Mesa Verde Cactus (*Sclerocactus mesae-verdae*)
10 Year Transplant Monitoring Report
Shiprock Fairgrounds
2001-2011

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INTRODUCTION

Mesa Verde cactus (*Sclerocactus mesae-verdae*) is a diminutive cactus that occurs with a limited distribution in San Juan County, New Mexico and Montezuma County, Colorado (Mikesic and Roth 2008). The species is an edaphic obligate, occurring only in clay-loam soil derived from Mancos or Fruitland shale (USFWS 2011). It is listed as threatened under the federal Endangered Species Act, and endangered (group 3) under the Navajo Endangered Species Act (44 F.R. 62471; 16 U.S.C. §1530 *et seq.;* Navajo Nation Division of Natural Resources 2008). Total numbers for the species are estimated at approximately 4,200 individuals (USFWS 2011).

In addition to being a habitat specialist, the future persistence of the Mesa Verde cactus is threatened by herbivory, climate change, and human activities. During the last 30 years, most substantial losses have been attributed to insect predation, rodent damage, trampling by livestock, drought, poaching, energy development, and construction in and around the town of Shiprock (USFWS 2011; Ladyman 2004).

NNHP has supervised two transplants of Mesa Verde cactus. To our knowledge, only one additional transplant of the species has occurred on Navajo Nation land. Though avoidance is always preferable to transplanting, there are situations where it is necessary to salvage plants via transplant rather than allow their destruction. In these instances, recording the transplant methods and monitoring the survival rate of the transplants is crucial. This document reports the success, after ten years, of transplanting 54 Mesa Verde cacti at the Shiprock Fairgrounds.

METHODS

On March 27, 2001, Navajo Natural Heritage Program staff excavated 55 Mesa Verde cacti from the south-central portion of the proposed Northern Navajo Fairgrounds site located south of Shiprock, New Mexico, east of US HWY 491, and north of Navajo Route 36. The roots of the cacti were slightly trimmed to stimulate root growth and then dipped in a diluted Clorox solution in an effort to prevent bacterial infections. The cacti were then stored at the greenhouse of the Navajo Fish & Wildlife Department for two weeks to allow the roots to heal over. Only one cactus died during this period.

On April 9, 2001, five monitoring plots were delineated within the designated non-development zone of the future fairgrounds. The monitoring plots were mapped and the boundaries marked with rebar and wooden stakes. Monitoring plot location and size was determined based on the presence of existing Mesa Verde cacti. Naturally occurring cacti serve as a control and are monitored together with the transplanted cacti during annual monitoring efforts.

On April 10, 2001, 54 cacti were planted within the established monitoring plots. All together there were 49 naturally occurring cacti and 54 transplanted cacti (Table 1). All plants were mapped, numbered and tagged.

Monitoring has taken place annually since 2001, except for the year 2010. For each tagged plant, monitoring consists of recording plant vigor, number and status of reproductive structures, and diameter. Multi-stemmed cacti are counted as one plant, but stems are measured individually for vigor, reproductive status and diameter.

Table 1. Number of Mesa Verde Cacti transplanted into each of five monitoring plots at the Shiprock Fairgrounds in 2011, and the number of cacti previously occurring within the plots.

Plot No.	No. Naturally Occurring	No. Transplanted
1	11	11
2	4	8
3	9	8
4	9	13
5	16	14
Total	**49**	**54**

T-tests were used to test for differences in mortality rates, diameter, and reproductive output for transplanted vs. naturally occurring cacti each year of the study. T-tests were done in in the program Sigmaplot (Systat Software 2006). One-way analysis of variance was used to test for differences in reproductive output among years. Analysis of variance was done in the program R (The R Foundation for Statistical Computing 2011).

RESULTS

The majority of the cacti that were recorded at the start of the study in 2001 died within two years (Fig. 1). This high mortality has been attributed to exceptionally dry years in 2002 and 2003 (Roth 2008; Fig. 2). Mortality rates were equally high among both transplanted and naturally occurring cacti (Table 2; α=0.05). Most of these deaths occurred between the 2002 and 2003 sampling seasons.

As of 2011, the five monitoring plots contained 19 naturally occurring cacti and 19 transplanted cacti. Of the 19 naturally occurring cacti remaining in the plots, only four are survivors from 2001, the year of the transplants. Of the remaining 15, three were first observed in 2003, four were first observed in 2005, five were first observed in 2007, and three were found in 2011.

New germination kept pace with mortality in the naturally occurring population for the last few years. Between 2008 and 2011, three cacti died and three germinated.

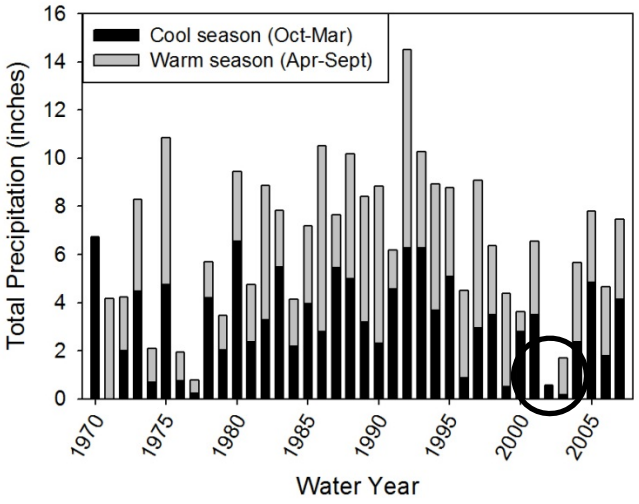

Figure 2. Total precipitation in Shiprock, NM, coded by precipitation falling during the cool season (October-March) and the warm season (April-September) for water years 1970-2007. Water years start the October preceding the calendar year and run through the September of that calendar year.

Table 2. Mortality rates and t-tests testing for differences in mortality rates for naturally occurring vs. transplanted cacti in five monitoring plots at Shiprock Fairgrounds, 2001-2011. There was no mortality in 2006 or 2008, so t-tests could not be performed for those years.

	Mortality Rate		t- test results		
Year	Naturally Occurring	Transplanted	*t*	*df*	*p*
2001-2002	0.12	0.09	0.20	8	0.85
2002-2003	0.77	0.57	0.56	8	0.59
2003-2004	0.23	0.14	0.77	8	0.46
2004-2005	0.17	0	1.61	7	0.51
2005-2006	0	0	N/A		
2006-2007	0.13	0	1.50	7	0.18
2007-2008	0	0	N/A		
2008-2009	0.05	0	1.14	7	0.29
2009-2011	0.06	0.03	0.90	7	0.40

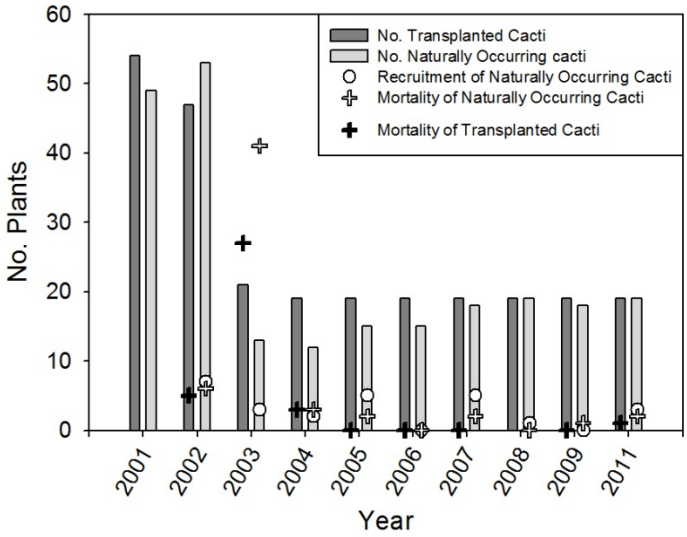

Figure 1. Total number , recruitment, and mortality of naturally occurring and transplanted Mesa Verde cactus clusters in five plots at the Shiprock Fairgrounds transplant site, 2001-2011.

The transplanted population has been holding steady as well; since 2004 there have been 19 living transplants.

In 2008, all naturally occurring cacti and 89% of the transplanted cacti were in excellent health (Fig. 3). Since then, vigor has declined slightly for the naturally occurring population, with 4 cacti, or 12%, classified as "good" rather than excellent in 2011. Of the transplanted cacti, 45% were in excellent health in 2011, 45% were in good health, and 10% were classified as being in fair health.

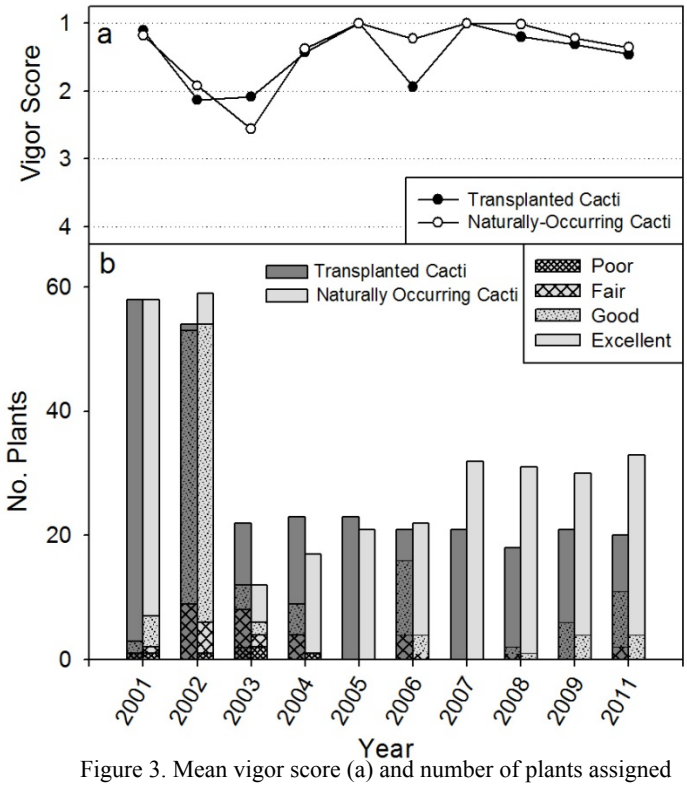

Figure 3. Mean vigor score (a) and number of plants assigned each vigor score (b) for transplanted and naturally occurring Mesa Verde cacti at the Shiprock Fairgrounds transplant site, 2001-2011. Vigor scores range from 1 (excellent), to 4 (poor).

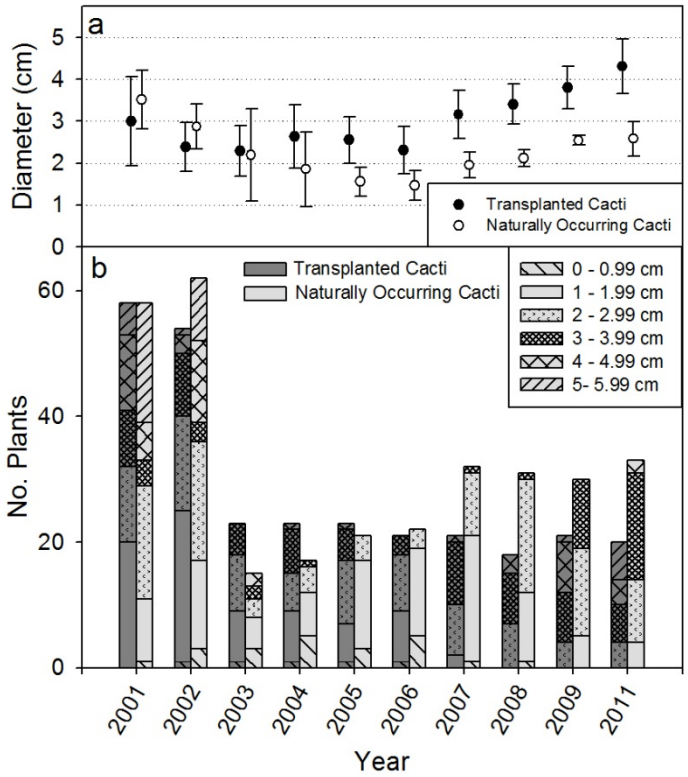

Figure 4. Mean diameter ± 1 standard error (a) and size class distribution (b) for transplanted and naturally occurring Mesa Verde cacti in five plots at the Shiprock Fairgrounds transplant site, 2001-2011.

At the beginning of the study, and until 2005, the mean diameter of transplanted cacti and naturally-occurring cacti was statistically identical (Fig. 4a, Table 3, α=0.05). Beginning in 2005, transplanted cacti were on average larger than the naturally occurring cacti. For both groups, there was a trend of decreasing diameter in the early 2000s, followed by an increase in the late 2000s. The initial decrease in diameter was more pronounced within the naturally-occurring group, while the later increase was more pronounced for the transplanted cacti (Fig 4a). Between 2006 and 2011, the naturally occurring population increased from an average 1.5 cm diameter to an average 2.6 cm diameter. Mean diameter of transplants increased from 2.6 cm in 2006 to 4.3 cm in 2011.

In 2011, the majority of naturally occurring cacti (51%) were in the 3-3.99 cm size class, followed by 30% in the 2-2.99 cm size class (Table 4, Fig. 4b). Size class distribution was more even with the transplants, with 50% of cacti less than 4 cm in diameter, and 50% greater than or equal to 4 cm diameter (Table 5, Fig. 4b).

Table 3. T-test results testing for differences in plant diameter between transplanted and naturally occurring groups of Mesa Verde cactus in five monitoring plots. Each row reports results of one t-test. *p<.05. **p<.01.

Year	t	df	p
2001	0.90	8	0.39
2002	1.37	8	0.21
2003	-0.16	8	0.88
2004	-1.42	7	0.20
2005	-3.11	7	0.02*
2006	-2.53	7	0.04*
2007	-3.76	7	0.01*
2008	-5.02	7	0.001**
2009	-4.81	7	0.002**
2011	-4.58	7	0.003**

Table 4. Size class distribution for naturally occurring Mesa Verde Cacti in five plots at the Shiprock Fairgrounds transplant site, 2001-2011.

Size class	2001	2002	2003	2004	2005	2006	2007	2008	2009	2011
0 - 0.99cm	1	3	3	5	3	5	1	1	0	0
1 - 1.99cm	10	14	5	7	14	14	20	11	5	4
2 - 2.99cm	18	19	3	4	4	3	10	18	14	10
3 - 3.99cm	4	3	2	1	0	0	1	1	11	17
4 - 4.99cm	6	13	2	0	0	0	0	0	0	2
5 - 5.99cm	19	10	0	0	0	0	0	0	0	0

Table 5. Size class distribution for Mesa Verde Cacti transplanted into five plots at the Shiprock Fairgrounds transplant site, 2001-2011.

Size class	2001	2002	2003	2004	2005	2006	2007	2008	2009	2011
0 - 0.99cm	0	1	1	1	1	1	0	0	0	0
1 - 1.99cm	20	24	8	8	6	8	2	0	0	0
2 - 2.99cm	12	15	9	6	10	9	8	7	4	4
3 - 3.99cm	9	10	5	7	5	3	10	8	8	6
4 - 4.99cm	12	3	0	1	1	0	1	3	8	4
5 - 5.99cm	5	1	0	0	0	0	0	0	1	6

For each year of the study, there is no significant difference between natural and transplanted groups in per-plant reproductive output (Fig. 5, Table 6; α=0.05). Reproductive effort was at its highest in 2001, the first year of the study, with the greatest number of reproductive structures produced overall and the greatest number of reproductive structures per plant, for both transplants and naturally occurring cacti (Fig. 5). The term "reproductive structure" can refer to a flower or a fruit, in any of their various stages (flower bud, flower in full bloom, aborted flower, immature or mature fruit.)

Reproductive output decreased in 2002 and remained low for several years. There has been a gradual increase in reproductive effort for the transplanted and naturally occurring cacti, with the highest numbers in 2011. However, one-way analysis of variance indicates that there is no statistical difference in per-plant reproductive output among the ten years of data (Table 7; α=0.05).

Table 7. Analysis of variance results testing for differences in per-plant reproductive output among years. Data is graphically represented in Fig. 5a.

Source of Variation	df	SSE	MSE	F	P
Year	1	0.64	0.64	1.04	0.31
Residual	91	5.22	0.62		

Table 6. T-test results testing for differences in per-plant reproductive output between transplanted and naturally occurring groups of Mesa Verde cactus in five monitoring plots. Each row reports results of one t-test. There are no results in 2006 because all plants were sterile that year.

Year	t	df	p
2001	0.18	8	0.86
2002	2.03	8	0.08
2003	1.00	8	0.35
2004	-1.16	7	0.28
2005	-2.08	7	0.08
2006		N/A	
2007	-1.93	7	0.09
2008	-0.80	7	0.45
2009	-0.86	7	0.42
2011	-2.01	7	0.08

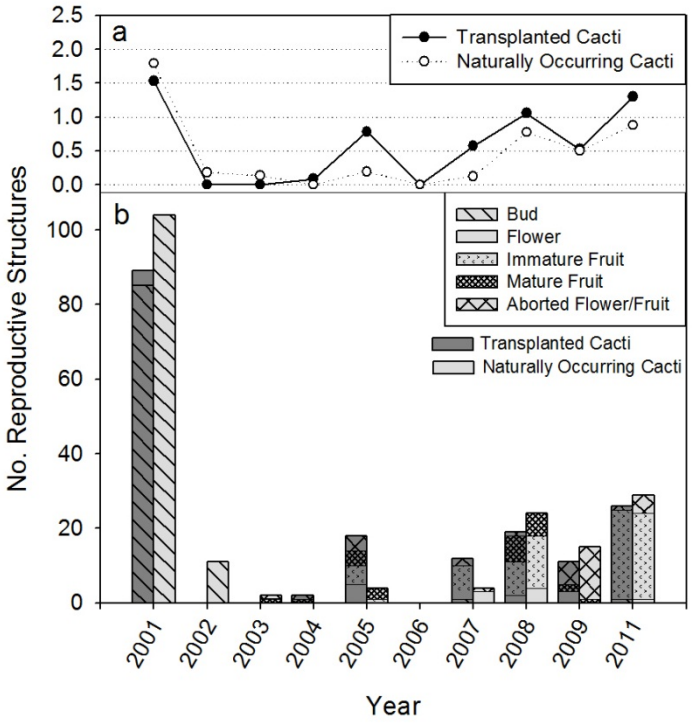

Figure 5. Reproductive output of transplanted and naturally occurring Mesa Verde cactus in five plots at Shiprock Fairgrounds, 2001-2011. Reported as total number of reproductive structures, coded by phenologic phase (b), and as average number of reproductive structures per plant measured in the population (a).

DISCUSSION

In the past, efforts to transplant Mesa Verde cactus were considered unsuccessful. The first known attempt occurred on Navajo Nation land in 1986. Due to lack of documentation, it is impossible to accurately assess its success. Thirty-five cacti were transplanted out of a road right-of-way and haphazardly monitored. Plants were not tagged, and the plant locations were mapped imprecisely. Three years later, in 1989, fewer than ten Mesa Verde cacti were found at the transplant site (Hevron 1995). Because of the lack of mapping and documentation, there is no way to tell if those remaining cacti were surviving transplants, progeny of the transplants, or part of the naturally-occurring population.

The second transplant effort was undertaken by NNHP in 1995. Twenty-nine cacti were transplanted out of a road right-of-way near Cudei, New Mexico. Cacti were monitored, along with naturally occurring cacti as a control group, for ten years. In this case, the drought of 2002 followed by an infestation of cutworms in 2003, led to nearly complete mortality. By 2004, only four transplanted cacti and two naturally occurring cacti remained in the study plots. All remaining cacti showed signs of insect damage in 2004 (Roth 2004).

As in the Cudei example, the Shiprock Fairgrounds transplants experienced high mortality as a result of the drought in the early 2000s. However, the mortality levels were not as high as they were at the Cudei transplant site, and insect infestation not so complete. Several plants at Shiprock Fairgrounds were noted to have insect damage in 2003, but some of those plants survived the predation.

At Shiprock Fairgrounds, survival, vigor, reproductive output, and plant diameter declined at the same time as the drought occurred, and increased in subsequent years. These trends were consistent among transplanted and naturally occurring cacti alike. In fact, statistical analysis could detect no differences between the two groups, except for plant diameter beginning in 2005. Transplanted cacti were on average larger from 2005 to 2011; this size difference is likely due to the fact that the naturally occurring cactus group includes newly recruited cacti, while the transplant group did not. Inclusion of young cacti would lower the mean diameter relative to the transplants, which are all over ten years old.

Monitoring of the Cudei experiment showed depressed reproductive output of transplanted cacti relative to naturally occurring cacti for the first five years after transplanting. This could be due to stress of the transplant, or because the transplants were on average smaller than the control group for the first five years of the study. Cully *et al*. (1993) showed that larger diameter Mesa Verde cacti produce significantly greater numbers of fruit each year compared to small cacti. Because the drought occurred immediately after the reproductive output of the two groups equalized, it is impossible to extrapolate this trend any further. Reproductive output of the Shiprock Fairgrounds transplants was equal to that of the control cacti for the duration of the experiment. However, the effect of the drought in the first year after transplanting confounds these results so thoroughly that it would be inappropriate to conclude that this trend would apply under normal conditions.

Transplanting a rare or endangered plant should always be a last resort, after all options for avoidance have been ruled out. However, when it needs to occur it is crucial to meticulously document all methods used during the transplant and precise locations for each plant. This is especially important when plants are small, as in the case of the Mesa Verde cactus, and when they are being transplanted into an existing population. Only with this type of record keeping, combined with medium- to long-term monitoring, can the success of the transplant be assessed. In this case, the transplant methods used for the Shiprock Fairgrounds cacti can be considered effective. Despite the fact that mortality rates were high, survival was equal between the transplant and control groups. The stress of the transplant apparently did not lower the cacti's ability to withstand the stress of a drought that commenced within one year of transplant. The effect of transplanting on short-term reproductive output could not be assessed from this monitoring data, however. In the future, tracking reproductive output of transplants should be a priority when designing monitoring programs for Mesa Verde cactus transplants.

REFERENCES

Cully, A., et. al. 1993. Preliminary results from a long-term study of Mesa Verde cactus (*Sclerocactus mesae-verdae*). *Proceedings of the Southwestern Rare and Endangered Plant Conference*. Eds. R. Sivinski and K. Lightfoot. New Mexico Forestry and Resources Conservation Division Miscl. Publ. No. 2.

Hevron, B.E. 1995. *Transplantation of Mesa Verde Cactus,* Sclerocactus mesae-verdae*, as mitigation on the Navajo Nation*. Internal memo. Navajo Natural Heritage Program, Department of Fish & Wildlife, Window Rock, AZ.

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

Mikesic, D. and D. Roth. 2008. *Navajo Nation Endangered Species List Species Accounts*. Navajo Natural Heritage Program, Department of Fish & Wildlife, Window Rock, AZ.

Navajo Nation Division of Natural Resources Department of Fish and Wildlife. 2008. *Navajo Endangered Species List.* Resources Committee Resolution No. RCS-41-08. Available online at <http://nnhp.nndfw.org/endangered.htm>

Roth, D. 2008. *Monitoring Report:* Sclerocactus mesae verdae *Transplant Project, Northern Navajo Fairgrounds, Shiprock, San Juan County, NM*. Unpublished annual update prepared for the Navajo Natural Heritage Program, Window Rock, AZ.

Roth, D. 2004. *Monitoring Report: Mesa Verde Cactus Trasplantation for BIA Route N57– Cudei Rd, San Juan County, NM*. Unpublished report prepared for Navajo Natural Heritage Program, Department of Fish & Wildlife, Window Rock, AZ.

U. S. Fish and Wildlife Service. 2011. *Mesa Verde Cactus (*Sclerocactus mesae-verdae*) 5-Year Review Summary and Evaluation*. New Mexico Ecological Services Field Office, Albuquerque, NM.

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