Monitoring Report

MESA VERDE CACTUS
(*Sclerocactus mesae-verdae*)

1986 – 2020

Daniela Roth

NM Energy, Minerals, & Natural Resources Department
Forestry Division
Santa Fe, NM

Prepared for the
U.S. Fish & Wildlife Service, Region 2
Albuquerque, NM
(USFWS Grant Award No. F19AP00929)

INTRODUCTION

Mesa Verde cactus (*Sclerocactus mesae-verdae*) was listed Threatened under the Federal Endangered Species Act in 1979 (44 FR 62471). It is also listed Endangered in the State of New Mexico (19 NMAC 21.2). The primary reasons for federal listing included illegal collection, highway construction, and off-road vehicle use. NatureServe considers Mesa Verde cactus a globally and State imperiled species (G2/S2). The species is assigned a low overall conservation rank of 'under conserved' by the New Mexico Rare Plant Conservation Strategy due to moderate to high levels of documented threats, documented population declines and limited distribution (EMNRD – Forestry Division 2017).

Mesa Verde cactus is endemic to the Four-Corners region of northwestern New Mexico and southwestern Colorado. The total range of this species is an area of approximately 75 x 30 miles, stretching from near Naschitti in southern San Juan County, New Mexico, to about 10 miles north of the New Mexico border in Montezuma County, Colorado. Distribution within this range is sporadic and widely scattered. At least 95% of Mesa Verde cacti occur on tribal lands, primarily on Navajo Nation lands in New Mexico. In New Mexico, Mesa Verde cactus also occurs on small blocks of BLM and State Trust lands, north of Waterflow. Small numbers of cacti also occur on Public Service Company of New Mexico lands and private lands.

Mesa Verde cactus habitat occurs within the Colorado Plateau ecoregion, one of seven ecoregions represented in the state of New Mexico (Griffith et al. 2006, Level III). The ecoregion is characterized by low variable annual rainfalls, averaging 7 inches in Shiprock, NM (WRCC 2019). The topography is eroded badlands of numerous small dry drainages between low hills and ridges at elevations between 4,800 and 6,560 ft. The majority of the occupied habitat consists of Mancos Shale which is a silty sediment of marine origin that is highly alkaline and saline. A relatively small portion of the total habitat occurs on the east side of the Farmington Hogback near Waterflow, New Mexico, on Fruitland Shale which is fluvial in origin. This shale is highly sodic and also contains quantities of selenite gypsum.

Vegetation cover in Mesa Verde cactus habitat is sparse and has the appearance of a nearly barren badland. It is most frequently associated with low-growing species of saltbush (*Atriplex cuneata, A. corrugata, A. confertifolia*). Other woody associates are *Artemisia spinescens* and *Frankenia jamesii*. Grass cover is typically sparse, but can include *Hilaria jamesii, Sporobolus* *cryptandrus* and *Oryzopsis hymenoides*. Herbaceous annuals, including invasives, such as *Halogeton glomeraturs, Salsola kali, Descurainia pinnata, Chorispora tenella, Bromus tectorum*, and *Eremopyrum triticeum*, can be common during wet years and entirely absent during periods of drought.

Mesa Verde cactus can reach an age of 50 years or more (Coles et al. 2012). Individual cacti reach reproductive maturity at 2 - 3 years of age, although some seedlings becoming established in difficult microhabitats may take longer. Flower buds begin to swell in early April and bloom during late April and early May. Fruits mature in late May and through June. Number of flowers and success in fruit-set are strongly correlated to size and condition of the individual plant. Large mature individuals can reach up to 19 cm in diameter (Cully et al. 1992).
Long term demographic monitoring has variously occurred on BLM lands, Navajo Nation, and Ute Mountain Ute lands (Coles et al. 2012; Cully et al. 1992; Hazelton 2011, 2013; Kendall 2010; Roth 2004, 2008; Sivinski 1999, 2003, 2007).

STUDY AREA AND METHODS

The Waterflow monitoring site was established on BLM land north of Waterflow, New Mexico, in 1986. This plot was monitored every spring for 10 years (1986-1995). Thereafter infrequent monitoring was accomplished in 1999, 2003, 2007, and biennially since 2014 by the New Mexico Forestry Division, BLM staff, and a variety of volunteers.

The monitoring site is located on silty shale of the Fruitland Formation which is a sparsely vegetated, almost barren badland of low ridges and dry drainages. The perennial vegetation provides only 6% ground cover and is mostly composed of low-growing species of saltbush (*Atriplex cuneata, Atriplex corrugata, Atriplex confertifolia*). Within the past decade halogeton (*Halogeton glomeratus*) has invaded the monitoring site, covering the majority of the occupied habitat within the monitoring site and throughout the area north of Waterflow during wet springs.

The monitoring site is a 100 x 200-meter rectangle with a grid of steel rebar stakes along the plot boundaries. Prior to 2016, individual cacti were located by triangulating surveyor tapes from two assigned stakes marking the monitoring site boundaries. Individual cacti were tagged with rectangular numbered aluminum tags. After a 7-year monitoring gap the majority of these tags was either gone or no longer readable in 2014, which made relocating previously documented cacti challenging. In 2014 surveyors walked evenly spaced transects throughout the 100 x 200-meter monitoring site and flagged every cactus found. Individual plants were then mapped with a GPS and tagged with round, individually numbered metal tags. In an effort to further simplify the sampling design, ensure maximum detection of tagged cacti, and to better capture recruitment of small individuals and seedlings, we established 41 sub-monitoring plots in 2016 inside the 100 x 200-meter monitoring site. Each plot has a 1m radius from the plot center and originally contained at least one tagged, live cactus. Each plot center is marked by a rebar or wooden stake with a numbered aluminum tag and its location was mapped with a Garmin Monterra GPS.

Data collected for each cactus includes stem diameter, reproductive status (number of flowers and/or fruits), number of stems, and condition. Condition was evaluated by assigning a vigor rank (1 = excellent, 2 = good, 3 = fair, 4 = poor, 5 = dead). In addition, percent cover of *Halogeton glomeratus* is visually estimated inside each sub-monitoring plot.

RESULTS

The total number of Mesa Verde cactus in the Waterflow monitoring site has fluctuated since 1986 (Figure 1). It was relatively low in 1986 when the original plot was established. The plot population began to trend upward (except 1990) and was fairly large during the early years of the 1990s until it reached another low point in 1995. The highest number of plants was recorded in 1999 (235 plants). This was likely due to the very favorable rainfall year of 1997, which received 11.45 inches of precipitation, followed by another above average rainfall year in 1998 (from weather station at adjacent San Juan Coal Mine). Most of the cacti in the 1999 plot population were juvenile, non-flowering individuals (Figure 2). A similar favorable precipitation year occurred in 1990 followed by several years of normal rainfall, which correlates positively with an increase in cactus density within the plot after 1990. The low density year of 1990 followed an especially dry period in 1989, which was a year receiving only 3.82 inches of precipitation. The very low density year of 1995 cannot be explained by the precipitation data. Many dead cacti were found in the plot that year and are assumed to have been killed by the longhorn cactus beetle (*Moneilema semipunctatum*), a frequent native predator of cacti. The population increased significantly after 1995 and was at an all time high in 1999, likely due to several years of good rainfall amounts favoring germination and establishment of new cacti. The population crash observed in 2003 followed an extremely dry period with only 2 inches of precipitation from September 1, 2001 to August 31, 2002. Only 26 of the 235 individual cacti found in May 1999 were still alive in April 2003 and the total population had decreased from 235 cacti in 1999 to 74 in 2003 (Figure 1). The dead cacti were hollowed-out and most of the surviving cacti had damaged, chewed-up stems, presumably by longhorn cactus beetle or army cutworm (Lepidoptera) predation in 2002. The population appeared to be recovering in 2007, when 113 cacti were found at the monitoring site. However, only 48 cacti were found in 2014, with only somewhat of an increase in 2016 (62 plants). In 2018 the majority of tagged cacti (89%) within the sub-monitoring plots were gone, likely due to rodent predation. Only 7 live plants were found, 2 of them new recruits. Few dead plants were found (4), but many tagged areas were found to contain remaining spine clusters (18). Mortality likely occurred soon after the 2016 monitoring season (J. Kendall, BLM, observation 2016), leaving little evidence for the cause of mortality in 2018. No significant disturbance was observed, but small holes and gopher mounds were found within the monitoring site and the monitoring plots (Figure 2). All of the monitoring plots were surveyed in 2020. Only 9 plants were found within the 41 sub-monitoring plots, plus one seedling. Four of the 9 plants were new recruits, one plant was missing. None of the plants were found dead and the majority were rated in excellent condition.

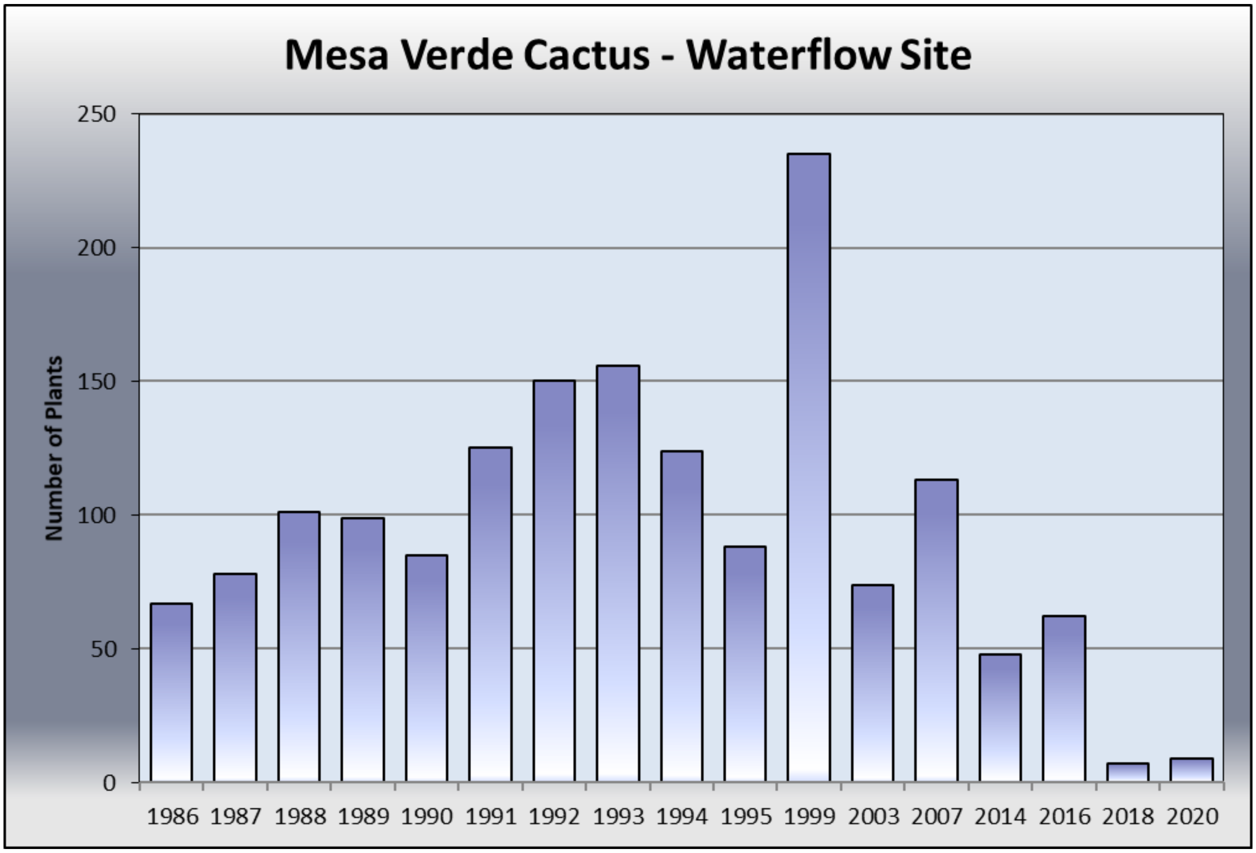

Figure 1. Number of Mesa Verde cacti located in the Waterflow monitoring plot between 1986 and 2020.

Figure 2. Mesa Verde Cactus sub-plot showing tag of missing cactus and shallow holes, likely dug out by rodents (2018).

Density within size classes also varied greatly over the study period (Figure 4). Mesa Verde cactus size is often indicative of relative age. Cacti that are 2 cm or less in diameter are considered juveniles or seedlings. They can (but seldom do) begin to produce flowers at a young age when the stems reach about 2.0 cm in diameter. They begin to regularly produce 1- few flowers at the 4-6 cm stage, but the large cacti (>6 cm or multistemmed) produce the greatest per-plant number of flowers (up to 27/plant). Reproductive effort varies greatly from year to year and is typically associated with rainfall. The lowest reproductive efforts were recorded in 2003 and 2018, when only 9 % and 0% of the plants inside the monitoring plot were flowering or fruiting (Table 1). The largest reproductive efforts were recorded in 1995, 2014 and 2016, when 88%, 94% and 87% of the population was flowering or fruiting. In 2020 22% of 9 plants were flowering.

Table 1. Reproductive effort of *Sclerocactus mesae-verdae* at the Waterflow, New Mexico monitoring plot.

Year	Number of Cacti Reproductive	Percent of Population Reproductive
1986	42	64%
1987	54	73%
1988	51	67%
1989	66	67%
1990	48	58%
1991	102	82%
1992	116	83%
1993	108	76%
1994	92	76%
1995	81	88%
1999	51	22%
2003	7	9%
2007	54	48%
2014	45	94%
2016	54	87%
2018	0	0
2020	2	22%

The numbers of seedlings detected can vary greatly depending on precipitation or the keenness of the observers, or both. Unfortunately, the original monitoring plot was very large, making it difficult to detect the small cryptic cacti, especially seedlings, juveniles, and small non-flowering plants (Figure 3). Since monitoring resumed in 2014 the invasive annual halogeton (*Halogeton glomeratus*) has invaded the area, including the monitoring site, making it even more difficult to detect small non-flowering individuals. In 2016, smaller sub-plots were established within the large monitoring site to address this issue and better capture recruitment in the future. In May of 2016, the average cover of halogeton was 9% within the 41 sub-monitoring plots, ranging from 0 to 30%. Plants were generally found in depauperate condition and of small statute, likely in response to limited rainfall in March of 2016 (0.02 inches) in a winter with otherwise good rainfall (2.96 inches, November through April 2015/2016). No halogeton was found in any of the monitoring plots in 2018, likely due the extreme drought during the winter and spring of 2017/2018 (0.97 inches, November through April 2017/2018). The winter of 2019/2020 was excellent, recording 3.07 inches between November 2019 and the end of April 2020. However, no Halogeton was observed within the sub-monitoring plots and only a few plants were seen within the larger monitoring site. Low rainfall in April is likely responsible for the lack of Halogeton in 2020. April 2020 received only 0.01 inches of rain (WRCC 2020).

Figure 3. Seedling and juvenile Mesa Verde cactus.

Adult cactus density was generally more stable until 2003 when nearly all large cacti were killed by insects. The majority of the plot population is usually medium-sized plants (2.1- 6.0 cm)(Figure 4). However, in the years 1993,1999, and 2020 the juvenile class had greater densities than the next larger size class. This is likely due to recruitment events caused by optimum rainfall amounts in the 1990s, or, as in 2020, indicating a young, recovering population. Only one seedling/juvenile plant was documented in 2014 (0.2 – 2.0 cm in diameter). Despite favorable rainfall in 2015 and 2016, and the establishment of smaller sub-plots, no juveniles or seedlings were recorded in 2016. Two of the remaining 7 plants found in 2018 were new recruits in the seedling/juvenile age class. Both were located in the same plot. Four new plants were found in 2020, one of which was a seedling. Three of the new recruits were located in the same plot, which also produced new recruits in 2018.

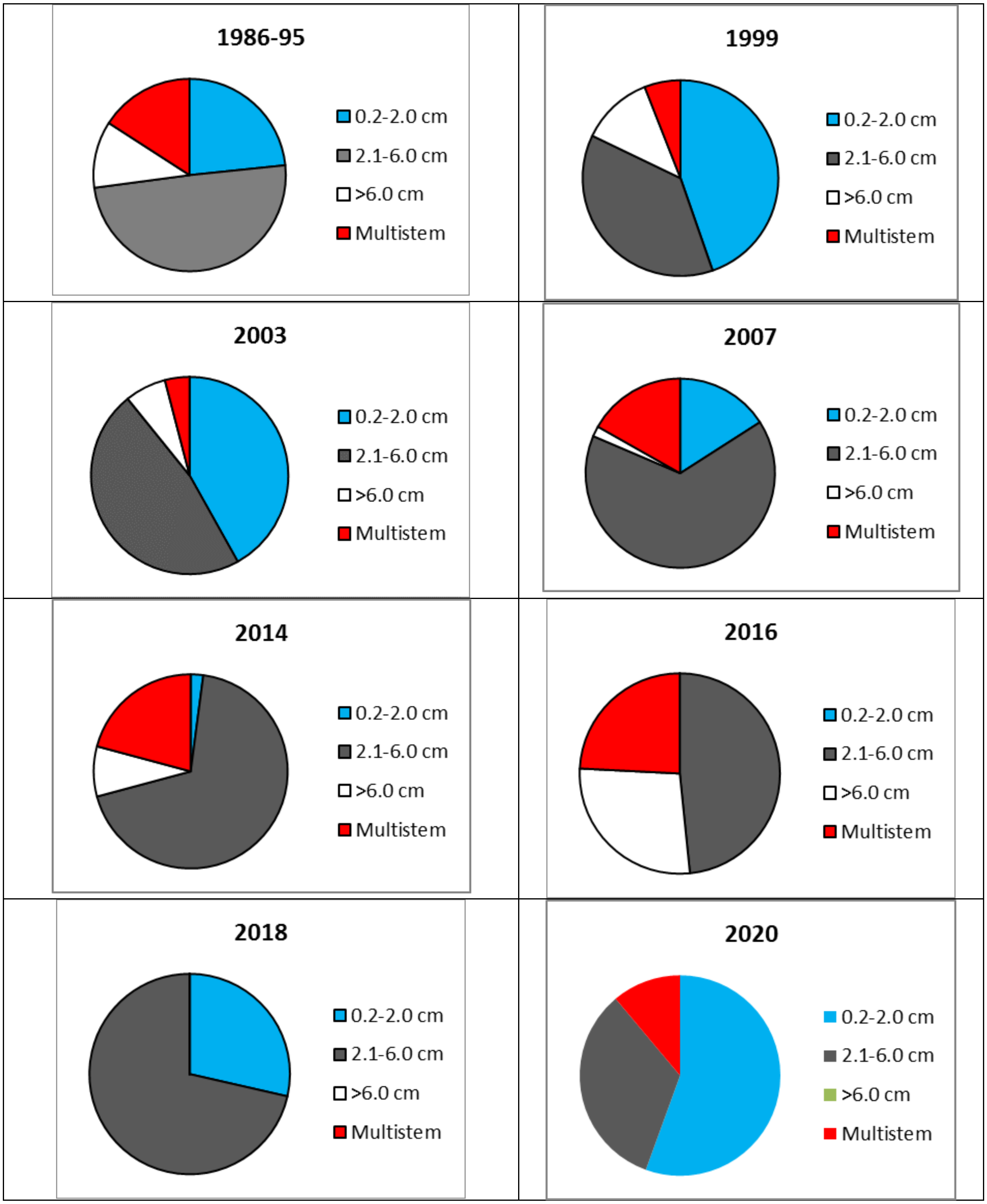

Figure 4. Size class distribution of Mesa Verde cactus between 1986 and 2020 at the Waterflow monitoring site.

In 2003 all data sheets were reexamined for causes of mortality in this population (Sivinski 2003). Usually the cause could not be determined. From 1986 to 1999, the dead remains of the monitored cacti could only be found 35% of the time. Usually no remains were located. In three instances (1987, 1994 and 1995) holes in the ground or crumpled tags were found suggesting that one or a few cacti had been removed by cactus poachers. The 2003 monitoring year was different. The dead remains of 76% of the cacti that had died since 1999 were still visible and assumed to be victims of insect predation during the summer of 2002. Unless cacti are eaten by rodents, trampled, or removed from site, dead cacti can remain on site for several years following mortality. In 2018, very few dead plants were found, but at approximately 30% of locations of the 62 plants tagged in 2016 spine cluster were found in the immediate vicinity of tags, indicating predation by rabbits or rodents. No dead plants were found in 2020.
Since 2014 vigor of individual plants is recorded. The majority of plants were found in good to excellent condition in 2014 and 2016 (Figure 5). Twenty-one new plants were found within the newly established sub-monitoring plots in 2016. None of the new plants were in the seedling/juvenile size class (0.2 – 2.0 cm in diameter). These were likely overlooked during the 2014 monitoring year, when the entire 100 x 200 m monitoring site was surveyed. In addition, 2014 was a drought year and smaller plants may have been at ground level or below, making them difficult to detect. In 2018 the majority of plants were dead (89%). The 7 plants found alive were in good to fair condition, none of them were ranked in excellent condition. In 2020 all plants were found in excellent or good condition.

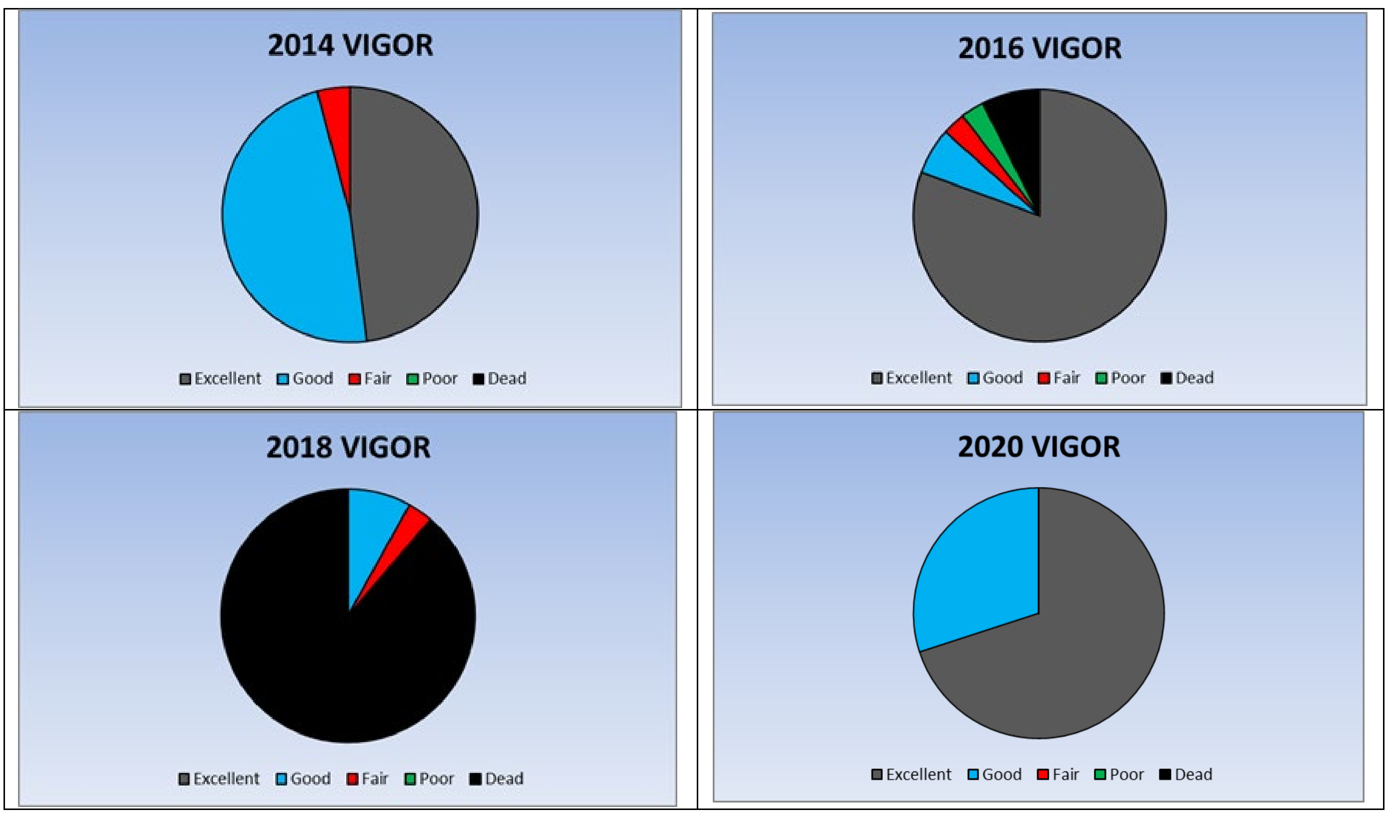

Figure 5. Vigor of Mesa Verde Cactus plants at the Waterflow monitoring plot in San Juan County, NM.

The longhorn cactus borer beetle (*Moneilema semipunctatum*) is a native predator of cacti, typically on species of *Cylindropuntia* and *Opuntia* (Figure 6). However, more recently this beetle has been observed to use various species of *Sclerocactus* as an alternate host (Woodruff 2010). The larvae of these beetles burrow into the stem of the cactus and pupate in the cactus and emerge as adults in the summer. The caudex of a beetle-damaged Mesa Verde cactus can survive for period of months and even initiate new stems, but the majority of plants eventually die from desiccation or secondary infections. In addition, army cutworms (*Euxoa* sp.) are thought to be responsible for the massive die-off of cacti in the BLM monitoring plots in 2002, and possibly elsewhere (BLM 2003). Insect predation results in hollowed out dead plants which can remain on site several years after mortality occurs.

Cactus borer beetle (*Moneilema semipunctatum*) 2017.

Army cutworm (*Euxoa* sp.) 2003.

Figure 6. Cactus borer beetle larvae emerging from Mesa Verde cactus in 2017, and army cutworm pulled from a Mesa Verde cactus in 2003 (BLM photo).

The 2002-2003 rangewide insect kill of Mesa Verde cactus has been the most extreme during the 30+ years that Mesa Verde cactus populations have been monitored. Monitoring plots on BLM lands near Waterflow, New Mexico, had mortality rates of 68.5% (this study) and 97.1% on another BLM plot (Barney Wegener and John Kendall, BLM-Farmington District, 2003). Similar declines were noted in 2003 on the Navajo Nation in New Mexico and the Ute Mountain Ute Reservation in Colorado (Ladyman 2004; Roth 2004, 2008; Coles 2012). The 2018 mortality of most plants at the BLM Waterflow monitoring site was localized and likely caused by resident gophers in 2016. Although predation by rodents and rabbits is not uncommon, this level of mortality caused by rodents has not been previously documented for Mesa Verde cactus.

CONCLUSIONS AND RECOMMENDATIONS

Although the Mesa Verde cactus population at the Waterflow monitoring site has been shown to fluctuate, the population never fully recovered from the 2002 extreme die-off documented in this and other monitoring sites (Roth 2004; Kendall 2010; Hazelton 2011; Coles et al. 2012). The majority of plants that established at the monitoring site since 2002 were dead in 2018, with only a few plants remaining and little recruitment in 2020. Recruitment is episodic and related to periods of favorable precipitation. Prior to 2018, the greatest mortality event at the Waterflow population and other monitoring sites was documented in 2003 and was the result of insect predation during 2002. The mortality event documented in 2018 is largely attributed to rodent predation that likely occurred in 2016. The disappearance of a large number of plants between 1986 and 1991 from the Waterflow monitoring site was partly attributed to illegal collection and partly to the activity of pocket gophers (Cully et al. 1992). Low numbers of plants found at the monitoring site in 2014 indicates that another mortality event may have occurred between 2007 and 2014. No dead plants were found in 2014, indicating that plants died several years prior, possibly during the drought years of 2009 and/or 2012, or due to rodent predation. It is possible that some smaller, non-flowering plants were missed in 2014 because the majority of tags were missing or no longer associated with plants (pulled out of the ground). Indeed, more plants were found during the 2016 monitoring year, some of which were likely present in 2014, but were not found. A related rare cactus of San Juan County, Brack's cactus (*Sclerocactus cloverae* ssp. *brackii*), incurred similar high mortality rates caused by rodent or rabbit predation throughout its range in during the winter of 2014/2015 (Greenlee 2015; Roth 2015; Muldavin et al. 2016; Ecosphere 2018).

However, it is also possible that the population is in decline as a result of prolonged drought conditions and a diminishing seed bank as reproductive adults have declined over the past 15 – 20 years. In addition, halogeton has invaded the study site. This annual invasive weed is known to produce mineral salts which may inhibit or depress plant growth in associated species. The impacts of changes in soil chemistry on the germination and establishment of Mesa Verde Cactus is unknown.
Two coal-fired power plants are located within a few miles of all Mesa Verde cactus populations. The San Juan Generating Station is located on the NE side of the Hogback ACEC and has been in operation since the 1970s. The Four Corners Generating Station is located just south of the San Juan River has been in operation since the early 1960s. They are the largest source of air pollution in the state of New Mexico and a source for acid train. Mesa Verde cactus is restricted to highly alkaline gypsiferous soils of the Mancos and Fruitland Shale formations. This high degree of specificity suggests that the species may be highly susceptible to alterations in soil chemistry, possible rendering the microhabitat unsuitable for sufficient recruitment to offset mortality over time. Long term emissions from coal fired power plant may alter the soils physical properties and concentrations of available nutrients and trace elements. Soil acidification could be contributing to low recruitment levels.

A status survey in 2020 found only 129 live plants outside existing monitoring plots throughout the once occupied habitat in the 10,000-acre BLM ACEC, where there should have been

hundreds if not thousands (Roth 2020). Some levels of population fluctuations maybe be natural for Mesa Verde cactus, but long-term monitoring results indicate that recruitment no longer offsets mortality.
To better understand the decline of this population, the dynamics of the primary mortality agents, and to gain a better understanding of overall population trends of Mesa Verde cactus on BLM lands, monitoring needs to be more frequent and should cover the entire range of the species. Additional plants were found during a status survey in 2020, outside of the subplots, but within the greater plot in 2020. Establishing additional subplots to track trends within this plot should be considered. The BLM has added monitoring plots elsewhere on the ACEC in 2020, based on status report findings. Continued monitoring is essential to understand population trends and the causes of decline.

Management actions and conservation measures need be developed and implemented to address and hopefully halt a continued decline. Management actions may include additional protection measures, population augmentation, reintroductions, ex-situ conservation through seed storage, additional studies to research causes of decline (pollinator availability, pollination success, seed banking, inbreeding depression, predation, impacts of invasive species on germination and establishment, soil acidification), and rangewide surveys to document the current abundance and distribution of the species.

ACKNOWLEDGEMENTS

This report was largely adapted from previous progress reports written by Bob Sivinski, former botanist for the NM State Forestry Division. Data collected by Bob Sivinski, Anne Cully, and Paul Knight from 1986-2007 were used to generate figures and tables to determine trends for this progress report. Data collection was aided by John Kendall, Jamie DeMarco, Sheila and Owen Williams, BLM, and a variety of volunteers throughout the years.

Funding for this project has been provided by the U.S. Fish and Wildlife Service, Region 2, Albuquerque, NM, through Section 6 Endangered Species grants, received through 2020.

LITERATURE CITED

Bureau of Land Management. 2003. Mesa Verde cactus investigation, Hogback ACEC. Farmington BLM, 27 March 2003.

Coles J. J., K.L. Decker, and T.S. Naumann. 2012. Ecology and population dynamics of *Sclerocactus mesae-verdae* (Boissev. & C. Davidson) L.D. Benson. Western North American Naturalist 72(3): 311-322.

Cully, A., P. Knight, R. Sivinski, M. Olwell, D. E. House, and K. Lightfoot. 1992. Preliminary results from a long-term study of Mesa Verde cactus *(S. mesae-verdae).* In: Proceedings of the Southwestern Rare and Endangered Plants Conference – 1992. R. Sivinski and K. Lightfoot (eds.), pp. 108-120, Misc. Publ. No. 2, New Mexico Forestry and Resources Conservation Division, Santa Fe.

Ecosphere Environmental Services. 2018. Brack's hardwall cactus 2018 monitoring report. Enterprise Products Western Expansion Project III. Unpublished report prepared for the Bureau of Land Management, Farmington, NM, the New Mexico Energy, Minerals, and Natural Resources Department – Forestry Division, Santa Fe, NM, and Enterprise Products

EMNRD- Forestry Division. 2017. New Mexico Rare Plant Conservation Strategy. Prepared and developed by Daniela Roth and the New Mexico Rare Plant Conservation Strategy Partnership. Santa Fe, NM.

Greenlee. E. 2015. Presumable jackrabbit and rodent predation on *Sclerocactus cloverae* ssp. *brackii*. Memorandum to Daniela Roth, EMNRD – Forestry Division, from the State of New Mexico Commissioner of Public Lands.

Griffith, G.E., J.M. Omernik, M.M. McGraw, G.Z. Jacobi, C.M. Canavan, T.S. Schrader, D. Mercer, R. Hill, & B.C. Moran. 2006. Level III Ecoregions of New Mexico (color poster with map, descriptive text, summary tables, and photographs): Reston, Virginia, U.S. Geological Survey (map scale 1:1,400,000). http://ecologicalregions.info/htm/nm_eco.htm

Hazelton A. F. 2011. Mesa Verde Cactus *(Sclerocactus mesae-verdae)*10 Year Transplant Monitoring Report -Shiprock Fairgrounds 2001-2011. Unpublished report prepared for the Navajo Natural Heritage Program, Department of Fish & Wildlife, Window Rock AZ, 86515

Hazelton A. F. 2013. Mesa Verde Cactus *(Sclerocactus mesae-verdae)* Monitoring Report -El Malpais Monitoring Site 2008 - 2013. Unpublished report prepared for the Navajo Natural Heritage Program, Department of Fish & Wildlife, Window Rock AZ, 86515.

Kendall, J. 2010. Bureau of Land Management Hogback ACEC Mesa Verde cactus plot data and status updates. Excel database received by the USFWS, May 3, 2010. Bureau of Land Management, Farmington, New Mexico.

Ladyman, J. 2004. Status Assessment Report for *Sclerocactus mesae-verdae* (Mesa Verde Cactus). Prepared for: The Navajo Natural Heritage Program, Window Rock, AZ.

Muldavin, E., R. Sivinski, M. East, Y. Chauvin, and M. Horner. 2016. Brack's hardwall cactus. Distribution, habitat, and status survey 2015. Natural Heritage New Mexico Report 390 – May 2016. Unpublished report prepared for the BLM State Office, Santa Fe, NM.

Roth, D. 2004. Monitoring Report: Mesa Verde cactus transplantation for BIA Route N57 –

Cudei Rd, San Juan County, NM. Navajo Natural Heritage Program.

Roth, D. 2008. Monitoring Report: *Sclerocactus mesae-verdae* transplant project - Northern Navajo Fairgrounds, Shiprock, San Juan County, NM. Navajo Natural Heritage Program.

Roth, D. 2015. Brack's cactus monitoring plots – site visit. Memorandum to Andrew Frederick, EMNRD – Forestry Division, from the EMNRD – Forestry Division.

Roth, D. 2020. Status report. Mesa Verde cactus (*Sclerocactus mesae-verdae*). BLM Hogback ACEC, Waterflow, NM. Energy, Minerals and Natural Resources Department, Forestry Division, Santa Fe, NM. Unpublished report prepared for the U.S. Fish and Wildlife Service, R2, Albuquerque, NM.

Sivinski, R. 1999. Mesa Verde cactus: A fourteen-year demographic summary of the Waterflow, New Mexico study plot. New Mexico Forestry Division - Energy, Minerals and Natural Resources Department, Santa Fe. Unpublished report prepared for the U.S. Fish and Wildlife Service, R2, Albuquerque, NM

Sivinski, R. 2003. Mesa Verde cactus: An eighteen-year demographic summary of the Waterflow, New Mexico study plot. Energy, Minerals and Natural Resources Department, Forestry Division, Santa Fe, NM. Unpublished report prepared for the U.S. Fish and Wildlife Service, R2, Albuquerque, NM.

Sivinski, R. 2007. Mesa Verde cactus: a twenty-one-year demographic summary of a Waterflow, New Mexico study plot. New Mexico Energy, Minerals, and Natural Resources Department, Santa Fe, New Mexico. Unpublished report prepared for the U.S. Fish and Wildlife Service.

USDI-Fish & Wildlife Service. 1984. Mesa Verde cactus (*Sclerocactus mesae-verdae*) Recovery Plan. Region 2, Albuquerque, NM.

USDI-Fish & Wildlife Service. 2010. Mesa Verde Cactus *Sclerocactus mesae-verdae* (Bossevain & C. Davidson) L. Benson. 5-Year Review: Summary and Evaluation. U.S. Fish and Wildlife Service, Albuquerque, New Mexico

Western Regional Climate Center. 2019 & 2020. Monthly total precipitation (inches) at the Farmington AG SCI CTR, NM. Accessed online at https://wrcc.dri.edu/cgi-bin/cliMAIN.pl?nm3142

Woodruff, D. 2010. The cactus and the beetle. Utah Native Plant Society, Salt Lake City, UT. Sego Lily Vol. 33: 3.