Knowlton's Cactus (*Pediocactus knowltonii*):
Progress Report
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For U.S. Fish & Wildlife Service, Region 2
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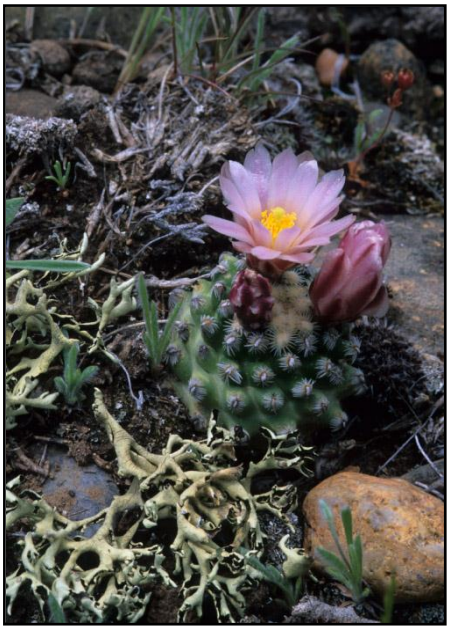


INTRODUCTION

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 most rare 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 (<50) 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. 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*), Rocky Mountain juniper (*Juniperus scopulorum*) and black sagebrush (*Artemisia nova*). 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 to13 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. 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 has 2-15 heads per plant.

MONITORING PROGRAM

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 is marked with a numbered metal tag held in the ground by an 8-penny nail. Most tags are reliably persistent, however, a few may be missing each year and some adult plants have, of necessity, been tagged again with a new number.

Population Trends

The densities of *P. knowltonii* in the study plots at the type locality between 1986 and 2011 are shown in Table 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, and then continuously decreased from 1995 to 2008 to a number below the original 1986 density. The steep decline and increase between 1995 and 1997 is an artifact of detection. 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 between 1995 and 1997 should, actually, be more gradual than shown in Table 1.

There are no weather stations near the TNC Preserve, but a severe, long-term drought has been apparent in the Four Corners Region since 1999 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 and recruitment has not offset mortality in the natural population during most years.

Table 1. Plant numbers per plot, *Pediocactus knowltonii* type locality, 1986 - 2011.

Plot/Year	C	D	G	H	J	K	L	M	N	P	Sum
1986	2	100	13	27	13	24	44	2	1	5	231
1987	3	99	14	32	15	26	45	2	1	7	244
1988	2	100	14	34	17	25	48	2	2	4	248
1990	--	135	13	49	28	39	63	2	3	8	340
1991	5	133	11	46	27	35	60	4	2	8	331
1992	6	152	12	49	57	30	61	4	3	8	350
1993	6	150	13	57	33	26	70	4	4	7	370
1994	6	162	17	64	35	28	84	4	5	6	411
1995	6	158	16	56	29	25	79	3	4	6	382
1996	5	125	7	36	21	17	58	3	3	3	278
1997	7	144	5	48	26	19	68	3	5	3	328
1998	8	144	5	42	28	18	74	3	5	3	330
1999	8	146	8	40	28	16	70	3	1	3	321
2000	5	119	5	36	28	16	73	3	5	4	294
2001	5	125	4	47	31	16	64	3	4	4	303
2002	5	87	3	40	26	10	46	3	3	4	227
2003	4	70	4	33	26	14	52	3	5	4	215
2004	6	78	4	36	25	12	61	3	5	4	234
2005	5	71	4	33	22	12	58	2	5	2	214
2006	5	73	4	35	22	10	58	1	5	2	215
2007	5	64	4	33	21	8	53	1	5	3	197
2008	6	63	1	29	22	7	42	1	4	3	178
2009	7	71	1	29	24	4	44	1	4	4	189
2010	9	76	1	28	30	5	40	1	4	4	198
2011	11	85	1	30	34	5	45	1	4	4	220

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 cobbley 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 at Navajo Lake approximately 5 miles to the south.

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 adjacent to 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.

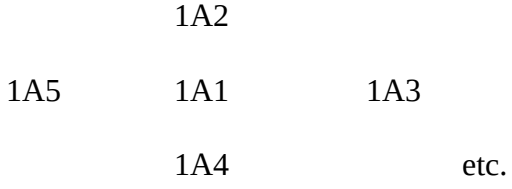
An additional 250 cuttings were taken in the spring of 1991 (Sivinski and McDonald 2007). Each of the parent plants used for the 1991 cuttings were marked so that they could be monitored for any mortality that resulted from the stem cut. In September 1991, a total of 149 five month-old clones where planted 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. 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

Each five-plant cluster is arranged with the center plant being No. 1, the southern-most plant as No. 2, then clockwise to No. 5:



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 were still alive. Another 25 indicated dead plants or an area were 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 persisted very well for many years. Nineteen years after planting, 59 (39%) of the original Navajo #1 transplants were still surviving in 2004 and 3 new cacti had been recruited. 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 (Table 2).

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 the surviving plants to remain anchored in the soil during the following winters.

The Navajo #1 and #2 transplants slowly dwindled away, without significant recruitment, until entire transplant population catastrophically declined in the winter of 2005/2006. Rodent or rabbit predation in 2006 killed most of the Knowlton's cactus plants remaining at the Navajo

Lake transplant location (Table 2). This was the most severe level of predation observed at this location during the 20 years it had been monitored and both the Navajo #1 and Navajo #2 transplant sites were abandoned in 2007. The BLM #1 transplant site was also seriously impacted by predation in 2006 and again in 2007. Several of the cacti damaged by rodents or rabbits in 2007 still had succulent caudices and were counted as living, but most of these were dead by 2008.

Table 2. Total number of *Pediocactus knowltonii* counted at the Navajo Lake and BLM #1 transplant sites and percent of initial transplant population.

	Navajo No. 1		Navajo No. 2		BLM No. 1	
	N	%	N	%	N	%
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	61	41%	68	67%	69	46%
2003	65	43%	66	65%	67	45%
2004	62	41%	56	55%	64	43%
2005	57	38%	51	50%	62	42%
2006	20	13%	15	15%	57	38%
2007	Abandoned		Abandoned		59	40%
2008					48	32%
2009					48	32%
2010					50	34%
2011					51	34%

Stem Diameter

Approximately one quarter of the type locality population is made up of individuals with multiple stems that range from 2-15 heads. This characteristic has proved useful in recovery operations since these plants can be cloned by removing one of the heads to make separate plants. These clones can then be planted at other locations. Many of the transplants at the Navajo Lake and BLM transplant sites developed into multiple-stemmed plants as they aged (Table 3.). This characteristic is environmentally induced by stem damage or partial burial from sediment deposition.

Table 3. Percentage of multiple-stemmed *Pediocactus knowltonii* at the type locality and transplant populations.

	Type	Nav #1	Nav #2	BLM#1
1988	26.7	3.2		
1989	27.9	5.0		
1990	25.8	6.0		
1991	28.0	12.1		0
1992	28.6	16.8		1.0
1993	26.2	25.5		2.0
1994	27.3	25.5		3.5
1995	24.2	28.7		2.1
1996	21.9	34.8	0	5.3
1997	24.5	41.2	0	4.3
1998	21.8	38.6	2.6	5.6
1999	22.7	45.6	4.1	7.4
2000	22.4	42.6	12.7	7.5
2001	27.4	49.2	16.0	8.8
2002	24.2	45.9	17.2	14.5
2003	26.0	50.1	21.2	13.4
2004	32.9	59.7	30.4	23.4
2005	31.3	59.6	31.4	24.2
2006	38.1	50.0	26.7	21.1
2007	30.5	--	--	33.9
2008	29.8	--	--	35.4
2009	29.6	--	--	35.4
2010	30.8			40.0
2011	29.1			43.1

The collection of stem diameter data for Knowlton's cactus has questionable value since multiple-stemmed individuals preclude any useful comparison of individuals and size classes. All juveniles start out as single-stemmed plants, but by the time they are flowering adult size (10-

15 mm), they may or may not begin to develop the completely different morphology of multiple stems. As each individual ages, it is more and more likely to become multiple-stemmed. Stem diameter measures of single-stemmed plants do have value in identifying individual plants in the study plots and for some year and site comparisons.

The mean stem diameter of single stem plants at the type locality represents a normal population of all age classes with small seedlings and large, older cacti. This value should remain fairly constant at the type locality unless there is a shift in the age class structure of the population. The mean stem diameter at the transplant sites represents the growth rate of a single cohort that is maturing over time (Table 4). Few new seedlings are present at the transplant sites. Some yearly variation should be expected since soil moisture and stem turgidity will vary from year to year. For instance, 1996 and 2002 were extremely dry years and are reflected by smaller stem diameters at all sites.

Table 4. Mean diameters (millimeters) of single-stemmed *Pediocactus knowltonii* at the type locality and transplant sites.

Year	Type Locality	Navajo #1	Navajo #2	BLM #1
1991	13.3 (n=260)	15.2 (N=94)		11.4 (N=149)
1992	16.0 (n=273)	21.6 (N=89)		12.9 (N=137)
1993	15.8 (n=304)	27.9 (N=76)		18.5 (N=118)
1994	17.3 (n=333)	22.7 (N=73)		14.4 (N=110)
1995	15.2 (n=325)	23.7 (N=67)	11.3 (N=98)	16.0 (N=94)
1996	12.1 (n=217)	17.8 (N=45)	11.3 (N=76)	12.1 (N=76)
1997	14.4 (n=244)	22.7 (N=51)	14.9 (N=81)	16.4 (N=89)
1998	13.3 (n=258)	28.6 (N=46)	14.7 (N=74)	16.0 (N=85)
1999	14.4 (n=248)	22.6 (N=37)	15.5 (N=70)	17.8 (N=75)
2000	13.0 (n=228)	20.7 (N=39)	14.7 (N=62)	16.4 (N=74)
2001	15.4 (n=220)	22.4 (N=34)	16.5 (N=63)	20.8 (N=73)
2002	10.5 (n=172)	17.1 (N=33)	13.8 (N=58)	15.9 (N=59)
2003	13.3 (n=157)	19.6 (N=32)	15.7 (N=52)	17.4 (N=58)
2004	14.6 (n=154)	20.5 (N=26)	16.3 (N=39)	21.9 (N=49)
2005	15.6 (n=147)	25.0 (N=23)	22.6 (N=35)	25.1 (N=47)
2006	14.9 (n=133)	22.3 (N=10)	15.3 (N=11)	21.4 (N=45)
2007	15.6 (n=137)	--	--	23.4 (N=39)
2008	12.6 (n=133)	--	--	19.1 (N=31)
2009	14.8 (n=133)	--	--	21.4 (N=31)
2010	15.3 (n=140)	--	--	17.6 (N=40)
2011	15.8 (n=156)	--	--	24.7 (N=29)

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 diameter, single-stemmed, juvenile cacti from a 21-year reproductive comparison in Table 5.

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 51% of adult-size cacti, which was the greatest percentage for reproductive effort at that location during this 21-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 5. Reproductive activity of *Pediocactus knowltonii* at the type locality and transplant sites. (* Excludes < 10 mm, single-stemmed 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
2004	207	61	56	64

2005	204	57	51	62
2006	204	20	15	57
2007	182	--	--	59
	Type	Nav #1	Nav #2	BLM #1
2008	158	--	--	48
2009	169	--	--	48
2010	184	--	--	50
2011	198	--	--	51
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%)
2004	79 (38%)	30 (49%)	26 (46%)	40 (63%)
2005	72 (35%)	38 (67%)	31 (67%)	39 (63%)
2006	24 (12%)	3 (15%)	3 (20%)	19 (33%)
2007	33 (18%)	--	--	19 (32%)
2008	42 (27%)	--	--	24 (50%)
2009	41 (24%)	--	--	21 (44%)
2010	72 (39%)	--	--	30 (60%)
2011	63 (32%)	--	--	36 (70%)
Flowers/Flowering Plant				
1991	1.8	1.5		
1992	2.2	1.7		
1993	1.5	1.4		1.0
1994	1.8	1.5		1.0
1995	1.8	1.9		1.4
1996	1.4	1.0	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	1.0
2003	1.7	2.6	1.9	1.8
2004	1.9	2.4	1.7	1.9
	Type	Nav #1	Nav #2	BLM #1
2005	1.8	2.7	2.3	2.2
2006	1.3	1.7	1.0	1.6
2007	1.7	--	--	2.1
2008	1.3	--	--	1.7
2009	1.5	--	--	1.7
2010	1.7	--	--	2.4
2011	1.8	--	--	2.1

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 seedling 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 3 (17%) of these germinants remain as adult cacti in 2006 and no recruitment has been observed from any new seeds produced by adult cacti on this plot. This seed plot was abandoned in 2007.

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 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 were 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 of 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. A total of 48 cacti, or 43% of the plot population, were blooming in 2011. The 2002 total of 96 cacti represents a 4.3% establishment of the 2,250 seeds planted (Table 6). Six new seedlings were found in 2004, five new cacti were found in 2005, four in 2006, one in 2007, and three in 2008, three in 2009, five in 2010, and fifteen in 2011. The longevity of *P. knowltonii* seed in the soil seed bank is not known, but it seems most likely that the 2004 and subsequent years recruits are the offspring of reproductive cacti in the plots and not arising from seed planted in 1994.

Table 6. Numbers of *Pediocactus knowltonii* seedlings in three replicate plots at the BLM location. Each plot has No Treatment (NT), Brushed (Brus.) and Cultivated (Cult.) blocks.

	Plot #1			Plot #2			Plot #3			
	NT	Brus.	Cult.	NT	Brus.	Cult.	NT	Brus.	Cult.	SUM
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

2003	21	2	10	8	7	4	11	20	14	97
2004	20	2	10	6	7	4	13	24	14	100
2005	20	1	10	7	8	5	15	23	14	103
2006	20	1	10	7	8	5	15	23	15	104
2007	21	1	10	7	8	5	14	22	11	99
2008	20	1	10	7	6	4	15	20	13	96
2009	21	1	10	7	6	4	15	20	14	98
2010	20	1	9	9	7	4	16	20	13	99
2011	23	2	13	9	6	5	18	22	14	112

A 2005 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. The disturbance of the cultivated treatment was less visible by 2008; however, the severe erosion in the cultivated block of Plot 2 did not fully heal.

RECRUITMENT

Survival of Knowlton's cactus cuttings to the reintroduction sites has been surprisingly good, but cannot be considered a success until there are new cacti becoming established from natural reproduction in sufficient numbers to offset mortality. 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 No. 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 No. 1 site in 2003, ten years after the first reproductive efforts in this transplant population and another two new plants were located in 2008. To date, only six new cacti have been detected as new recruits to both BLM and Navajo transplant locations. Recruitment does not equal mortality at the transplant populations, and these continue to decline.

Recruitment at the seed plots was initially difficult to assess because 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 seeds planted in the plot. Over time the Navajo seed plot failed because it did not recruit any new individuals while the original germinants were gradually dying. The BLM seed plots, however, have maintain a relatively stable number of individuals over the last decade and is most recently exceeding mortality with recruitment of new individuals.

CONCLUSIONS

Twenty-five years of monitoring at the *Pediocactus knowltonii* type locality have demonstrated that this population slowly fluctuates in number. 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.

These monitoring data indicate a natural population that experienced a trend of increasing numbers during the late 1980s and early 1990s, and then a gradual and continuous decline to the lowest point recorded in 2008. The peak population of 1994 would be about 14,000 cacti, if the 1992 estimate of 12,000 plants was accurate. By this same 1992 benchmark, the monitoring plot data suggest a total population of only 6,100 cacti in 2008. This decline represented a confluence of low reproduction and predation by rodents or rabbits. 2009 to 2011 showed small gains in type locality population and may signal a reverse in the trend of continuous decline.

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 declined in numbers at the transplant sites over time and are not being replaced by new recruits. The entire transplant population at Navajo Lake suffered catastrophic decline from rodent predation in 2006 when there were only 35 scattered individuals remaining of the 252 cacti that have been planted there during the last 20 years. This transplant population declined since it was planted and has been abandoned and judged a failed effort. The BLM #1 transplant population has also been declining, but should continue to be monitored. Habitat characteristics at both the Navajo and BLM#1 locations are not identical to the type locality habitat. The sandy, somewhat drier soils at the Navajo transplant site eventually proved to be unsuitable for maintaining a population of this species.

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. After 13 years the small population in the seed plots at the BLM #1 location was stable with recruitment roughly equal to mortality until 2007 and 2008 which had net declines in number of cacti. Slight increases in numbers were found in 2009 to 2011 and appear to constitute a small, but stable or growing, population.

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 and 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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