreased slightly between 2011 and 2012, from 4.5cm to 4.3cm (Fig 6b) . This decrease was primarily due to shrinkage; stems that were present in the plots in both 2011 and 2012 shrank an average of 0.4 cm during that year (Fig. 7).

In 2013, mean stem diameter remained constant at 4.3 cm, despite the fact that all 7 stems that suffered mortality that year were large (greater than 5cm; Fig. 6b). Stems that persisted from 2012 to 2013 grew 0.2 cm on average. Two new seedlings were discovered in 2013.



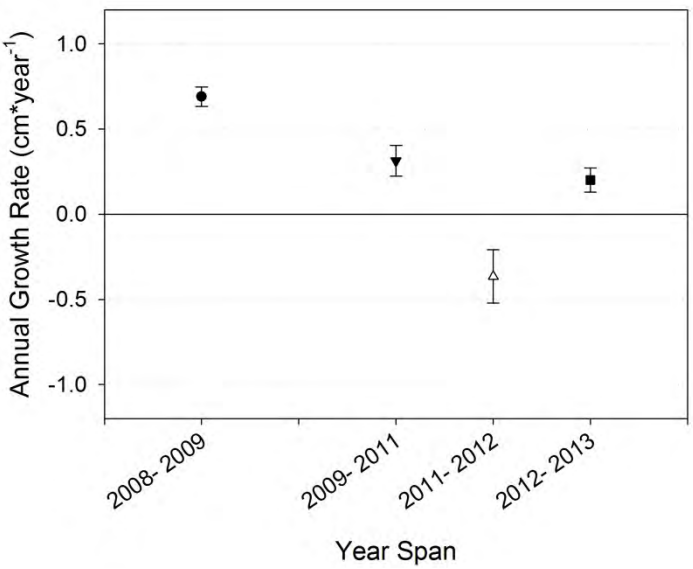


Fig. 7. Mean stem diameter annual growth rate ±1 SE, for Mesa Verde Cacti in 3 permanent monitoring plots from 2008 to 2013.

Vigor

Cactus vigor was high the first two years of the study, with all stems rated as good or excellent in 2008 and all but 2 stems rated good or excellent in 2009 (Fig. 8, Fig. 9).

In 2011 and 2012, mean vigor score dropped, with fewer stems rated "excellent" (Fig. 8). In 2011, 11 stems rated "fair" or "poor," and in 2012, 10 stems rated "fair" or "poor." This poor vigor correlates with the lower growth rates observed during those years (Fig. 7). Several of the cacti rated "fair" or "poor" in 2012 had been stepped on by a horse. By 2013, 3 of the 4 cacti rated poor the year before had died, while the 4th cactus had recovered from being stepped on by a horse.

In 2013, average vigor recovered to pre-2011 levels, with most stems rated "excellent" and only 2 stems rated as "fair" or "poor."

Fig. 6 (left). (a) Mean stem diameter ±1 SE of live Mesa Verde Cacti in 3 permanent monitoring plots from 2008 to 2013.
(b) Number of live stems in each of 4 size classes for the same monitoring plots and years.

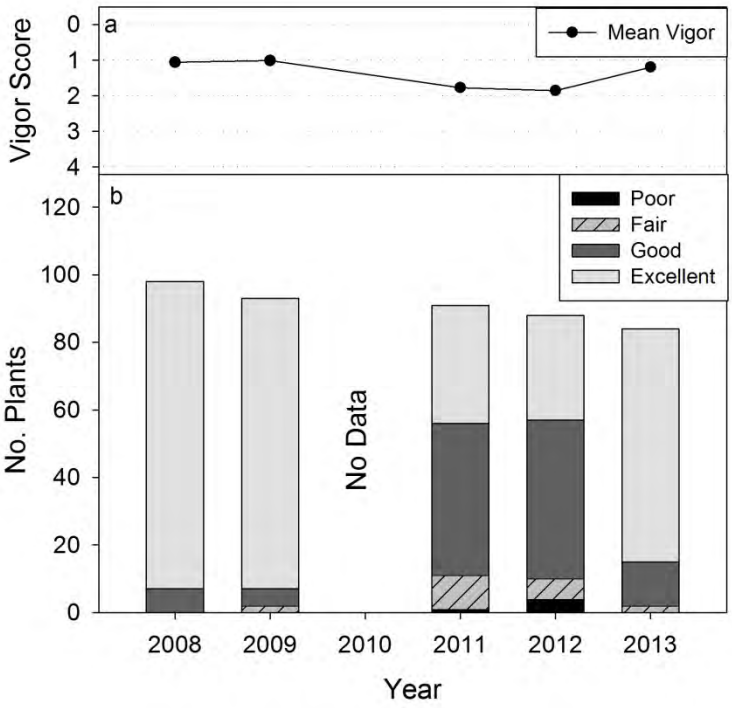


Fig. 8. (a) Mean vigor score for all live Mesa Verde Cacti in 3 plots, for each year from 2008 to 2013. See table 1 and fig. 9 for more information on vigor assessments and corresponding scores. (b) Number of cacti assessed with each vigor score from 2008 to 2013.

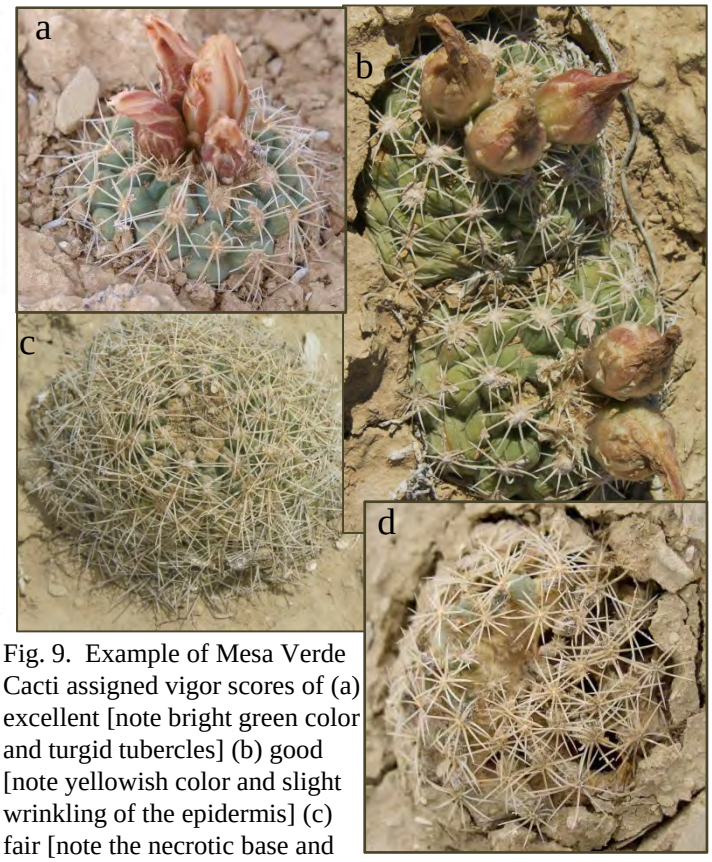


Fig. 9. Example of Mesa Verde Cacti assigned vigor scores of (a) excellent [note bright green color and turgid tubercles] (b) good [note yellowish color and slight wrinkling of the epidermis] (c) fair [note the necrotic base and yellowing above] and (d) poor [not quite dead yet]. Photos (b) and (c) by B. Elliott. Photo (d) by D. Roth.

Reproduction

Reproductive effort varied drastically from year to year. 2008 represented the year with the greatest reproductive effort, with a total of 231 flowers and fruits, only one of which aborted (Fig. 10). On average, reproductive effort for the population that year was 2.3 reproductive structures per stem (Fig. 11).

Reproductive effort was lowest in 2012, with a total of 75 flowers and fruits, one of which aborted (Fig. 10). This translated to a population reproductive effort of 0.84 reproductive structures per stem (Fig 11).

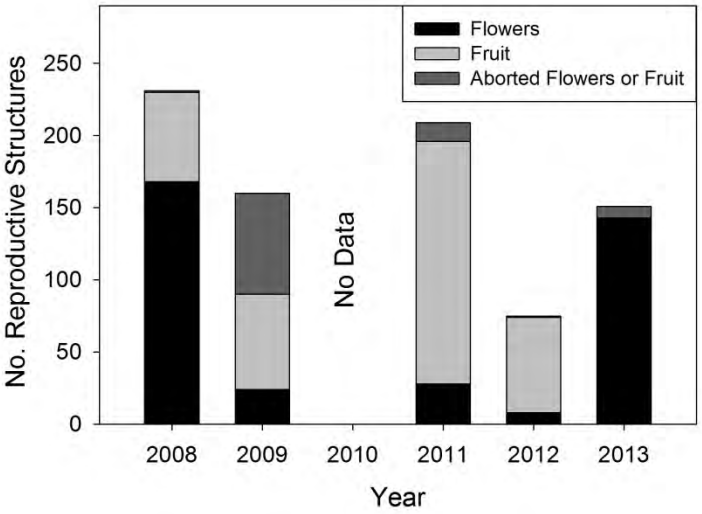


Fig. 10 (above). Number of flowers, fruits, and aborted flowers or fruits produced each year by Mesa Verde Cacti in 3 permanent monitoring plots

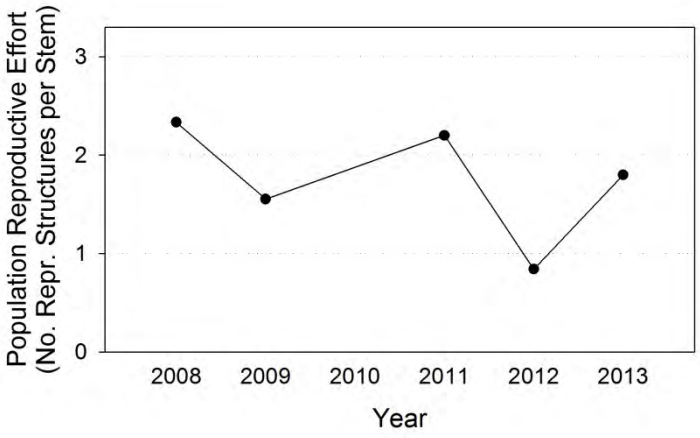


Fig. 11 (left). Mesa Verde Cactus population reproductive effort per year, from 2008 to 2013, in 3 permanent monitoring plots.

Precipitation

For the duration of the study, annual precipitation remained below average (Fig. 12). Annual precipitation varied from 4.4 inches in the 12 months preceding the 2013 monitoring visit to 7.84 inches in the 12 months preceding the 2011 monitoring visit.

Winter precipitation, defined as total precipitation from December through April preceding the monitoring visit, predicted the population's reproductive effort (P=0.048; Table 3; Fig.13). Winter precipitation also appears to correlate with mean vigor score and cactus growth rate (Fig. 13) but those relationships were not statistically significant (Table 3).

Other than the first year of the study, there was only one year, 2009, when more new cacti were discovered than declared dead, and that year also had the highest winter precipitation (data points circled in fig 13c).

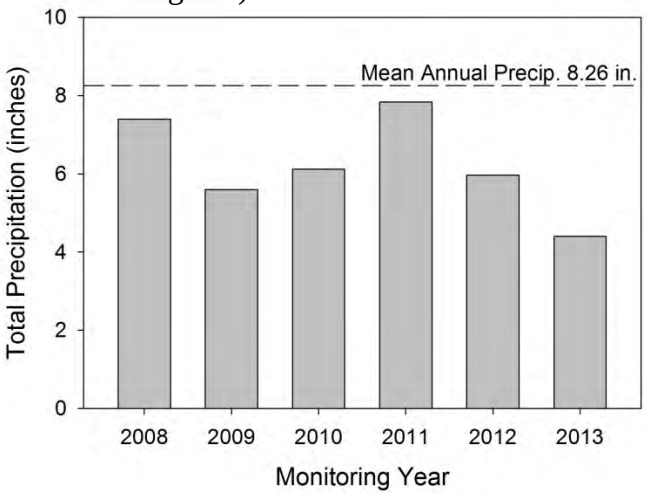


Fig. 12. Annual precipitation as measured by the Farmington Ag C gauge near Fruitland, for the duration of the study. Annual precipitation is calculated as the total precipitation for the 12 months (May through April) preceding each monitoring visit. Mean annual precipitation is based on the period of record of 1978-2012 as reported by the Western Regional Climate Center.

Table 3. Results of 3 separate simple linear regression analyses, testing the ability of winter precipitation to predict a response variable.

Response variable	Coefficient	t	df	P
Population Reproductive Effort	0.71	3.24	3	0.048*
Mean Vigor Score	-0.41	-1.93	3	0.15
Stem Growth Rate	0.39	1.77	2	0.22

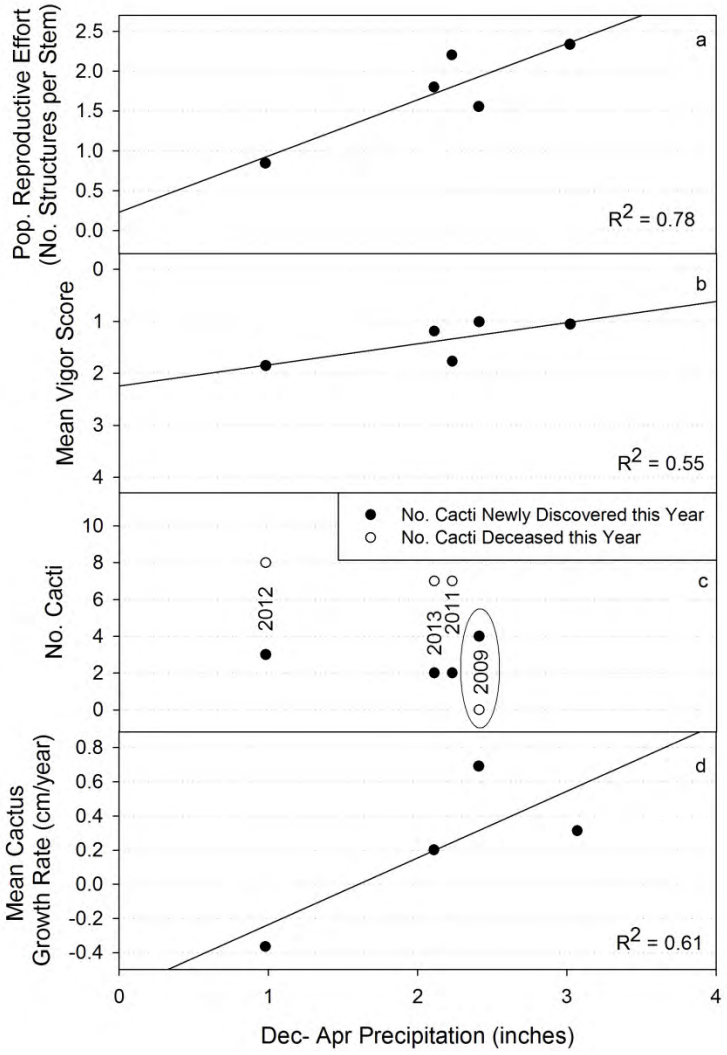


Fig. 13. Population (a) reproductive effort, (b) vigor score, (c) mortality and newly discovered cacti, and (d) stem growth rate, as a function of winter precipitation, from 2008 to 2013. Simple linear regression lines are displayed, as are the corresponding R^2 values.

April precipitation remained well below average for all years except for 2011 (Fig. 14). April 2013 precipitation is not yet available, making the data set quite small for determining if there is relationship between April precipitation and population demographics. However, based on this limited data set, April precipitation does not appear to influence mortality, reproductive effort, or cactus vigor (Fig. 15). While 2011 was an above-average year for April precipitation, it was not an extraordinary year for Mesa Verde Cacti in this population.

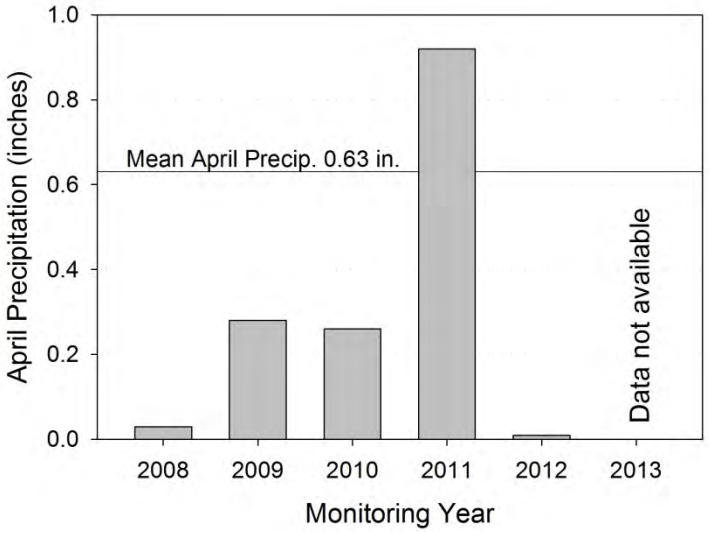


Fig. 14. Precipitation during the month of April throughout the monitoring study. Mean April precipitation is based on the period of record of 1978-2012 as reported by the Western Regional Climate Center.

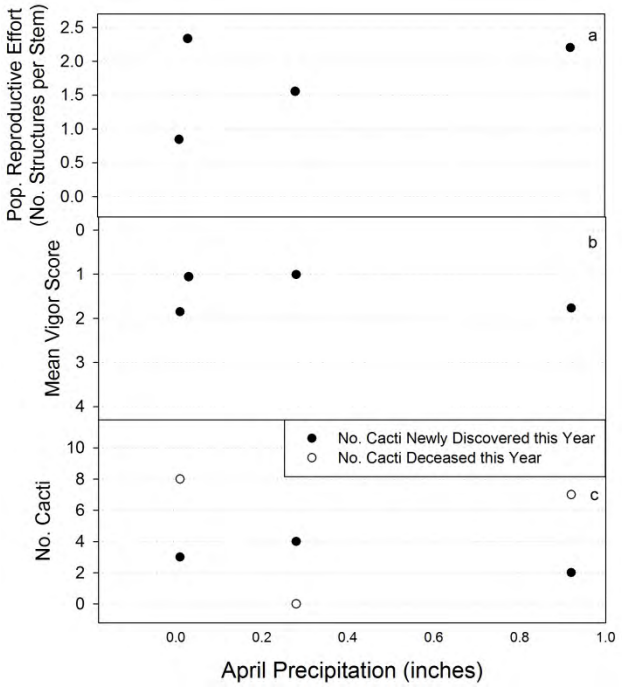


Fig. 15. Population (a) reproductive effort, (b) vigor score, and (c) mortality and newly discovered cacti, as a function of April precipitation from 2008 to 2012.

DISCUSSION

Demographics

Coles *et al*. (2012) reported and analyzed 20 years of monitoring data for Mesa Verde Cactus in 3 permanent plots in southern Colorado. The Colorado plots were larger (50m X 200m) than the *El Malpais* plots discussed in this report, providing a larger sample size of cacti (346 cacti in the final year of monitoring, compared to fewer than 100 in the *El Malpais* plots). This larger sample size, combined with the longer time period of the study, allowed the authors to conduct a population viability analysis and more thoroughly examine the relationship between demographics and climate metrics.

New seedlings were observed during 18 out of 20 years of Coles *et al*.'s study, but most years, germination was relatively low. Four major germination events were recorded: 1988, 1994, 1998-2000, and 2004. In this Colorado study, germination episodes were most strongly correlated with April precipitation. In contrast, April precipitation did not correlate with seedling abundance or any other demographic factors in the *El Malpais* plots. However, with the short duration of the *El Malpais* study, the drought conditions, and the scarcity of seedlings, this is not surprising.

Based on 5 years of data from *El Malpais*, there does appear to be a relationship between winter precipitation and several population metrics, particularly reproductive effort. Contrary to convention which divides the water year into standard 3 or 6 month increments, I chose to analyze these relationships based on a five month interval from December through April. This is because in preliminary data analysis it appeared that plentiful December precipitation did influence population metrics, while cool season precipitation that fell earlier in the year (October and November) did not influence cactus vigor or reproduction. In future years, as a larger data set becomes available, the validity of this relationship will be re-assessed.

Coles *et al*.'s population viability analysis revealed a stable population in southern Colorado, with a very small rate of increase. This is despite the study capturing the effects of an extreme drought in 2002-2003 and more than one serious beetle infestation. The data set for *El Malpais*, on the other hand, shows a steady modest rate of decline, with mortality consistently outpacing germination by a few cacti per year. In order to tell if this New Mexico population is truly less stable than the Colorado populations measured by Coles *et al.*, a much longer data set is necessary. Mortality has outpaced germination since 2008, but there has been no large germination event since then, either.

The primary cause of Mesa Verde Cactus mortality in southern Colorado was infestation by beetle larvae, followed by drought/ seedling failure. In the *El Malpais* plots, no beetle infestation was observed, and the majority of mortality could not be attributed to any cause. It is probable that many of these "unknown cause" mortalities were due to drought. A few mortalities in the *El Malpais* study could be directly attributed to threats identified by the USFWS: erosion (3 cacti); damage by livestock (3 cacti); and off road vehicle use (1 cactus). These total a minority (31%) of recorded mortality.

Mesa Verde Cactus Resilience

In the *El Malpais* plots, 3 of 6 cacti recovered from damage by horse hooves. Two of these recovered cacti even produced flowers the year after being stepped on. In Colorado, 20% of beetle-damaged cacti survived to produce more stems (Coles *et al.* 2012). While it is extraordinary that some cacti survived these disturbances, the survival rates are low, and do not negate the threat posed by factors that have the potential to physically damage the Mesa Verde Cacti. It is noteworthy that Mesa Verde Cacti can sometimes survive serious physical damage, and resource managers should be aware of the possibility. However, reports of extraordinary cactus survival are occasionally made to the Navajo Natural Heritage Program, and presented as justification for delisting. Monitoring programs are crucial for determining the population-scale effects of such disturbances. Otherwise, such cases are simply anecdotes, and difficult to interpret in the context of the species' overall status.

Feral horses in the *El Malpais* Conservation Area. Photo taken April 25, 2013.

Management implications

The *El Malpais* plots are within a Mesa Verde Cactus Conservation Area, and within a Biological Preserve as designated by the Navajo Nation's Biological Resource Land Use Clearance Policy that guides development to avoid damaging protected wildlife and habitats. The primary implication of this relatively new land status is that the Navajo National Department of Fish and Wildlife no longer recommends approval of development within these areas, unless the project is compatible with the preserve's conservation goals. The threats posed to the Mesa Verde Cacti within the *El Malpais* Conservation Area are unfortunately related to the little development that is already in place, as well as unregulated activities that occur there. Feral horses are ubiquitous on the Navajo Nation, and in 2013, a herd of 7 roamed the vicinity of the monitoring area over the course of the two day monitoring visit. Currently, the Bureau of Indian Affairs, Navajo Nation Department of Agriculture, and many local chapters are conducting feral horse round-ups throughout the Navajo Nation in an effort to reduce the impact of unregulated grazing on the range.

Thus far, attempts to limit public access to the *El Malpais* Conservation Area have been largely unsuccessful. In 2006-2007, five gates were constructed blocking common access points, but despite the presence of signs reading "Ecologically Sensitive Area," visitors bypassed the gates by driving around them and further damaging habitat. In 2007, WAPA agreed to replace 4 of the gates with earthen berms. Unfortunately, it is nearly impossible to restrict public access to this Conservation Area. For example, as of April 2013 the transmission line access road was badly washed out between the highway and the monitoring plots. Despite this, a determined driver had found a way around by driving a couple hundred feet up the wash and creating a new "road" through Mesa Verde Cactus habitat back to the transmission line access road. It may have been this same vehicle that drove onto one of the monitoring plots to turn around.

Future Research

Annual monitoring will continue into the foreseeable future, in order to track population demographics and assess threats. Information gathered by monitoring programs like this one is valuable to the U.S. Fish and Wildlife Service for assessing listed species' status and potentially documenting recovery.

ACKNOWLEDGEMENTS

This report format was adapted from monitoring reports written by D. Roth, former botanist for the Navajo Natural Heritage Program. Data collected by Roth in 2008-2009 were used to generate figures and determine trends for this monitoring report. The study design is attributed to Ms. Roth as well.

Thank you to P. Kyselka for field assistance in 2012. Thanks also to B. Elliott for kindly allowing me to use his photos.

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