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

## *El Malpais* Monitoring Site
## The Navajo Nation
## 2008-2019


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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. Approximately 95% of the specie's range occurs on Navajo Nation tribal trust land, with some populations occurring within adjacent Ute Southern Ute, BLM, and New Mexico state lands (Roth 2018). It is restricted to clay-rich soils derived from the Mancos and Fruitland shale formations known as "badlands" which have high salt and metal content and poor infiltration. On the Navajo Nation, there are also "outlier" populations of Mesa Verde cactus occurring in the Sheep Springs area in Menefee Formation. Perennial vegetation in these badlands is generally sparse (5-15%, Coles et al 2012) and dominated by low growing shrubs such as *Atriplex corrugata, A. gardneri, A. confertifolia, Tetradymia spinescens*, and *Frankenia jamesii* (Ladyman 2004). Grasses are infrequent and include *Sporobolus airoides, Pleuraphis jamesii,* and *Artistida purpurea*. In high moisture years annual native and invasive grasses and forbs can include *Halogeton glomeratus, Bromus tectorum, Salsola tragus, Eremopyrum triticeum, Descurainia pinnata,* and *Chorispora tenella*.

Mesa Verde cactus is a small (rarely larger than 6 in), globose cactus in the genus *Sclerocactus* that produces cream to yellow or occasionally pink flowers in the springtime (mid-April through mid-May). It is self-compatible, though self-fertilization results in reduced seed set; and mainly pollinated by small native solitary bees in the *Halictidae* and *Anthophoridae* families (Heil and Porter 1994). 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 within the Department of Fish and Wildlife 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 identified 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 specie's status also discussed climate change and insect predation as threats (USFWS 2011). In particular, the native longhorn beetle (*Moneilema semipunctatum)* has been shown to be a primary cause for mortality of reproductive stems in Colorado Mesa Verde populations, particularly during drought years (Coles et al 2012).

The *El Malpais* monitoring site is located within the 7,416 acre *El Malpais* Conservation Area northwest of Shiprock, New Mexico. Plots were established in Mancos Shale soils with associated species including: *Halogeton glomeratus*, *Malcolmia africana, Atriplex corrugata, Atriplex gardnerii*, *Eremopyron tritecium, Descurainia pinnata, Lappula occidentalis, Salsola tragus, Plantago, Sporobolus cryptandrus, Eriastrum, Sphaeralcea, Allium, Stanleya pinnata, Oenothera caespitosa, Cleomella palmeriana, Cymopterus, Townsendia annua, Camissonia, Vulpia octoflora, Bromus tectorum,* and *Chaenactis*. 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) outlined 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 anthropogenic 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 second report prepared from the monitoring data from this site; it will address demographic trends and their relationship with drought and other measurable threats from 2008 to 2019.

## 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. It is impossible to tell whether clusters of cactus are attached to a single root underground or represent clusters of individuals. Therefore, the following data was collected separately for each stem: stem diameter, a qualitative assessment of vigor, and number and type of reproductive structures, with each stem assigned a letter value depending on its cardinal position in the plot. 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. Cactus that had died were assigned a cause of death (or unknown) and tags were removed. Cactus that were not found but were not obviously dead (i.e. there were no holes where the cactus used to be or skeletons of the cactus visible) were assigned as "not found", in case they were alive but hidden under the soil. Tags for "not found" cactus were left in the plot until the cactus was "not found" for three subsequent monitoring years, at which point the cactus was marked as "dead" and tags were removed.

**Table 1.** Description of cactus status and associated vigor score. Table from Hazelton 2013.

| 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. |

During subsequent monitoring years (2009-2019) the plots were resurveyed in late April, ideally between 4/24 and 4/27. Tagged cacti were re-located, and plots were thoroughly resurveyed for untagged cacti, including seedlings. Any new untagged cacti were tagged and mapped. Data was not collected in 2010 and 2016 because there was no botanist at the Navajo Natural Heritage Program those years. Data was also not collected in 2020 due to NN COVID19 government travel restrictions.

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. 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's SCENIC webpage (https://wrcc.dri.edu/csc/scenic/data/station_data/). 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. Average annual, April, and winter precipitation was calculated based on the period of record of 1978-2019 as reported by the Western Regional Climate Center for the Farmington Ag C station.

Annual cactus growth rate was calculated for each interval between sampling visits as $d_f$-$d_i$ where $d_f$= final stem diameter and $d_i$ = initial stem diameter. Annual growth rate was only calculated for years where monitoring data was collected the following year (growth rate was not calculated for 2010 and 2016, when monitoring did not occur). Only stems that were present and measured during both the initial and subsequent year of the growth interval were included in each calculation. Population reproductive effort was calculated for each sampling visit as the total number of reproductive structures (flowers and fruits, including any that aborted) produced divided by the total number of live stems.

Simple linear regressions were used to predict population reproductive effort, mean stem growth rate, percent of stems vegetative, mean vigor, and number of dead stems based on winter, April, and annual precipitation. Linear regression was also used to predict the relationship between total reproductive structures produced and stem diameter size in a wet and dry year. All analyses were performed using R statistical software (R Core Team 2020).

RESULTS

*Population size:*

Throughout the study duration, 180 cactus individuals, clusters, or stems were assigned a tag number. Of these, 140 were single-stemmed individual cacti and 40 of these were either multi-stemmed cacti or clusters of cacti (it's impossible to tell if stems represent

**Figure 1.** Cluster of Mesa Verde representing either a cluster (cohort) of 7, likely related, individual cacti or a single cactus with 7 stems.

one individual or clusters of individuals without digging up plants, Figure 1). Of the multi-stemmed cacti; stem (or cluster) numbers ranged from 2-11, with an average stem number of 3.5. To reduce confusion and standardize monitoring results across years and between monitoring personnel, demography data are summarized on a per-stem basis throughout the rest of this report.

The number of live stems fluctuated by monitoring year (Figure 2), with monitoring years 2009 through 2013 showing an overall modest decline from 100 to 82 live stems. This decline was explained by mortality (Figure 2b) outpacing recruitment (Figure 2a) during the 2009 to 2013 monitoring interval. It is worth noting, however, that the number of new stems per year was calculated as the number of newly recorded stems found in each of the monitoring plots for each monitoring year. These could either represent new recruits (stems with a diameter of less than 2.0 cm), adults that were either overlooked by monitors in previous years, or stems that were underground and therefore undetected since plots were established in 2008 (Table 2). For example, the two new stems found in 2013 both had diameters of 0.9 cm, suggesting that they were new recruits for 2013 and not overlooked adult cacti. In 2011, however, all 4 new stems recorded were at least 2.5 cm in diameter, indicating that they were all likely overlooked adults.

**Table 2.** Tally of new stems (either new recruits, less than 2cm in diameter, or overlooked adults, greater than 2 cm in diameter), number newly dead stems, total number live stems, and number of stems not found by monitoring year for three permanent monitoring plots at the *El Malpais* monitoring site. Net gains/losses was calculated as the total number of new stems-total dead.

| *Monitoring Year* | *Number New Stems: Likely New Recruits* | *Number New Stems: Overlooked Adults* | *Number Dead* | *Number Live* | *Number NF* | *Net Gains/Losses* |
|---|---|---|---|---|---|---|
| 2008 | NA | NA | NA | 97 | NA | NA |
| 2009 | 2 | 2 | 0 | 100 | 1 | +4 |
| 2011 | 0 | 4 | 12 | 89 | 4 | -8 |
| 2012 | 2 | 1 | 4 | 87 | 6 | -1 |
| 2013 | 2 | 0 | 9 | 82 | 4 | -7 |
| 2014 | 10 | 7 | 0 | 91 | 6 | +17 |
| 2015 | 5 | 4 | 1 | 100 | 7 | +8 |
| 2017 | 35 | 7 | 43 | 95 | 12 | -1 |
| 2018 | 31 | 3 | 15 | 114 | 12 | +19 |
| 2019 | 54 | 4 | 8 | 170 | 7 | +50 |

In 2014, there were no new dead stems and 17 new stems found, bringing the total of live stems to 91 (just 6 below the 2008 tally). Positive population growth due to modest recruitment and just one new dead stem also occurred in 2015. High recruitment was recorded during monitoring years 2017-2019 (120 new recruits and 14 overlooked adults), though high mortality was also recorded during 2017 (66 new dead stems). Monitoring at this site did not occur in 2016, so it is difficult to say how many of these new recruits or dead stems would have been captured in 2016 data or truly were a result of 2017 climactic conditions. Overall, there has been a net increase of 73 stems within the three monitoring plots from 2008-2019, which is explained by unusually high recruitment occurring in 2017, 2018, and 2019.

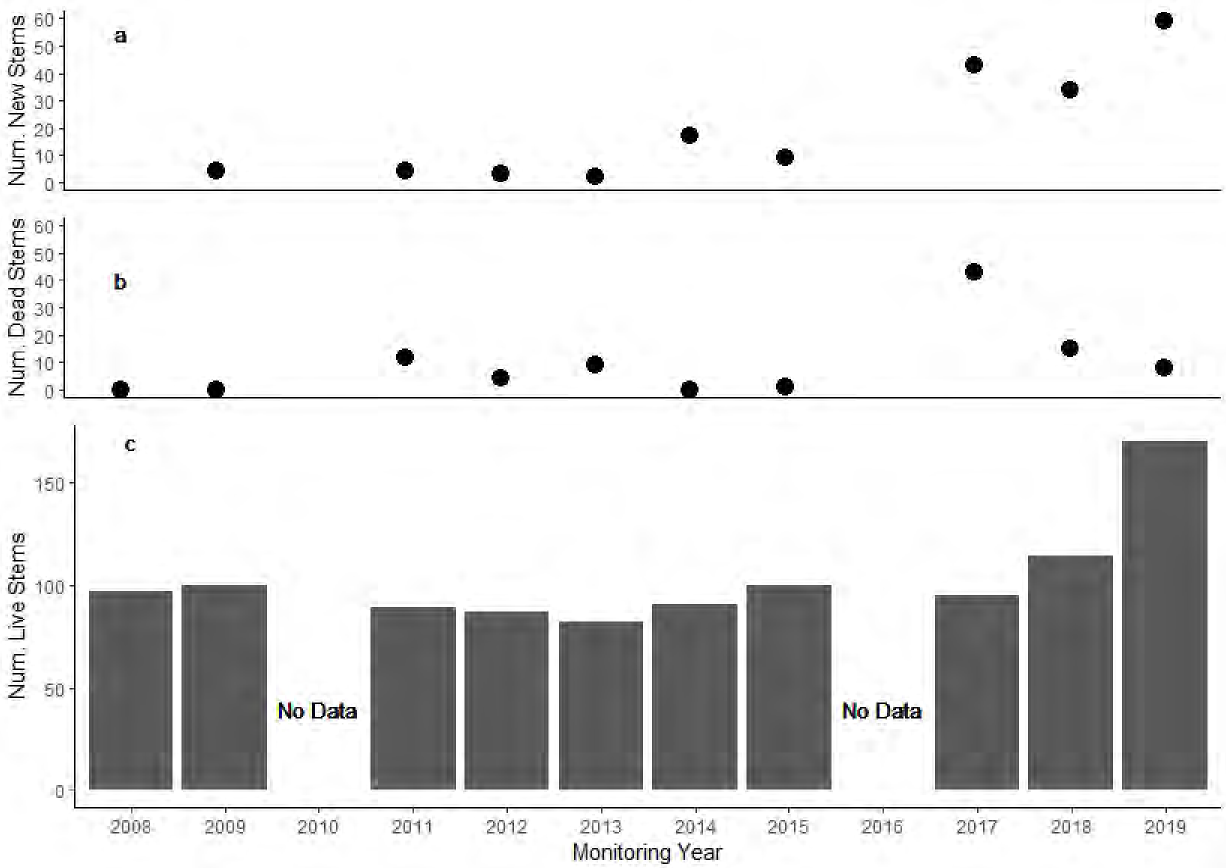


**Figure 2.** (a) Number of newly-observed stems, (b) number of newly counted dead stems, (c) total number of live stems counted in three permanent monitoring plots at the El Malpais monitoring site from 2008-2019.

*Survival/Mortality:*

Of the 270 stems monitored throughout the duration of this study to date, stems survived an average of 4.33 years (±0.19 SE). Twenty seven stems survived throughout the entire study period of 11 years (2008-2019). Of the 27 that survived from 2008-2019, the minimum diameter in 2019 was 3.7 cm, the maximum diameter was 8.8 cm, and the mean diameter was 5.76 cm.

From the monitoring period 2008-2019, a total of 92 stems were recorded as dead. For a majority of these stems, it was impossible to determine the cause of death (due to drought, predation, mechanical damage, erosion, etc.). Erosion was determined to be the cause of death for one cactus in 2011 (Hazelton 2013). In 2012, feral horses caused damage to 6 cacti by stepping on plants. One of these cactus died in 2012 and two others had died as of 2013. Three cactus had recovered as of 2013. One cactus in 2013 also died from mechanical damage as a result of someone turning their vehicle around in the monitoring plots. In 2015, only one stem was recorded as dead (cause unknown). In 2017, the death of 7 stems was attributed to mechanical damage from feral horses, with horse prints seen on top of or immediately adjacent to dead stems, and 3 stems had died due to erosion. Thirty three other stems were recorded as dead with no apparent cause. In 2018, the death of 2 stems was attributed to rodent damage, where stems were dug up from underground and the roots were consumed, while 2 stems were killed indirectly by being buried by rodent burrows. Eleven stems were recorded dead with cause unknown. In 2019, all 8 stems were listed dead as cause unknown.

One cactus (not dead) had hollow stems and insect damage to mature fruits due to predation by an unknown insect (Figure 3). I did not observe the cactus borer (*Moneilema semipunctatum)* or the army cutworm *(Euxoa spp)* on any of the damaged plants in 2019, although either species could have been present and hidden in stems. The arthropods I observed near and inside stems were ground beetle larvae in the *Carabidae* family, which are not known to be plant herbivores but instead feed on other insects (personal communication with Gary Alpert, entomologist, Northern Arizona University, 3/11/2021). It's possible that these insect predators were feeding on the insect herbivores feeding on the Mesa Verde cactus stems and fruits.

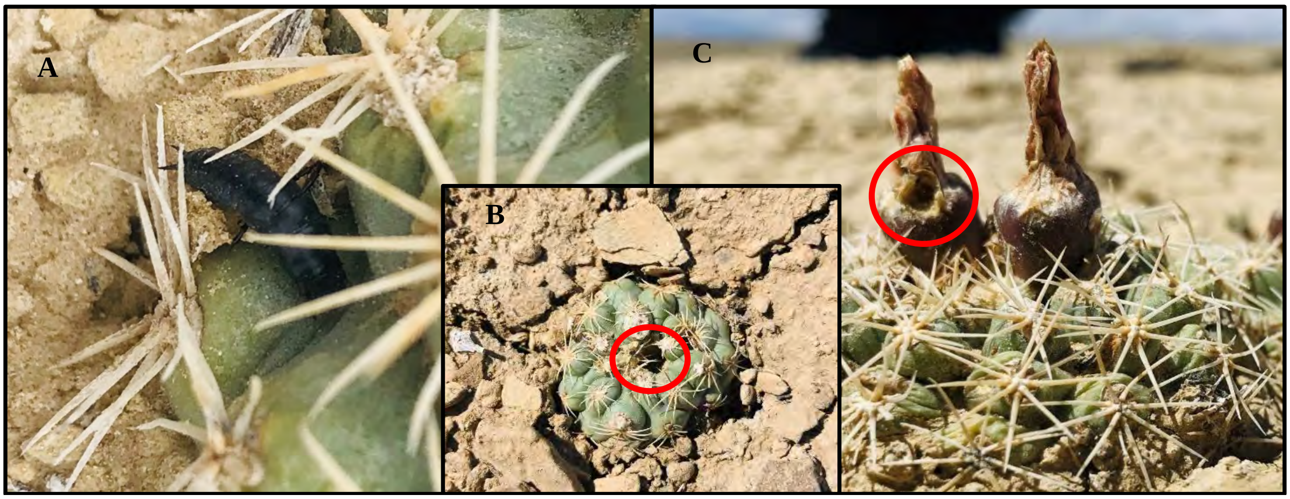


**Figure 3.** (a) Carnivorous ground beetle larvae in the *Carabidae* family observed on Mesa Verde cactus stems in 2019. Damage to Mesa Verde cactus stems (b) and mature fruits (c), likely from the cactus borer (*Moneilema semipunctatum*), though no borers were directly observed.

*Size Class/Population Growth Rate:*

Mesa Verde cactus stems shrink during unfavorable years and grow during favorable years. The monitoring intervals of 2008-2009, 2013-2013, 2014-2015, and 2018-2019 showed positive mean annual growth rates for stems (Figure 4). The monitoring intervals of 2010-2011, 2013-2014, and 2017-2018 showed negative mean annual growth rates for stems. Stems shrunk the most during the 2017-2018 monitoring interval (mean annual rate of -0.8cm ± 0.09 SE).

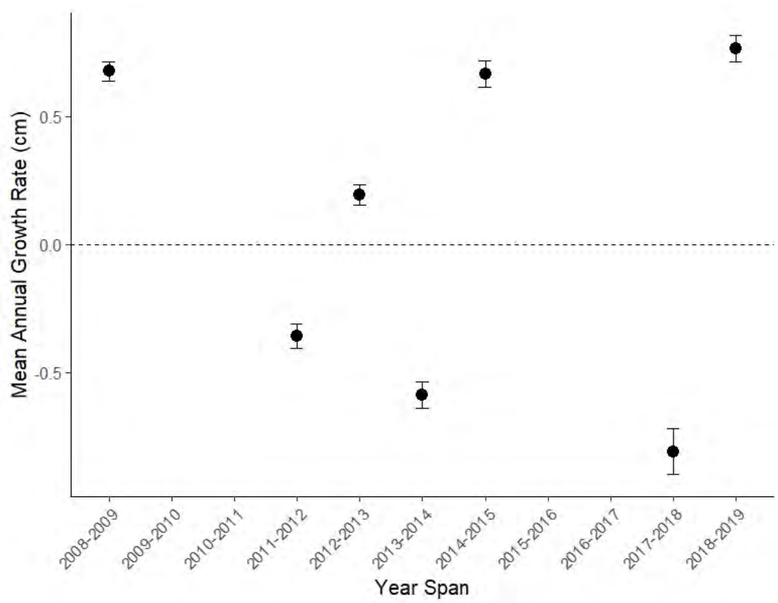


**Figure 4.** Mean stem diameter annual growth rate ±1 SE, for Mesa Verde stems in 3 permanent monitoring plots from 2008 to 2019.

On average, mean stem diameter increased from 2008-2011 (Figure 5a), as the number of cactus in the 4-5.9 and 6+ cm size classes increased by 21 plants, and seedling recruitment during that interval remained low (Figure 5b). From 2012-2014, mean stem diameter decreased from 4.35 cm ±0.18 SE to 4.18 cm ±0.19 SE. This decrease was primarily due to shrinkage of existing stems and not additions of stems in smaller size classes (Hazelton 2013). In 2015, mean stem diameter increased to 4.64 cm ± 0.20 SE, due to stem growth during this period as 14 additional stems were classified in the 6+ cm size class. Mortality and/or shrinkage of large adult stems in 2017 (-29 stems from the 4-5.9 cm and 6+ cm size classes) coupled with an increase of 27 stems in the 0.09 cm and 1-1.9 cm size classes led to an average decrease in mean stem diameter of -1.41 cm from 2015 to 2017. In 2018, there were even fewer stems in the 4-6.9 cm and 6+ size classes (loss of 19 stems from 2017-2018) and an increase in stems in the 0.09 cm and 1-1.9 cm size classes (gain of 25 stems from 2017-2018), which decreased the mean population diameter by 1.06 cm. In 2019, there were 101 stems classified as juvenile (0-1.9 cm size classes) and only 66 adults (2-6+ cm size classes). In comparison, the 2008 population was composed of 27 juveniles and 71 adults. From 2008 to 2019, mean stem diameter decreased by 0.8cm, due to the loss of large-stemmed adults coupled with an increase of stems in the seedling and juvenile size classes.

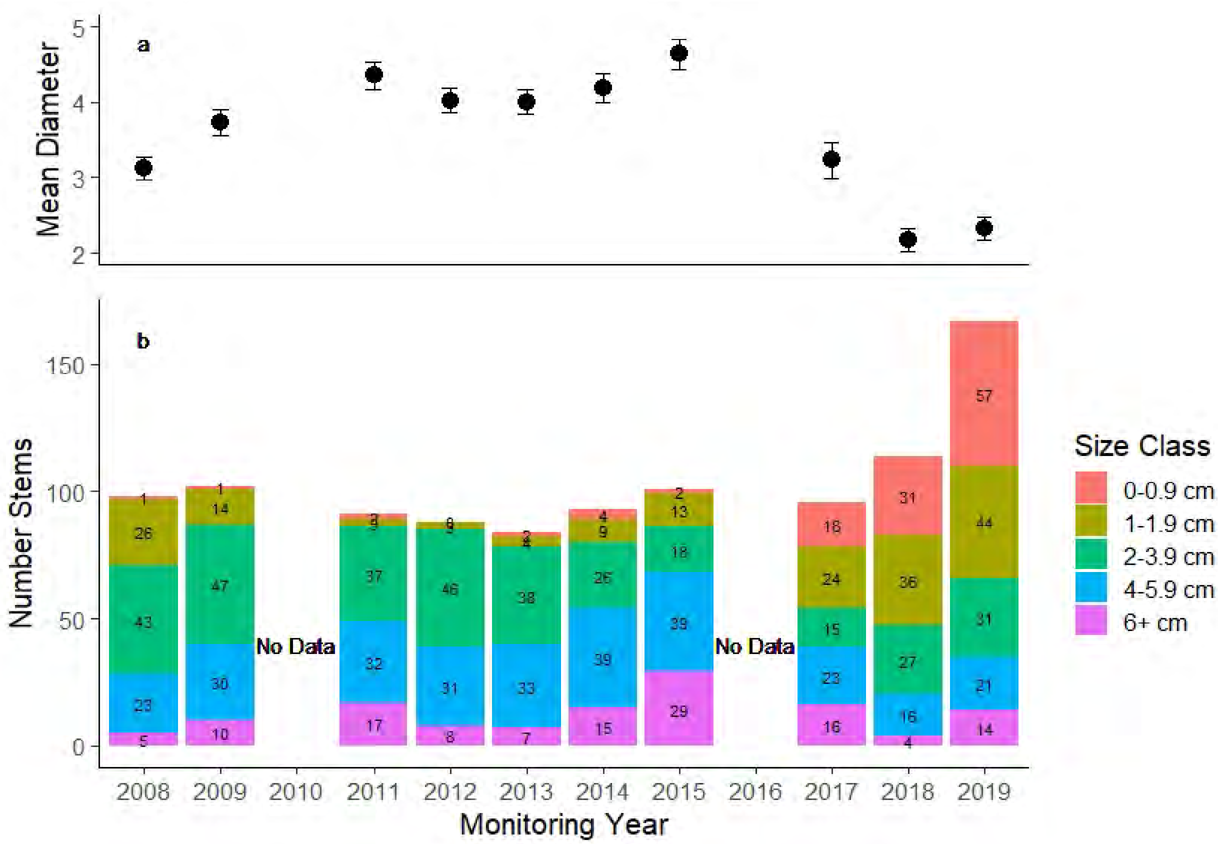


**Figure 5.** Mean diameter ±1 SE (a) and (b) number of live Mesa Verde cactus stems grouped by diameter size class within 3 permanent monitoring plots from 2008-2019.

*Vigor:*

Mesa Verde cactus stem vigor was high during the first two years of the study (2008, 2009), with no stems rated as “fair” or “poor” in 2008 and just two stems rated as “fair” in 2009 (Figure 6b). 2011 saw a decrease in mean vigor from 1.07 to 1.74 (Figure 6a), as the majority of stems monitored in 2011 were assigned a vigor of “good” instead of “excellent”. In 2012, vigor remained low with 6 stems rated as “fair” and 4 stems rated as “poor” as a result of stems being stepped on by feral horses. Three of the “poor” rated stems had died by 2013 and one recovered (Hazelton 2013). From 2013-2015, vigor increased to 1.04, back up to the 2008 vigor average. Most stems were rated as “excellent” during this period, no stems were rated as “poor”, and only 5 stems were rated as “fair”. Vigor dipped again in 2017 to an average of 1.54, due to 5 stems rated as “fair” and 6 stems rated as “poor”. The poor vigor observed is consistent with the low growth rate (Figure 4) and high mortality (Table 2) observed during the 2017 monitoring year. Average vigor increased to 1.18 and 1.24 in 2018 and 2019, with the majority of stems rated as “excellent”. In 2018, 6 stems were rated as “fair” or “poor”, which increased to 14 stems in 2019.

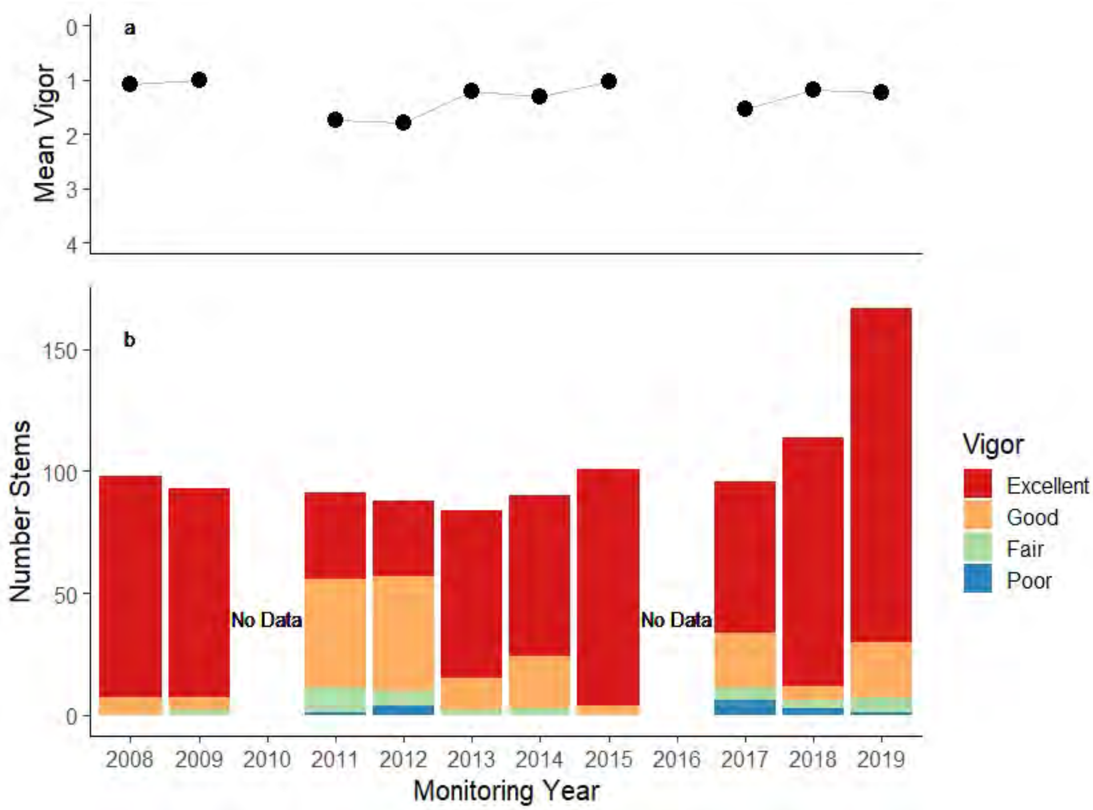


**Figure 6.** (a) Mean vigor scores for Mesa Verde cactus stems and (b) total number of live stems by vigor score in 3 monitoring plots from 2008-2019. See Table 1 for a description of vigor assessments.

*Reproduction:*

Mesa Verde cactus flowering and seed production occurs variably from year to year, with very few fruits and flowers produced in unfavorable years (Figure 7). On average, cactus within the three monitoring plots produced 200 (±39.8 SE) reproductive structures per year, which translated to an average population reproductive effort of 2.01 (±0.39 SE) structures per stem. The 2015 monitoring year was by far the most productive during the monitoring period from 2008-2019, with 458 flowers and fruits produced (14 of which were aborted). This translated to an average population reproductive effort of 4.58 structures per stem (Figure 8). In contrast, there were only 3 immature fruits produced total during the 2018 monitoring year, which translated to an average population reproductive effort of just 0.2 structures per stem.

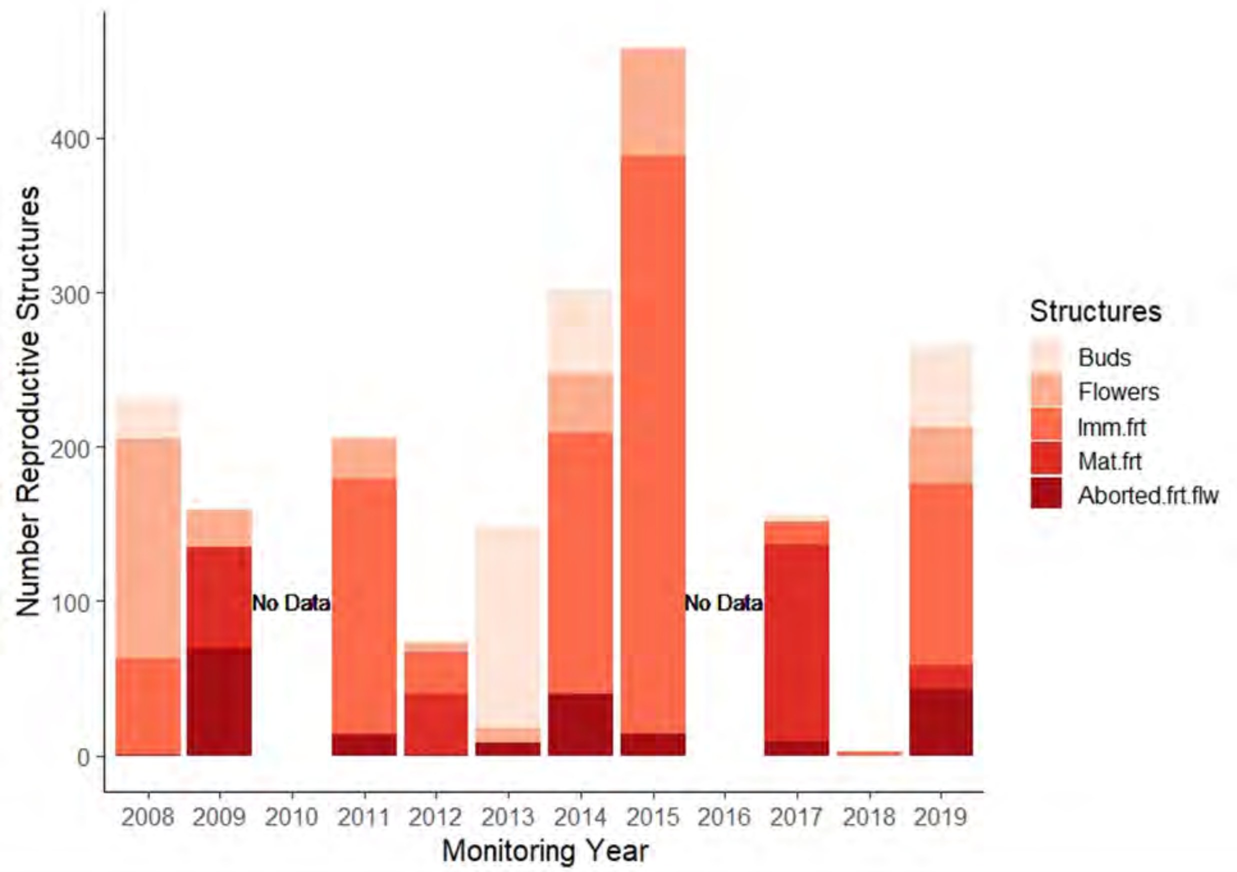


**Figure 7.** Total number of reproductive structures produced by type (buds, flowers, immature fruit, mature fruit, and aborted flowers/fruits) for Mesa Verde cactus stems in 3 permanent monitoring plots from 2008-2019.

By late April, when these plots are typically monitored, the majority of reproductive structures observed are either immature or mature fruits, with some buds and flowers observed. Notable exceptions occurred in 2008, when a majority of plants observed were in flower, and 2013, when a majority of the plants were still in bud and very few fruits or flowers were observed. Monitoring took place on 4/22 and 4/23 for these years, which is within the same timeframe when plots are typically monitored. It appears that cactus phenology in 2008 and 2013 was delayed as compared to other years, likely due to climactic factors.

Stems less than 1.6 cm in diameter did not produce flowering structures (Figure 9). Stems in the larger size classes were more likely to produce flowers and fruits than stems in the smaller size classes. On average, stems in the 2-3.9cm size class were reproductive 37% (±0.07 SE) of the time, stems in the 4-5.9cm size class were reproductive 76% (±0.09 SE) of the time, and stems in the 6+ cm size class were reproductive 84% (±0.08 SE) of the time.

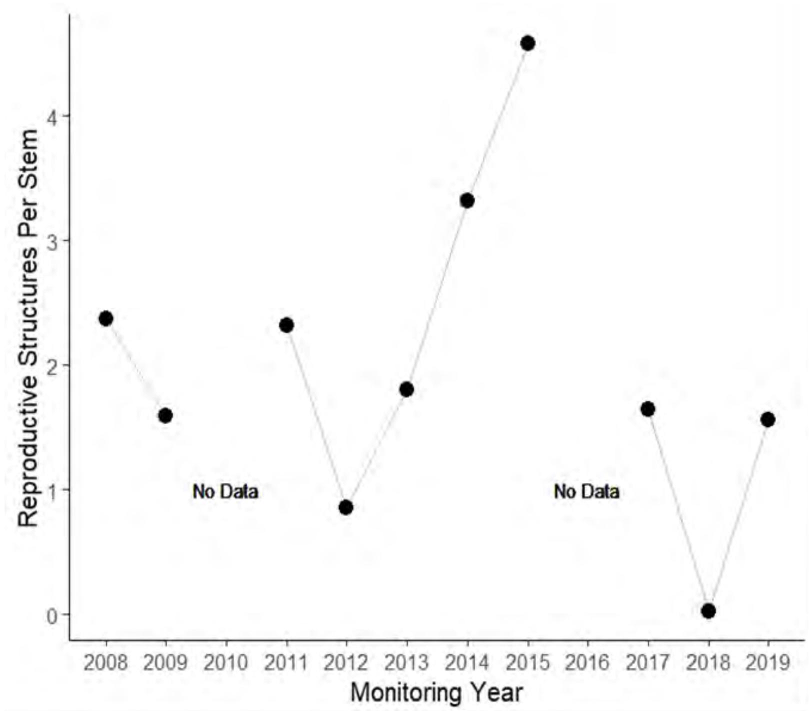


**Figure 8.** Mesa Verde cactus population reproductive effort (total number of Reproductive structures/number of live stems) within 3 permanent monitoring plots from 2008-2019.

*Precipitation:*

Total annual precipitation (calculated as total precipitation recorded from the 12 months preceding each monitoring visit) was lower than the station average of 8.25 in from 2008-2013 (Figure 10a). The year 2013 was the driest of the study duration, with a total annual precipitation of just 4.89 in (about half the average). From 2014-2019, three years had above-average moisture and three years had below-average moisture, with the highest annual precipitation recorded in 2016 (10.38 in).

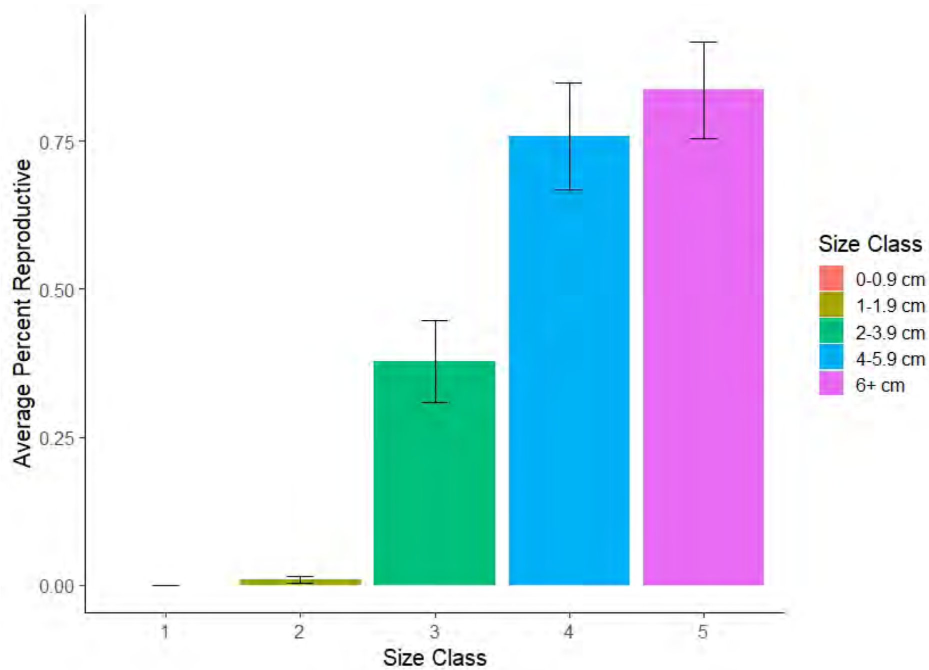


**Figure 9.** Average percent of reproductive Mesa Verde cactus stems ±1 SE by stem diameter size class in 3 permanent monitoring plots from 2008-2019.

Winter moisture (calculated as total precipitation from December through April preceding each monitoring visit), was also variable throughout the study; with higher than average winter moisture recorded in 2008, 2010, 2015, 2017, and 2019 (Figure 10c). Winter moisture in 2017 and 2019 was almost double the station average (4.64 and 4.58 in).

Average April precipitation in the Shiprock region is 2.84 in (Figure 10c). Above average or average April precipitation was recorded for 4 years and below-average precipitation was recorded for 8 years during the study duration. April 2017, in particular, was a very wet month, with 1.63 in rainfall recorded (over double the station average). April 2012, in contrast, received almost no precipitation (0.1 in).

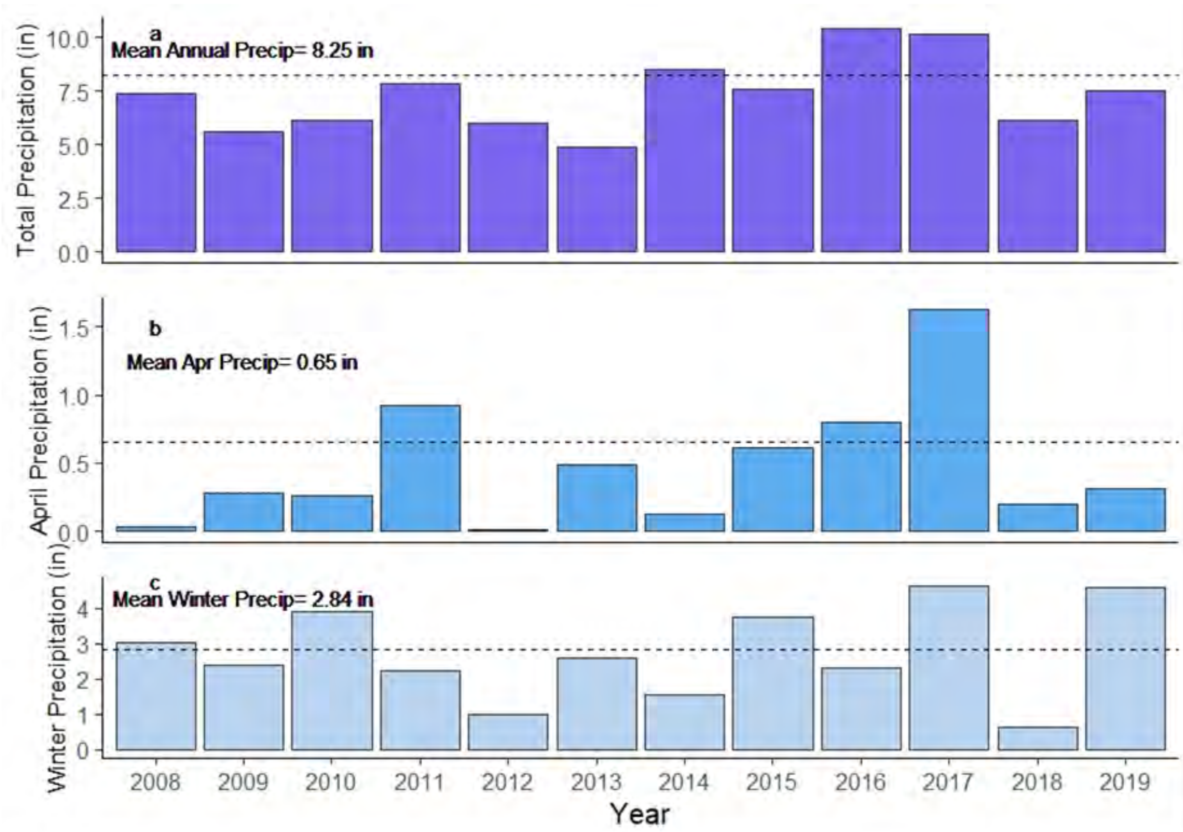


**Figure 10**. (a) Total precipitation from May-April preceding each monitoring visit, (b) April precipitation, (c) and winter precipitation from December-April, as recorded by the Farmington Ag C station located 25 miles southeast of monitoring plots. Averages are based on the station period of record from 1978-2019.

*Regressions:*

Simple linear regressions were performed to predict population reproductive effort, mean stem growth rate, percent of stems vegetative, mean vigor, and number of dead stems based on winter precipitation. A significant regression equation was found between winter precipitation and mean stem growth (F(1,8)=1.28, p=0.007), with an adjusted $R^2$ of 0.75 (Figure 10, Table 3). Winter precipitation did not predict population reproductive effort, percent of stems vegetative, number of dead stems, or mean vigor (Table 3). A previous study found a positive significant relationship between Mesa Verde cactus recruitment (new stems, Table 2) and April precipitation (Coles et al. 2012). A simple regression was performed to test this relationship for Mesa Verde cactus within the WAPA plots, which was not significant (F(1, 7)=0.24, p=0.64, adjusted R2=-0.11).

A simple linear regression was also performed to investigate the relationship between stem diameter and the total number of reproductive structures produced in a dry year (2012) and a wet year (2017). The number of reproductive structures produced was positively correlated with stem diameter; both in a wet year ($F(1,93)=143$, $p<0.0001$, adjusted $R^2=0.60$) and a dry year ($F(1,84)=20.54$, $p<0.0001$, adjusted R2=0.19, Figure 11). This illustrates the importance of large diameter stems in contributing to overall population reproductive output, even in dry years when few stems of any size were fruiting and/or flowering.

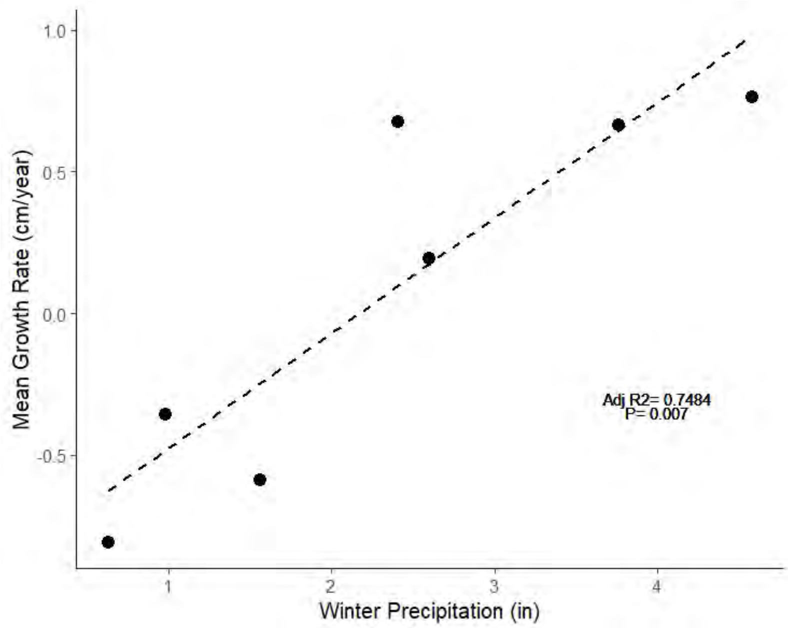


**Figure 10.** Relationship between stem mean growth rate and winter precipitation with fitted line.

**Table 3.** Simple linear regression results testing the relationship between winter precipitation (explanatory variable) and a number of response variables.

| Response Variable | Coefficient | t | df | P |
|---|---|---|---|---|
| Population Reproductive Effort | 0.34 | 0.3 | 8 | 0.29 |
| Mean Stem Growth | 0.4 | 4.34 | 5 | 0.007** |
| Percent Stems Vegetative | -0.05 | 0.05 | 8 | 0.43 |
| Number of Dead Stems | 3.49 | 3.08 | 8 | 0.29 |
| Mean Vigor | -0.04 | 0.07 | 8 | 0.56 |

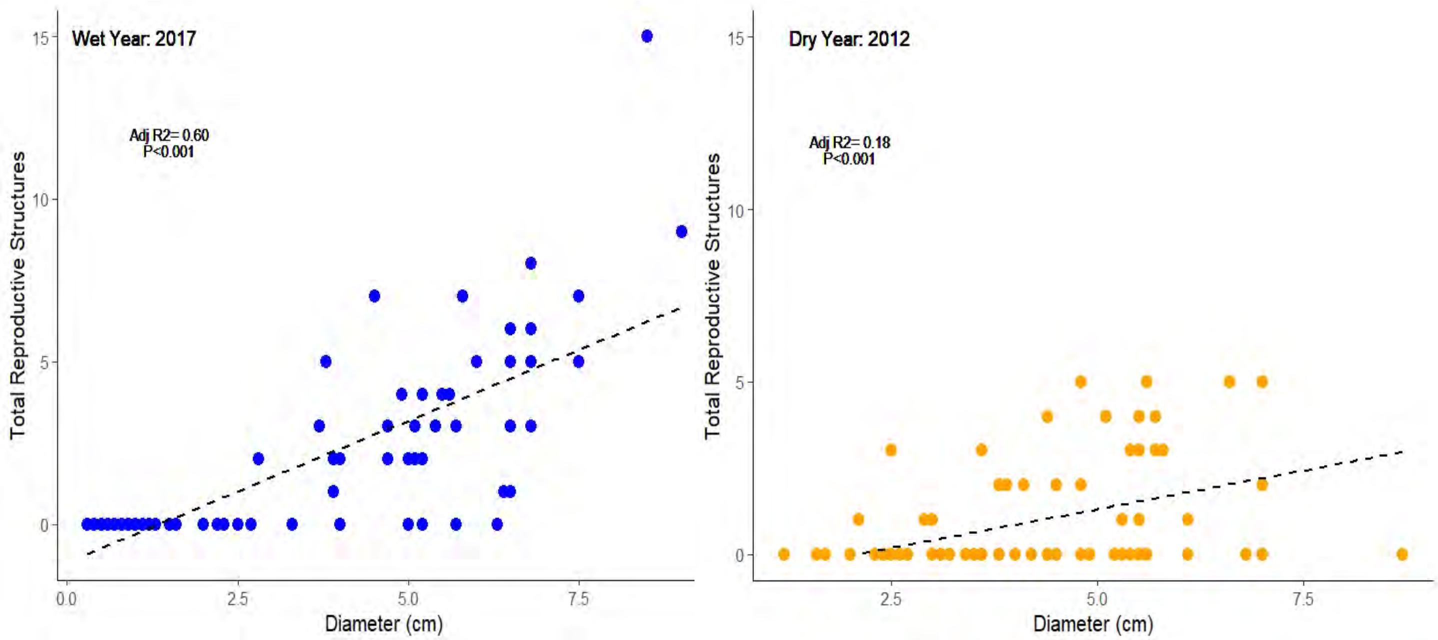


**Figure 11.** Relationship between Mesa Verde stem diameter and number of reproductive structures produced within 3 permanent monitoring plots in a wet year (2017) and a dry year (2012).

DISCUSSION:

In a previous monitoring report for this site, which covered the period from 2008-2013 (Hazelton 2013), A. Hazelton described a steady modest rate of decline for Mesa Verde cactus within the three WAPA plots, with mortality consistently outpacing recruitment by a few cacti per year. The past seven monitoring seasons from 2013-2019 have painted a more hopeful picture for Mesa Verde cactus within these plots, largely due to high recruitment recorded in 2017, 2018, and 2019. There are now 73 more stems than there were in 2008 when monitoring began, although a large number of these belong to the seedling and juvenile size classes (Figure 5). In a similar study of Mesa Verde cactus demographics in Colorado running from 1986-2005, Coles et al. (2012) tracked 569 plants first found as seedlings within three monitoring plots. Of these, 209 were still alive in 2005 and 63 were at least 10 years old. However, the average lifespan of these seedlings was slightly less than three years. It remains to be seen how many of the seedlings found in 2017-2019 will survive to become reproductive adults.

Coles et al. (2012) found a positive relationship between recruitment events and April precipitation, which was not a significant predictor of recruitment at the *El Malpais* plots. April, 2017 was an exceptionally wet month, and there were a large number of new seedlings recorded in the plots that year (35). However, the following two years (2018, 2019) also had very high recruitment (31 and 54 new seedlings recorded), and far below average April precipitation (Figure 10b). There were almost no cacti fruiting or flowering in 2018, which was also observed for Mesa Verde located within a 100 x 200 meter demography monitoring plot on adjacent BLM land north of Waterflow, NM. The very low number of reproductive plants was attributed to low winter moisture received in 2017/2018 (Roth 2018).

The years 2015-2017 had average to higher than average April precipitation, with 2015 being by far the most productive fruiting/flowering year of the study. A high percentage of Mesa Verde cactus (94% and 87%) were also reproductive within the Waterflow demography monitoring plot in 2014 and 2016 (no monitoring occurred in 2015, Roth 2018). It's likely that the high recruitment recorded in 2017-2019 at the *El Malpais* plots is a result of the exceptional fruiting/flowering year in 2015. Mesa Verde cactus seeds have seed coats that need scarification and require several cycles or freezing and thawing in order to sprout (Ladyman 2004). Therefore, a lag would be expected between highly productive years when many seeds are produced and high germination events when seedlings would be detected by monitoring. Coles (2003) hypothesized that Mesa Verde cactus seeds germinate in the fall in response to monsoonal moisture (July-September). However recruitment was not significantly correlated to precipitation in months other than April within the Colorado Mesa Verde cactus monitoring plots (Coles et al. 2012). Indeed, with the exception of 2017, monsoon moisture has been well below the 30-year normal for the past four years (Bansbach et al. 2020). It's currently unclear from this dataset exactly how recruitment is tied to winter, monsoonal, and April precipitation.

Anecdotally, it's possible that microhabitat variation and site selection plays a role in explaining recruitment/germination. Many of the new seedlings observed in 2017-2019 were found in plot three, which has more topography than plots one and two. Mancos shale soils have deep cracks, with surface soils between cracks forming a concrete-like hardpan that would be difficult for seeds to bury into. Several of the new Mesa Verde seedlings observed in 2017-2019 were found growing out of cracks in the soil formed by precipitation moving down hillslopes, where they have more access to moisture but are also more vulnerable to erosion. It's possible that these microsites created by the topography in plot three created more favorable niches for germination where Mesa Verde cactus seeds could access moisture, even in years when spring and/or monsoonal precipitation is low.

Although most of the plants that died within the *El Malpais* plots did not have an observable cause of death, the primary observable cause of death was mechanical damage from feral horses and livestock. There is some indication that cactus can recover from damage from horse hooves (Hazelton 2013), although survival rates are low. The primary causes of mortality to adult cacti within the Southern Colorado plots was infestation by beetle larvae (26%), and drought/seedling failure (19%), with beetles preferentially targeting large diameter plants over smaller plants (Coles et al. 2012). However, by 2005, damage from horse and/or livestock trampling became the leading cause of death to Mesa Verde cactus in plot two, surpassing beetle larvae predation.

Drought in 2002/2003 coupled with beetle larvae and army cutworm predation caused a large population crash at the Waterflow BLM plot (Roth 2018), with similar population crashes observed during a 2004 range-wide survey of Mesa Verde cactus populations on the Navajo Nation, also attributed to drought (Ladyman 2004). In 2018, only 7 live cactus were found at the Waterflow site (as compared to 62 in 2016), with mortality ascribed to rodent predation (Roth 2018). Unusually high rodent activity within the *El Malpais* plots was also observed in 2018, which killed four cacti. In 2019, insect damage from an unknown predator (likely larvae of the longhorn cactus beetle) was seen on a single Mesa Verde cactus stem within the *El Malpais* monitoring plots and at other populations on the Navajo Nation. However, insect predation on Navajo Nation populations seems to occur at much lower frequency and severity than has been observed in southern Colorado and on adjacent BLM lands. Cactus longhorn beetle and army cutworm population dynamics, habitat requirements, and other factors contributing to the severity and distribution of outbreaks should be explored in future studies of this species.

*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 impacts to protected wildlife and habitats. The primary implication of this land status is that the Navajo Department of Fish and Wildlife does not 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. Tracks were also ubiquitous through the area from 2017-2019. Directly addressing unregulated livestock and feral horse impacts in the Shiprock area through round-ups remains a management goal for NNHP. However, accomplishing this goal would require extensive collaboration with the Bureau of Indian Affairs, Navajo Nation Department of Agriculture, local chapters, grazing permittees, and grazing officials; as well as political support from the director of the Division of Natural Resources.

Thus far, attempts to limit public vehicle 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. As of 2019, the access road remains washed out and impassable just several hundred feet past the monitoring plots. No damage to plants within the monitoring plots from vehicles has been noted since 2013. However, the El Malpais Conservation Area covers a 6 x 4 mile area, which is crisscrossed by roads (either official or created by off-road driving). Limiting vehicular access to this entire area is not feasible. Instead, it may be worth trying to fence strategic (high density) Mesa Verde cactus protection areas within this Conservation Area to provide protection from both off-road vehicle use and livestock/feral horses. Fencing would require approval from grazing permitees (permit holders) and a chapter resolution (community support), as well as on-going maintenance by NNDFW to ensure that fencing does not get cut or removed by locals.

Continued pressure from these threats coupled with climate change, which is predicted to raise temperatures and alter existing precipitation regimes throughout the Southwest (Cayan et al 2010), could lead to a very tenuous future for Mesa Verde cactus on the Navajo Nation and throughout its range. Data from the *El Malpais* monitoring plots shows that recruitment is still occurring within at least one Mesa Verde cactus population on the Navajo Nation, although exactly what climactic and habitat conditions need to be met in order to observe this result in other populations remains to be explored. Given that Mesa Verde populations have been in steady decline at nearby monitoring sites (Roth 2018, Hazelton 2011), and NNHP's limited success in reducing known threats, *Ex situ* seed banking and conservation measures are warranted and likely necessary to avoid this species entering an "extinction vortex" (Bansbach 2020).

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