

Knowlton's Cactus (*Pediocactus knowltonii*): Eighteen Years of Monitoring and Recovery Actions

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ABSTRACT. *Pediocactus knowltonii* is a rare, endemic cactus that is presently known to occur on a single 10-hectare hill in northwestern New Mexico near the Colorado border. It was listed as federally endangered in 1979. Population monitoring and recovery actions were initiated when the Recovery Plan was adopted in 1985. The land at the type locality has been donated to The Nature Conservancy and long-term monitoring plots have been annually studied since 1986. This population reached peak density in 1994 and is presently in decline. A total of 301 clones were made and transplanted to two nearby habitats above the Los Pinos arm of Navajo Lake, beginning in 1985. Transplant survival and flowering were good, but natural recruitment has been slow. Seeding trials were also conducted at both locations in 1985 and 1991. Only 4% of seeds planted became established as adult plants and no new recruitment has yet been observed.

INTRODUCTION

Pediocactus knowltonii L. Benson (Knowlton's cactus), listed as endangered by U.S. Fish & Wildlife Service (USFWS) on November 28, 1979, is one of the rarest cacti in the United States. It was discovered in 1958 by the late Fred Knowlton and named by Lyman Benson (1961). Knowlton's cactus is known to occur only at its type locality on a small hill of about 10 hectares in San Juan County, New Mexico just south of the Colorado/New Mexico border above Navajo Lake. Extensive searches of this region in New Mexico and adjacent Colorado have failed to locate additional natural populations.

Shortly after its discovery, this *P. knowltonii* population was repeatedly visited by cactus collectors to obtain plants for the succulent hobbyist trade. This population was severely impacted

by the New Mexico Cactus and Succulent Society in 1960, which was under the mistaken perception that this site would be flooded by the newly constructed Navajo Reservoir. Field trips were organized to salvage the cacti from the type locality. Several thousand *P. knowltonii* plants were reportedly taken by this group of hobbyists (Paul Knight, personal communication, 1984). This rare cactus is presently available as plants or seeds from licensed commercial growers, which has relieved some of the collection pressures on the natural population.

In an effort to protect the only natural population of this rare cactus, the landowner (Public Service Company of New Mexico) donated the 10-hectare type locality to The Nature Conservancy (TNC). This small preserve was fenced to exclude livestock. A few cacti (<100)

occur on adjacent BLM land, which is also enclosed by a livestock-proof fence.

A recovery plan was developed for Knowlton's cactus and approved by USFWS in March, 1985 (USFWS, 1985). A reintroduction program into adjacent suitable habitats was identified as the primary effort towards recovery of this species. Monitoring at the type locality was also initiated to obtain information on growth and phenology from the natural population for comparison to the transplant efforts.

HABITAT AND POPULATION CHARACTERISTICS

Pediocactus knowltonii habitat occurs on Tertiary alluvial deposits overlying the San Jose Formation. These deposits form rolling, gravelly hills covered with piñon pine (*Pinus edulis* Englem.), Rocky Mountain juniper (*Juniperus scopulorum* Sarg.) and black sagebrush (*Artemisia nova* A.Nels.). A relatively dense soil cover of foliose lichen (*Parmelia* sp.) is an unusual aspect of the habitat. This cactus grows in full sun between cobbles and in the understory of sagebrush and conifers. Average annual precipitation is 30 cm, arriving mostly during late summer and winter months.

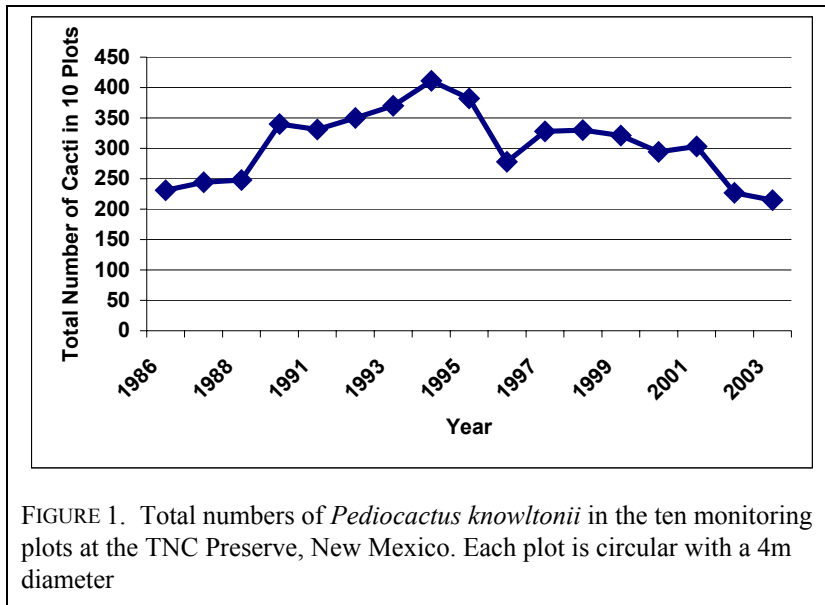
The only known natural habitat is the top and slopes of a single small hill. Knowlton's cactus density is variable at this location, but can be surprisingly high in some areas with up to 13 cacti per square meter. The total population in 1992 was estimated to be 12,000 plants by using a series of belt transects across the hill where this species occurs. Individual plants can become reproductive adults when they are 10 mm, or more, in diameter. Flowering peaks in early May and fruits ripen in June and July. This small cactus has

contractile roots, which can pull the entire plant below the soil surface during periods of severe drought. All Knowlton's cacti begin with a single-stem and most retain that morphology throughout their lives. However, plants that are damaged or buried for a long period will often become multi-stem plants. Approximately one-quarter of the natural population have 2-15 heads per plant.

MONITORING AND POPULATION TRENDS

Twenty-four circular monitoring plots (4 m diameter) were established in 1986 at the natural population of Knowlton's cactus in the TNC preserve. These plots have all conditions of slope, aspect, soil type, and associated vegetation on the small hill at the type locality. Only 11 of these plots contained Knowlton's cactus during the term of this study. One of these occupied plots (including rebar, tags, and an undetermined number of cacti) was removed by cactus poachers in 1995, so the final data set consists of a ten-plot total. Each plant within an occupied plot was measured and marked with a numbered tag held in the ground by a 8-penny nail. Stem diameter, and number of flowers or fruits have been recorded during the last eighteen years.

The total numbers of *P. knowltonii* within the study plots at the type locality between 1986 and 2003 are shown in Figure 1. The 1989 monitoring was incomplete (only 5 of 11 plots) and has been deleted from this analysis. Overall, the population trend increased by 78% from 1986 to 1994, then continuously decreased from 1995 to 2003 to a final number slightly below the original 1986 density. The steep decline and increase between 1995 and 1997 is an artifact of detectability. Many cacti had pulled into



the ground during the extreme drought year of 1996 and could not be accurately counted until 1997. Therefore, the trend line between 1995 and 1997 should, actually, be more gradual than shown in Figure 1.

There are no weather stations near the TNC Preserve, but a severe, long-term drought has been apparent in the Four Corners Region for the last several years and is probably the driving force behind the recent decline of this population. These small cacti are very drought tolerant, however, dry conditions cause an increase in rabbit and rodent attacks, which are frequently fatal. Recruitment to this population is not consistent over time and several years can pass between episodes of significant germination and establishment. A great many seedlings were observed during the early- and mid-1990s, but relatively fewer new plants were found in the monitoring plots during the years after 1995.

TRANSPLANTING PROGRAM

A ten-mile radius south of the *P. knowltonii* type locality was searched in

1985 and again in 1991 for suitable habitats that are similar to the natural habitat of this species. Suitability criteria were cobbly substrates in piñon-juniper woodland with a dominant shrub component of black sagebrush. Two locations were selected as potential reintroduction sites. One on Bureau of Land Management land approximately two

miles south of the type locality and another on Bureau of Reclamation land approximately 5 miles to the south at Navajo Lake.

The reintroduction (transplant) program began in May, 1985, when 250 stem cuttings were taken from multi-stem plants at the type locality. These clones were taken to a greenhouse and grown in pots over the summer until fully rooted. One hundred fifty of these adult clones were placed at the transplant location on the Los Pinos arm of Navajo Lake, which is hereafter referred to as the Navajo #1 Site. They were planted in fall of 1985 in a grid pattern at two-meter intervals along 15 lines of ten plants each (Olwell et al, 1987). This site was supplemented with another 102 cuttings planted on the south side of this grid in the early spring of 1995. These later transplants are in the same general area, but are referred to as the Navajo #2 Site.

An additional 250 cuttings were taken in the spring of 1991. Each of the parent plants used for the 1991 cuttings were marked so that they could be monitored

for any mortality that resulted from the stem cut. In September 1991, a total of 149 five month-old clones were planted on the BLM's Reese Canyon Area of Critical Environmental Concern (ACEC), which is referred to as the BLM #1 Site. This transplant effort differed from the Navajo Lake site by method of planting and placement pattern. The Navajo Lake plants were transplanted with the rooting medium still attached to the roots. The BLM #1 transplants were entirely bare-root plantings. The BLM #1 Site contains three lines of fifty plants each and spaced two meters apart (Fig. 2). Ten clusters of five plants (3-4 dm apart) are spaced at two-meter intervals along each line. The northern-most line is Line 1 and the southern-most Line 3:

1A	1B	1C	1D	1E	1F	1G	1H	1I	1J
2A	2B	2C	2D	2E	2F	2G	2H	2I	2J
3A	3B	3C	3D	3E	3F	3G	3H	3I	3J

FIGURE 2. Placement Pattern for Transplants at BLM #1 Site, arrangement of blocks.

Each five-plant cluster is arranged with the center plant being No. 1, the northern-most plant as No. 2, then clockwise to No. 5 (Fig. 3).

	1A2	
1A5	1A1	1A3
	1A4	

FIGURE 3. Placement Pattern for Plants within blocks.

These cacti do not all flower simultaneously. Therefore, the rationale for planting five-plant clusters is to increase the number of flowering plants in close proximity to one another and, hopefully, increase the potential for pollination and seed set.

Impacts of Cloning Operations

On 7 May 1991, Steve Brack, independent horticultural contractor, took 250 single-stem cuttings of Knowlton's cactus from multiple-stemmed individuals at the type locality population. After removing a cutting from the base of each cactus, a small rock was placed against the wound and a number was assigned to the donor plant.

This number was inscribed on an aluminum tag, which was anchored to the ground near the plant with a nail. Unfortunately, these tags were soft aluminum and 40 were torn away from their anchor nails (by wind?) and were lost.

A total of 210 secure marker tags were relocated in May of 1992. Of these, 185 donor plants that were still alive. Another 25 indicated dead plants or an area where no plant could be located and was assumed to be dead. This sample of 210 donor cacti experienced a 12 percent rate of mortality from May 1991 to May 1992. During this same period of time, unmolested, multiple-stemmed cacti in adjacent study plots experienced a natural mortality rate of 12.9 percent (n= 101). Therefore, no increase in mortality resulted from the stem damage incurred during the Knowlton's cactus cloning operation.

Transplant Survival

The clones at the transplant sites have persisted very well. Eighteen years after planting, 62 (41%) of the original Navajo #1 transplants were still surviving in 2003 (Table 1). An additional 102 cacti were transplanted to the Navajo Lake site in 1996 (Navajo #2), but immediately faced severe drought conditions that killed one-fifth of the new plants. The Navajo #2

transplant site had 66 (65%) of the original plants surviving in 2003, nine years after planting. Of the 149 cacti planted at the BLM #1 site in September 1991, 66 (44%) were still alive in May of 2003. This demonstrates the hardiness and suitability of this plant for establishing new populations through transplantation. The severe drought year 1996 cause many of these transplants to contract below the soil surface. These were not counted again until the following year (Table 1).

A significant problem with the method of autumn planting was encountered at the BLM #1 site. During the first winter after the September planting, approximately one third of the cacti were frost-heaved from the ground. These plants were found lying on the surface in a desiccated condition and were immediately replanted in March 1992. Several factors may be

responsible for this problem. Unlike the Navajo Lake site, these cacti were planted bare-root and may have lacked the additional anchor of artificial potting soil. The late season planting also did not allow sufficient time for root development prior to winter dormancy. Soils at the BLM #1 site also have a finer texture and retain water that could contribute to frost heaving. Fortunately, root development during the growing season of 1992 allowed these plants to remain anchored in the soil during the following winters.

Flowering and Fruiting

Comparison of Knowlton's cactus reproductive activity in the natural population at the type locality and transplant sites is difficult because the transplants are cohorts of aging adults while the natural population contains all age classes. Therefore, the type locality data is modified to exclude all < 10 mm

TABLE 1. Total number and percent survival of *Pediocactus knowltonii* transplants counted at the Navajo Lake and BLM #1 transplant sites.

	Navajo #1		Navajo #2		BLM #1	
	N	% surviving	N	% surviving	N	% surviving
1986	150	100%				
1987	140	93%				
1988	125	83%				
1989	119	79%				
1990	116	77%				
1991	107	71%			149	100%
1992	107	71%			137	92%
1993	102	68%			121	81%
1994	98	65%			114	76%
1995	94	63%	102	100%	96	64%
1996	69	46%	76	75%	76	51%
1997	85	57%	81	79%	93	62%
1998	75	50%	76	75%	90	60%
1999	68	45%	73	72%	81	54%
2000	68	45%	68	67%	80	54%
2001	63	42%	75	74%	80	54%
2002	63	42%	68	67%	69	46%
2003	62	41%	66	65%	66	44%

diameter, single-stemmed, juvenile cacti from a 13-year reproductive comparison in Table 2.

Knowlton's cactus is reproductively unusual for cacti since it initiates most of its flower primordia in the early autumn months. Therefore, spring flowering is greatly influenced by the condition of the plant during the previous growing season and the intervening winter months.

During the severe drought years of 1996 and 2002, very few plants attempted flowering and less than 10% of the flowers produced fertile fruits at the type locality and transplant sites. Even during years of good precipitation, this plant is not a prolific bloomer. In 1992, the natural population had flowers or fruits on only 51% of adult-size cacti, which was the greatest percentage of reproductive effort at that location during this 13-year period. The transplant sites are uniformly older, more mature cohorts that usually show higher reproductive effort than the natural population, which has uneven age classes. Seed production was not monitored at any of these sites.

TABLE 2. Reproductive activity of *Pediocactus knowltonii* at the type locality and transplant sites. (* Excludes < 10 mm, single-stem plants.)

	Type	Nav #1	Nav #2	BLM #1
Sample Size*				
1991	306	107		
1992	337	107		
1993	358	102		121
1994	410	98		114
1995	366	94		96
1996	231	76	58	68
1997	263	85	80	92
1998	258	75	76	90
1999	272	68	73	81
2000	228	68	69	80
2001	256	62	72	79
2002	152	59	62	67
2003	173	64	66	66
No. Plants in Flower (%)				
1991	145 (47%)	52 (49%)		
1992	178 (51%)	59 (55%)		
1993	111 (31%)	25 (25%)		3 (2.4%)
1994	180 (44%)	42 (43%)		6 (5.5%)
1995	153 (42%)	52 (55%)		16 (17%)
1996	18 (8%)	12 (16%)	2 (3%)	8 (12%)
1997	111 (42%)	51 (60%)	12 (15%)	36 (39%)
1998	77 (30%)	25 (33%)	11 (14%)	35 (39%)
1999	43 (16%)	9 (13%)	4 (5%)	23 (28%)
2000	66 (29%)	23 (34%)	16 (23%)	23 (29%)
2001	93 (36%)	26 (42%)	30 (42%)	43 (54%)
2002	9 (6%)	0 (0%)	0 (0%)	3 (4%)
2003	66 (38%)	33 (52%)	29 (44%)	30 (45%)
Flowers/Flowering Plant				
1991	1.8	1.5		
1992	2.2	1.7		
1993	1.5	1.4		1
1994	1.8	1.5		1
1995	1.8	1.9		1.4
1996	1.4	1	1.5	1.3
1997	1.8	2.2	1.2	1.4
1998	1.9	1.8	1.4	1.3
1999	1.4	1.9	1.3	1.3
2000	1.6	1.9	1.4	1.6
2001	1.7	2.3	1.6	1.9
2002	1.1	0	0	1
2003	1.7	2.6	1.9	1.8

SEEDING TRIALS

Direct seeding to the soil was attempted well outside the transplant grids at both the Navajo Lake and BLM locations. Very little Knowlton's cactus seed could be obtained from the natural population because most seeds are immediately harvested by rodents (probably *Peromyscus* sp.) from the maturing fruits. Few fruits reach a mature stage of dehiscence before being opened and emptied by rodents. Therefore, the majority of seeds used in seeding trials were obtained from greenhouse-grown plants.

Only 288 seeds were planted in the autumn of 1987 at the Navajo Lake seed plot. These were planted in one-meter grid intervals and at various depths at each grid point. A template was used that allowed seed placement in the three locations of 10 cm north, 10 cm south and 10 cm west of each grid point. Two seeds were placed in each hole at a predetermined depth. At the south axis location, seeds were left on the surface and lightly covered with a coating of fine soil. West axis seeds were planted at 0.5 cm depth, and north axis seeds were planted 1 cm below the surface.

This seed plot was monitored for germination every spring and autumn from 1988 to 1990 with no seedlings being detected. The 1991 assessment was not entirely complete because of the observer's unfamiliarity with the plot layout. In May of 1992, eight Knowlton's cactus seedlings were located. These seedlings appeared to be from 1-3 years of age. They were firmly established and represented all three planting depths. Although this sample is small, planting depths above 1 cm do not appear to make a difference in seedling establishment. Additional cacti continued to be found at this plot until 1997 for a total of 18 plants, which is a 6.25% establishment of seeds planted. Only 9 (50%) of these germinants remain as adult cacti in 2003.

Another seed plot was established at the BLM #1 site in January 1994. A total of 2,250 *P. knowltonii* seeds were purchased from a permitted vendor and planted in permanent plots. Each plot is a grid constructed with field fence laid flat on the ground and held in position with steel reinforcement rods. The mesh openings in the fence are 2x3 inches and a single seed was planted in each opening. There are three 4 x 15 foot lengths of fence, each with three

TABLE 3. Numbers of *Pediocactus knowltonii* seedlings in three replicate plots at BLM #1. Each plot has blocks of no treatment (NT), brushed (Brus.) and cultivated (Cult.) treatments.

	Plot #1			Plot #2			Plot #3			TOTAL
	NT	Brus.	Cult.	NT	Brus.	Cult.	NT	Brus.	Cult.	
1994	8	1	2	0	1	0	0	0	0	12
1995	24	4	19	12	1	4	0	5	8	77
1997	15	4	13	5	3	1	6	16	9	72
1998	10	3	10	2	2	3	5	1	8	44
1999	13	1	8	7	4	3	4	11	12	63
2000	17	4	7	5	4	3	6	9	10	65
2001	20	2	11	8	6	5	10	17	14	92
2002	20	2	11	8	5	4	10	22	14	96

different 4 x 5 foot treatments:

No Treatment: Native vegetation with no disturbance;

Brushed: Sagebrush clipped off at ground level, no surface disturbance;

Cultivated: All brush and herbaceous vegetation removed by hoeing the soil.

Each treatment within the three plot replications received 250 seeds. Seeds was planted at a depth of approximately 5 mm and a small amount of blasting sand was poured on each planting hole to control erosion.

Only 12 seedlings were observed to have germinated by June 1994. The new seedlings were very tiny and most did not survive the unusually hot summer of 1994. Only 4 of the original 12 survived to be counted again in May 1995. A total of 69 new germinants were counted in the 1995 assessment. The seedlings were not readily visible during the severe drought year of 1996 and a complete assessment was not made during that year. Only 30 (39%) of the 1995 seedlings survived to be counted again in May of 1997. The remaining 42 of the 1997 seedlings were recent germinants. A total 44 seedlings were observed in 1998 of which 20 were new germinants. This represents a significant number (48) of previous year's seedlings that failed to become established. By 2001, most of the seedlings were becoming larger and two had reached reproductive maturity and were flowering. Six were flowering in 2002, a severe drought year. Two new (2-year old) seedlings were found in 2003, which shows germination can still occur nine years after planting. A 2003 total of 97 cacti represents a 4.3% establishment of the 2,250 seeds planted (Table 3).

An analysis of variance for the random block design of this experiment showed no significant differences between plot treatments ($F=2.88$ with 2 and 4 degrees of freedom). Seedbed preparation is unnecessary and will, in fact, increase soil erosion when seed plots are placed on a slope.

RECRUITMENT

Survival of Knowlton's cactus cuttings at the reintroduction site has been surprisingly good, but cannot be considered a success until there are cacti becoming established from natural reproduction in sufficient numbers to offset mortality. Recruitment at the seed plots is difficult to assess because there may be a period of overlap for detecting the offspring of early germinants that became reproductive and shed seed into the plot and the late germinants that arise from the original seed planted in the plot. New plants at the transplant sites are difficult to find until they reach sufficient size to be readily seen by researchers.

The first evidence of recruitment was a single seedling found in 2002 at the Navajo #1 reintroduction site. This plant was an approximately 2-years old plant and was observed sixteen years after the first fruits were produced in this transplant population. Another two seedlings were observed at this location in 2003. A single new seedling was also found at the BLM #1 site in 2003, twelve years after the first reproductive efforts in this transplant population. To date, only four new cacti have been detected as new recruits to both transplant locations.

CONCLUSIONS

Eighteen years of monitoring at the *Pediocactus knowltonii* type locality

have demonstrated that this population fluctuates in density, probably in response to climatic conditions. Only one serious episode of cactus poaching was detected in 1996 when an entire monitoring plot and an undetermined number of cacti were removed from the natural population at the type locality.

Survivorship and reproductive efforts of Knowlton's cactus clones at all transplant sites has been good during the course of this study and the multi-stem donor plants in the natural population did not suffer from the loss of a single stem. These plants are relatively long-lived for small cacti; however, they are gradually dying away at the transplant sites and are not yet being replaced by new recruits. Direct seeding into new locations is a viable option to transplanting adult clones; however, only about 5% of the seed becomes established as adult plants and they require a longer period to become reproductive than do transplanted clones.

The feasibility of establishing new populations of Knowlton's cactus by transplantation or seeding at the rates in this study is yet to be established since natural recruitment to these new populations has been an exceedingly slow process. It is possible that a large volume of seed is being banked in the soil, but suitable conditions for germination and establishment have not yet occurred. Another possibility is that the high rate of seed predation by rodents that is evident at the natural population could also be seriously depleting seed production at the transplant locations. These hypotheses can be tested when the next episode of significant germination and establishment occurs in the natural population. If the transplant populations

are not similarly augmented by new recruits, then too little seed is surviving at these new locations to maintain viable populations. Larger transplanting or seeding efforts would be needed. Instead of a few hundred adult clones and a few thousand seeds, future efforts would need a few thousand adult clones or tens of thousands of seeds to have a chance for success.

Inadequate recruitment at these small, new populations at the transplant sites may offer some insight into the rarity of this species. How large must a founding population of Knowlton's cactus be to become established in new, suitable habitat? If it requires a few thousand plants, then the single, isolated, natural population of this cactus on one small hill is no longer a mystery. It would be unable to naturally attain such a high rate of dispersal to adjacent unoccupied habitats. If *P. knowltonii* were more widespread in the past and has suffered local extinctions, the surviving population could not repopulate those habitats. If, on the other hand, it evolved at this single location, it has simply been unable to colonize adjacent suitable habitats because the few seeds that may find their way to new locations are inadequate to found new populations.

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