Pediocactus knowltonii
(Knowlton's Cactus)

2013

Summary Report
(Section 6, Segment 27)

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INTRODUCTION

Pediocactus knowltonii L. Benson (Knowlton's cactus) 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 in 1961. It was listed endangered by U.S. Fish & Wildlife Service (USFWS) on October 29, 1979 (44 FR 62244). *Pediocactus knowltonii* 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 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 (USFWS 1985). Field trips were organized to salvage the cacti from the type locality. Several thousand *Pediocactus 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). The TNC Sabo Preserve was subsequently 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 *Pediocactus knowltonii* and approved by USFWS in March 1985. A reintroduction program into nearby 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 population dynamics of the natural population for comparison to the reintroduction 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 or partial shade between cobbles in the understory of sagebrush and conifers.

The only known natural habitat is the top and slopes of a single small hill within the TNC Sabo Preserve. *Pediocactus knowltonii* 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 1.0 cm, or more, in diameter. Individual stems produce on average one or two flowers (Sivinski 2011). 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 *Pediocactus knowltonii* plants 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-third of the natural population has 2-15 stems per plant.

Although there is no weather station in the immediate vicinity of the *Pediocactus knowltonii* study areas, the average annual precipitation at Aztec Ruins (ca. 25 miles SW of the type locality) is approximately 10 inches, ranging from 3 to 24 inches over a 96 year period (WRCC 2012). The majority of rainfall arrives during late summer and winter months. *Pediocactus knowltonii* is reproductively unusual for cacti since it initiates its flower primordia in the early autumn months, which over-winter as small buds. Therefore, spring flowering is greatly influenced by the condition of the plant during the previous growing season and the intervening winter months (Sivinski and McDonald 2007).

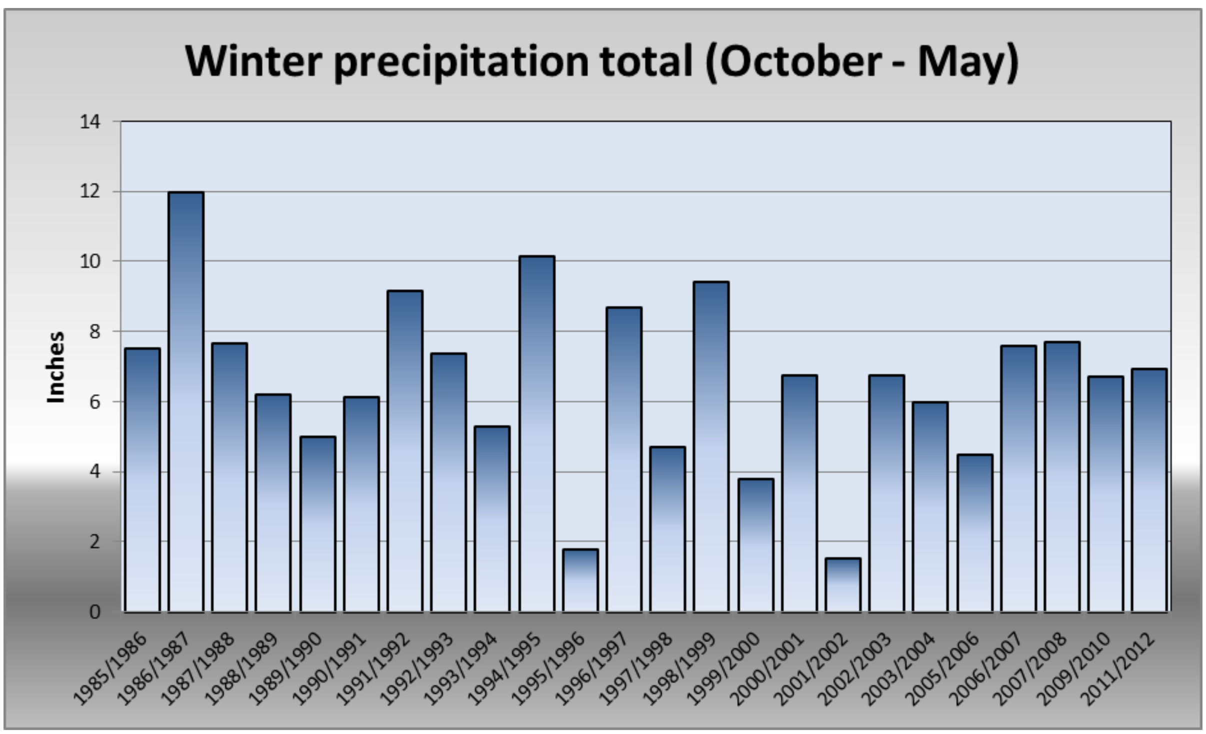

Figure 1. Winter precipitation from October through May at Navajo Dam, NM, from 1986 to 2012 (WRCC 2012). Years with insufficient data were omitted.

MONITORING PROGRAM

As of 2013 annual monitoring is taking place at

1. the TNC Sabo Preserve (1986 to present),
2. the BLM #1 Transplant Site (1991 – present),
3. the BLM #1 Seed Plots Site (1994 – present).

Two additional transplant sites (Navajo #1 and #2) were established in 1985 and 1995 respectively. Both Navajo sites were unsuccessful in maintaining populations and were abandoned in 2007.

Within monitoring plots individual cacti are tagged, then annually assessed for survival, plant diameter (mm) is measured and reproductive effort is recorded (# of flowers and fruits). Plants not found are recorded as missing (plant could not be located, 1st year), gone (plant could not be located for the second year), or dead (dead plant observed). Plants not observed for 3 consecutive years are considered dead. Newly found plants are tagged and measured along with the established cacti.

<u>TNC SABO PRESERVE (type locality, natural population dynamics monitoring)</u>

METHODS

Twenty-four randomly selected circular monitoring plots (4 m diameter) were established in 1986 at the natural population of *Pediocactus knowltonii* in the TNC Sabo Preserve (type locality) (Olwell *et al*. 1987). The plots had all conditions of slope, aspect, soil type, and plant community associated with the small hill at the type locality. Only 11 of these plots contained *Pediocactus knowltonii*. One of these occupied plots (including rebar and tags) was removed by cactus poachers in 1996 (Sivinski 1996). Therefore the final data set reported on consists of ten monitoring plots total. The center of each monitoring plot is marked by a rebar and an aluminum tag identifying the plot number. 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.

RESULTS

<u>Population Trend</u>

In 1989 monitoring was incomplete (only 5 of 11 plots were monitored) and was deleted from this analysis. In addition, 48 plants (all plot cacti) were poached between 1995 and 1996 from one of the monitoring plots. Therefore data collected prior to 1996 from this plot was not included in this analysis.

Overall, the number of plants within the 10 monitoring plots at the type locality has been declining over the past 27 years (Figure 2). Although the population trend initially increased by 78% from 1986 to 1994, it continuously decreased from 1995 to 2008 to a number below the original 1986 density (Figure 2). Plant numbers are gradually increasing since 2008 but have not yet returned to the number of plants initially found in the monitoring plots (231). The dry winter of 1995 to 1996 corresponded to a steep decline in plant numbers, which dropped by 27% within one year (Figures 1 & 2). However, the steep decline and increase between 1995 and 1997 was considered 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 might actually be more gradual than shown in Figure 2. A similar drought during 2001/2002 is considered the main cause of a steep decline in plant numbers in 2002 (Figures 1 & 2). The number of plants found in the monitoring plots decreased by 25% from 2001 to 2002 (Figure 2). Conversely, the sharp increase in the number of plants found in the monitoring plots in 1990 might reflect the establishment of seedlings during the unusually high rainfalls in the winter of 1986/1987 (Figure 1). Seedlings are commonly not detected for several years following germination due to their small size. In 2013, 216 plants were found within the ten monitoring plots.

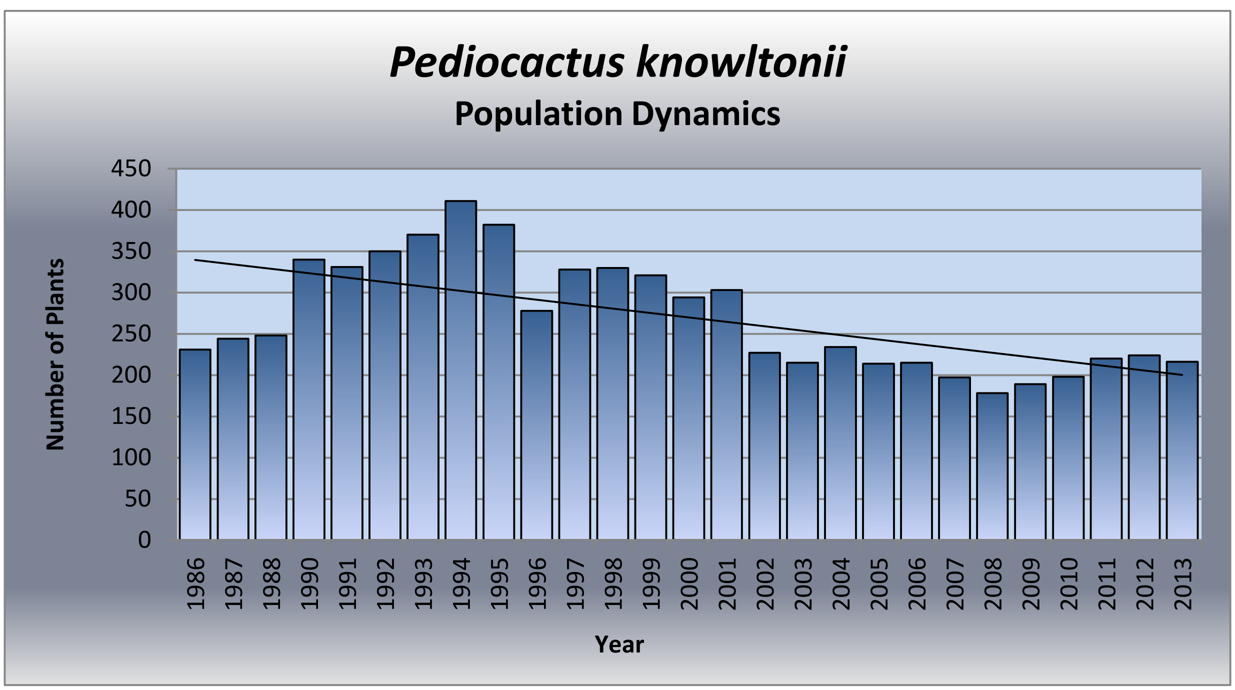

Figure 2. Number of *Pediocactus knowltonii* in 10 monitoring plots at the type locality in San Juan County, NM, 1986 - 2013.

Reproduction

Reproductive effort has been measured at the type locality since 1991. The average reproductive effort during the last 22 years, as measured by the percent of plants reproducing within the monitoring plots, was 30%, ranging from 4% at its lowest in 2002 to 51% at the highest in 1992 (Figure 3). Reproductive effort was lowest during the drought years of 1996 and 2002 (Figures 1 & 3). The total number of flowers and fruits produced in the 10 monitoring plots ranged from 10 (9 plants) in 2002 to 410 (180 plants) in 1994. In 2013, 47% of the 216 plants found were reproductive. 190 flowers and fruit were found on a total of 102 reproductive *Pediocactus knowltonii* plants.

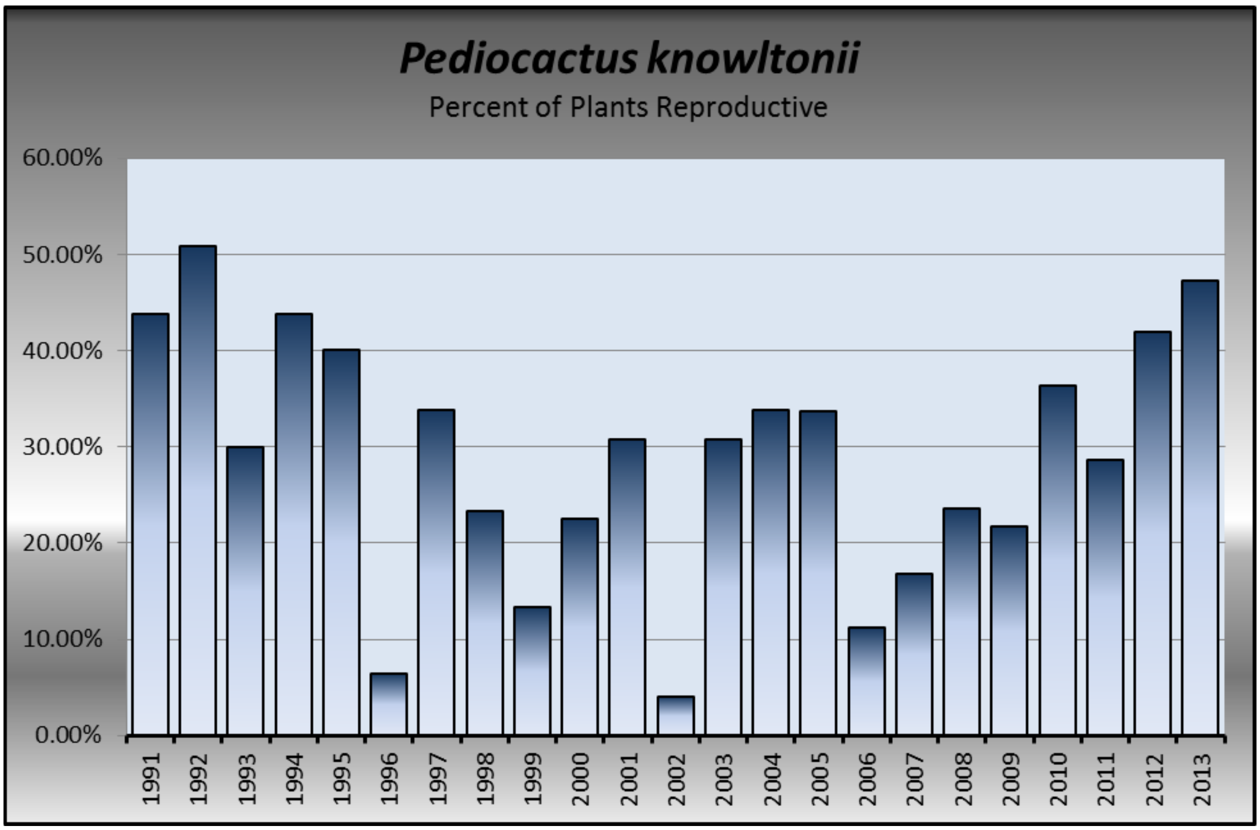

Figure 3. Percent of plants reproductive in 10 *Pediocactus knowltonii* monitoring plots in San Juan County, NM, from 1991 to 2013.

<u>Mortality and Recruitment</u>

Approximately 10 percent of the original 231 plants within the monitoring plots were alive in 2013. Since the majority of these survivors measured 10 mm or more in diameter in 1986 and were therefore at least several years old, it is estimated that *Pediocactus knowltonii* can live for at least 30 years in its natural habitat. Mortality and recruitment can fluctuate annually and among plots. Seedlings are small and are often not detected for several years following germination. Sixteen new plants were recorded in 2013. Thirty-eight plants were found missing (27) or gone (11). Two were found dead.

Drought conditions and the associated lower levels of reproduction and recruitment are likely the driving force behind the decline of this population (Figure 1). Although these small cacti are very drought tolerant, dry conditions can cause an increase in rabbit and rodent attacks, which are frequently fatal. Recruitment to this population is not consistent over time and many 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 after 1995. Recruitment has not offset mortality in the natural population during most years.

<u>Stem Diameter and Size Class Distribution</u>

The mean diameter of the natural population fluctuates somewhat between years, but was lowest during the drought years of 1996 and 2002 (Table 2). In 2013 the mean diameter of *Pediocactus knowltonii* in the natural population was 1.58 cm (Table 2).

The size class distribution at the type locality represents a normal population of all age classes including seedlings, reproducing adults, and fewer large, older cacti (Figure 5). This value should remain fairly constant at the type locality unless there is a shift in the age class structure of the population due to a germination or mortality event. The majority of individuals are young, reproducing adults, with a diameter of 1.1 – 2.0 cm (Figure 5). In 2013 approximately 14% of all plants in the natural population were seedlings or juvenile, non-reproducing plants less than 1.0 cm in diameter.

All juveniles start out as single-stemmed plants, but by the time they are flowering adult size (1.0-1.5 cm), they may begin to develop multiple stems in response to disturbance (Table 1). As each individual ages, it is more and more likely to become multiple-stemmed. Therefore the percentage of multi-stemmed individuals within a population can be an indicator of overall population age and disturbance levels. Individual stem diameter of multi-stemmed plants is not measured because they do not contribute to our understanding of age-class distribution. Currently approximately one third of the type locality population is made up of individuals with multiple stems that range from 2-15 heads (Table 1, Figure 5).

REINTRODUCTION PROGRAM

1. TRANSPLANTS

METHODS

A ten-mile radius south of the *Pediocactus knowltonii* type locality was searched in 1985 and again in 1991 for suitable habitats that are similar to the natural habitat of this species (Ecosphere 1985; Olwell *et al.* 1987, Sivinski 1992). Suitability criteria were cobbley substrates in piñon-juniper woodland with a dominant shrub component of black sagebrush. Two locations were selected as suitable 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 (Olwell *et al.* 1987). 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. This site was supplemented with another 102 cuttings planted on the south side of this grid in the early spring of 1995 (Sivinski 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 Lightfoot 1992). Parent plants used for the 1991 cuttings were marked so that they could be monitored for any mortality that resulted from the stem cut. 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.

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 sites 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:

	1A2		
1A5	1A1	1A3	
	1A4		etc.

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 success and seed set.

RESULTS

Impacts of Cloning Operations

Unfortunately 40 of the 250 aluminum tags placed with the parent plants in 1991 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 parent plants were still alive, resulting in 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 cloning operation.

Population Trend

Navajo #1 & #2

The Navajo #1 and #2 transplants slowly dwindled away, without significant recruitment. The entire transplant population catastrophically declined in the winter of 2005/2006, when rodent or rabbit predation killed most of the plants remaining at the Navajo Lake transplant location (Figure 4) (Sivinski 2006). This was the most severe level of predation observed at this location during the 20 years it had been monitored. Only 3 seedlings were found in the Navajo #1 & #2 transplant sites in the 20 years of monitoring. The first evidence of recruitment was a single seedling found in 2002 at the Navajo #1 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. By 2007 only 35 scattered individuals of the original 352 plants remained in the Navajo #1 and Navajo #2 transplant sites. Both sites were abandoned in 2007 (Sivinski 2007).

BLM #1

The transplanted population of 149 individuals slowly declined between 1991 and 2008 within the BLM #1 transplant site (Figure 4). During the first winter after the September 1991 planting, approximately one third of the cacti were frost-heaved from the ground (Sivinski and Lightfoot 1992). 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 #1 & #2 sites, 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 dry winter of 1995/1996 likely contributed to steep declines at all three transplant sites, as well as the type locality (Figures 1, 2, & 4).

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 (Figure 4). The BLM # 1 transplant site has been stable or is slightly increasing since 2008. In 2013, 52 plants were recorded in the BLM #1 transplant site.

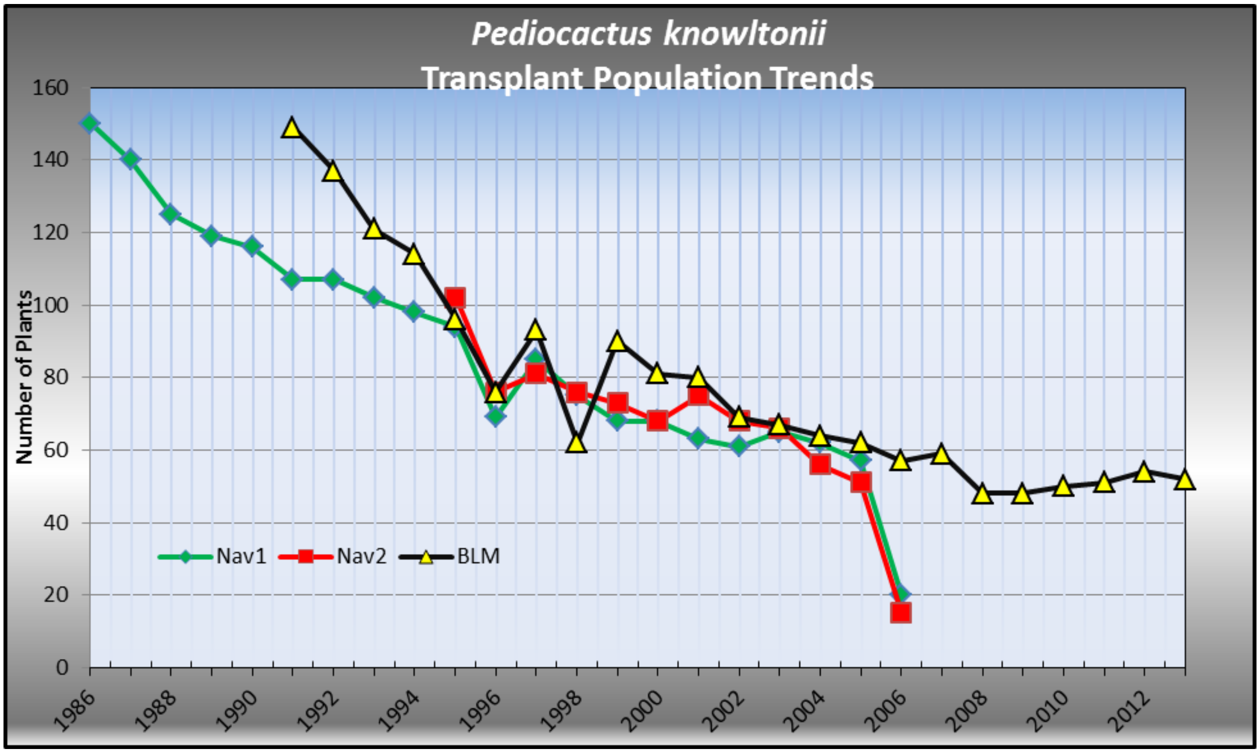

Figure 4. Total number of *Pediocactus knowltonii* plants at three transplant sites in San Juan County, NM.

Stem Diameter and Size Class Distribution

The mean diameter of *Pediocactus knowltonii* plants at the BLM transplant sites steadily increased for the first 10 years after the original transplant in 1991, then stabilized between 2 and 2.5 cm (Table 2). It fluctuates somewhat between years, but was lowest the during drought years of 1996 and 2002, which is consistent with results from the Navajo sites and the naturally occurring plants at the type locality. In 2013 the mean diameter of *Pediocactus knowltonii* at the BLM transplant site was 2.00 cm, which is considerably larger than the mean diameter at the type locality (Table 2).

Many of the transplants at the Navajo and BLM transplant sites developed into multiple-stemmed plants as they aged (Table 1, Figure 5). The development of multi-stems is environmentally induced by stem damage or partial burial from sediment deposition. 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.

Although the size class distribution at the BLM transplant site still follows a normal curve with the majority of individuals placing into the young reproducing adult size class of 1.1 – 2.0 cm in diameter, the curve is skewed towards larger, older individuals and multi-headed plants (Figure

5). Twenty-two years after the transplant effort, the percentage of large and multi-stemmed individuals at the BLM #1 transplant site is highest (33%) among the three monitored populations (type locality, transplants, seed plots) while the percentage of small, juvenile individuals (< 1.0 cm in diameter) remains well below the type locality values, indicating an aging population with little recruitment (Table 1, Figure 5). This is also indicated in the larger mean diameter of single stemmed plants for all three monitored sites.

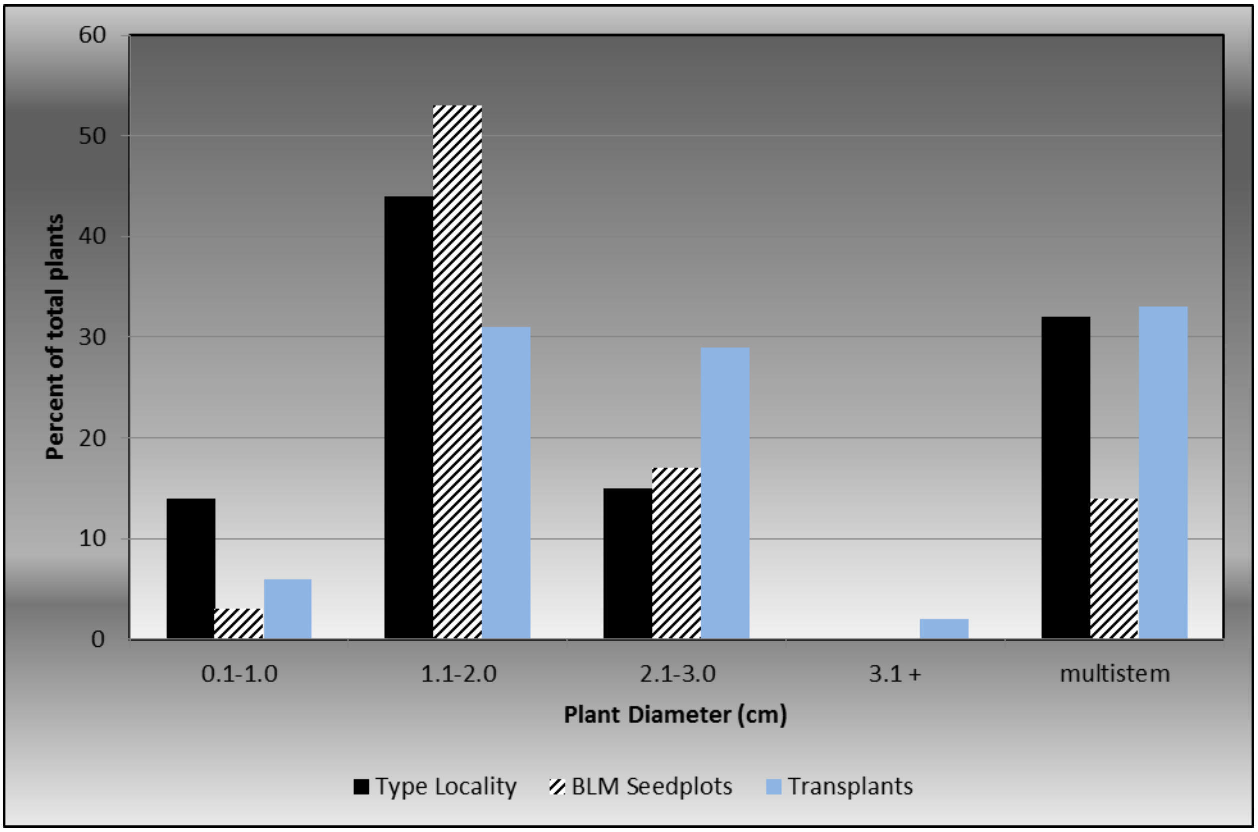

Figure 5. Size class distribution of *Pedicoactus knowltonii* populations at the type locality, BLM seed plots, and BLM #1 transplant monitoring sites in 2013.

Table 1. Percentage of multiple-stemmed *Pediocactus knowltonii* at the type locality and transplant populations from 1991 to 2013.

Year	Type Locality	Navajo #1	Navajo #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
2012	32.1	--	--	39.6
2013	31.5	--	--	32.7

Table 2. Mean diameters (centimeters) of single-stemmed *Pediocactus knowltonii* at the type locality and transplant sites from 1991 to 2013.

Year	Type Locality	Navajo #1	Navajo #2	BLM #1
1991	1.33 (n=260)	1.52 (N=94)	--	1.14 (N=149)
1992	1.60 (n=273)	2.16 (N=89)	--	1.29 (N=137)
1993	1.58 (n=304)	2.79 (N=76)	--	1.85 (N=118)
1994	1.73 (n=333)	2.27 (N=73)	--	1.44 (N=110)
1995	1.52 (n=325)	2.37 (N=67)	1.13 (N=98)	1.60 (N=94)
1996	1.21 (n=217)	1.78 (N=45)	1.13 (N=76)	1.21 (N=76)
1997	1.44 (n=244)	2.27 (N=51)	1.49 (N=81)	1.64 (N=89)
1998	1.33 (n=258)	2.86 (N=46)	1.47 (N=74)	1.60 (N=85)
1999	1.44 (n=248)	2.26 (N=37)	1.55 (N=70)	1.78 (N=75)
2000	1.30 (n=228)	2.07 (N=39)	1.47 (N=62)	1.64 (N=74)
2001	1.54 (n=220)	2.24 (N=34)	1.65 (N=63)	2.08 (N=73)
2002	1.05 (n=172)	1.71 (N=33)	1.38 (N=58)	1.59 (N=59)
2003	1.33 (n=157)	1.96 (N=32)	1.57 (N=52)	1.74 (N=58)
2004	1.46 (n=154)	2.05 (N=26)	1.63 (N=39)	2.19 (N=49)
2005	1.56 (n=147)	2.50 (N=23)	2.26 (N=35)	2.51 (N=47)
2006	1.49 (n=133)	2.23 (N=10)	1.53 (N=11)	2.14 (N=45)
2007	1.56 (n=137)	--	--	2.34 (N=39)
2008	1.26 (n=133)	--	--	1.91 (N=31)
2009	1.48 (n=133)	--	--	2.14 (N=31)
2010	15.3 (n=140)	--	--	1.76 (N=40)
2011	1.58 (n=156)	--	--	2.47 (N=29)
2012	1.64 (n=151)	--	--	2.05 (N=33)
2013	1.58 (n=148)	--	--	2.00 (N=35)

Mortality and Recruitment

Establishing a new population from cuttings cannot be considered a success until new cacti are becoming established from natural reproduction in sufficient numbers to offset mortality. Few new seedlings have been found at the transplant sites. New plants are difficult to find until they reach sufficient size to be readily seen by researchers. The first seedling was found in 2003 at the BLM #1 site, ten years after the first reproductive effort in this transplant population. In 2013 six new plants were located within the plots, eight plants were missing, 9 were gone (likely dead) and none of the plants were found dead. To date, only 12 cacti have been detected as new recruits to the BLM transplant locations.
Transplanted populations have a lower percentage of recruits (≤ 1.0 cm in diameter) and the highest percentage of large and multi-stemmed plants, indicating an aging population with little recruitment (Figure 5). Recruitment does not equal mortality at the transplant populations, and these continue to decline.

Reproductive Effort

Pediocactus knowltonii 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 fruits at the type locality and transplant sites (Table 3).

The percentage of reproductive plants within transplant populations has generally been higher than in the natural population at the type locality (Table 3). The highest percentage of reproductive plants for the BLM transplant site was 70% in 2011. The highest percentage of plants reproducing in the natural population was 54% in 2013. This can be attributed to the higher number of non-reproductive juveniles found within the natural population. Even with the type locality data modified to exclude all < 1.0 cm diameter, single-stemmed, juvenile cacti, the percentage of reproductive individuals remains higher among transplanted plants. Transplants are cohorts of aging adults while the natural population contains all age classes. Reproductive effort is highest among older & larger plants than among juvenile & smaller plants.
In 2013, 60 flowers and fruits were found on 27 plants larger than 1.0 cm in diameter and multi-stemmed individuals.

Table 3. Number and percentage of *Pediocactus knowltonii* plants in flower above 10 mm at the type locality and transplant sites from 1991 to 2013.

Year	Type Locality	Navajo #1	Navajo #2	BLM #1
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%)
2012	94 (47%)	--	--	29 (56%)
2013	101 (54%)	--	--	27(55%)

2. <u>SEED PLOTS</u>

METHODS

Direct seeding to the soil was attempted outside the transplant grids at both the Navajo Lake and BLM locations in 1987 and 1994 respectively (Knight and Cully 1987; Sivinski 1994). Very little *Pediocactus knowltonii* 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 the two seeding trials were obtained from greenhouse-grown plants.

In the fall of 1987, 288 seeds were planted at the Navajo Lake Seed Plot (Knight and Cully 1987). 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. In an effort to determine whether there was a difference in germination and establishment based on the location of the seed in the soil, 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.

Another seed plot was established at the BLM #1 site in January 1994 (Sivinski 1994). A total of 2,250 *Pediocactus 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 0.5 cm and a small amount of blasting sand was poured on each planting hole to control erosion. The purpose of seedbed treatment experiments was to determine whether seed germination and establishment differed between treatments and to get a better understanding of optimum germination and establishment requirements.

RESULTS

Navajo Lake Seed Plot

The Navajo Lake 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 *Pediocactus knowltonii* seedlings were located (Sivinski 1992). 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 did 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 288 seeds planted (Sivinski 1997). Only 3 (17%) of these germinants remained as adult cacti in 2006 and no additional recruitment was observed in this plot between 1997 and 2006. This seed plot was abandoned in 2007 (Sivinski 2007).

BLM Seed Plot

Population Trend

Six month after seeding 2,250 seeds a total of 12 seedlings were observed within the BLM Seed plots (Table 4, Figure 6). The new seedlings were very tiny and most did not survive the unusually hot summer of 1994 (Sivinski 1995). 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 (Sivinski 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 (Sivinski 1998). This represents a significant number (45%) of previous year's seedlings that failed to become established. The number of plants surviving in the plots and the number of new recruits increased through spring 2001. In 2002 there was a marked drop-off in the number of new plants within the monitoring plots (Figure 6). This was likely related to the drought of 2001/2002 (Figure 1). Fewer plants and no new recruits were found within the plots in 2013 (Figure 6). This may be related to the unfamiliarity of the surveyors with the study design and needs to be reevaluated in 2014.

Recruitment

The 2001 total of 92 cacti represents a 4.1% establishment of the 2,250 seeds planted. Since 2002, recruitment and establishment have been substantially less compared to previous years, with the largest number of new plants found in 2011 (15 new plants) (Figure 6). In 2013, there were no new plants found in the three study plots. No dead plants were found.

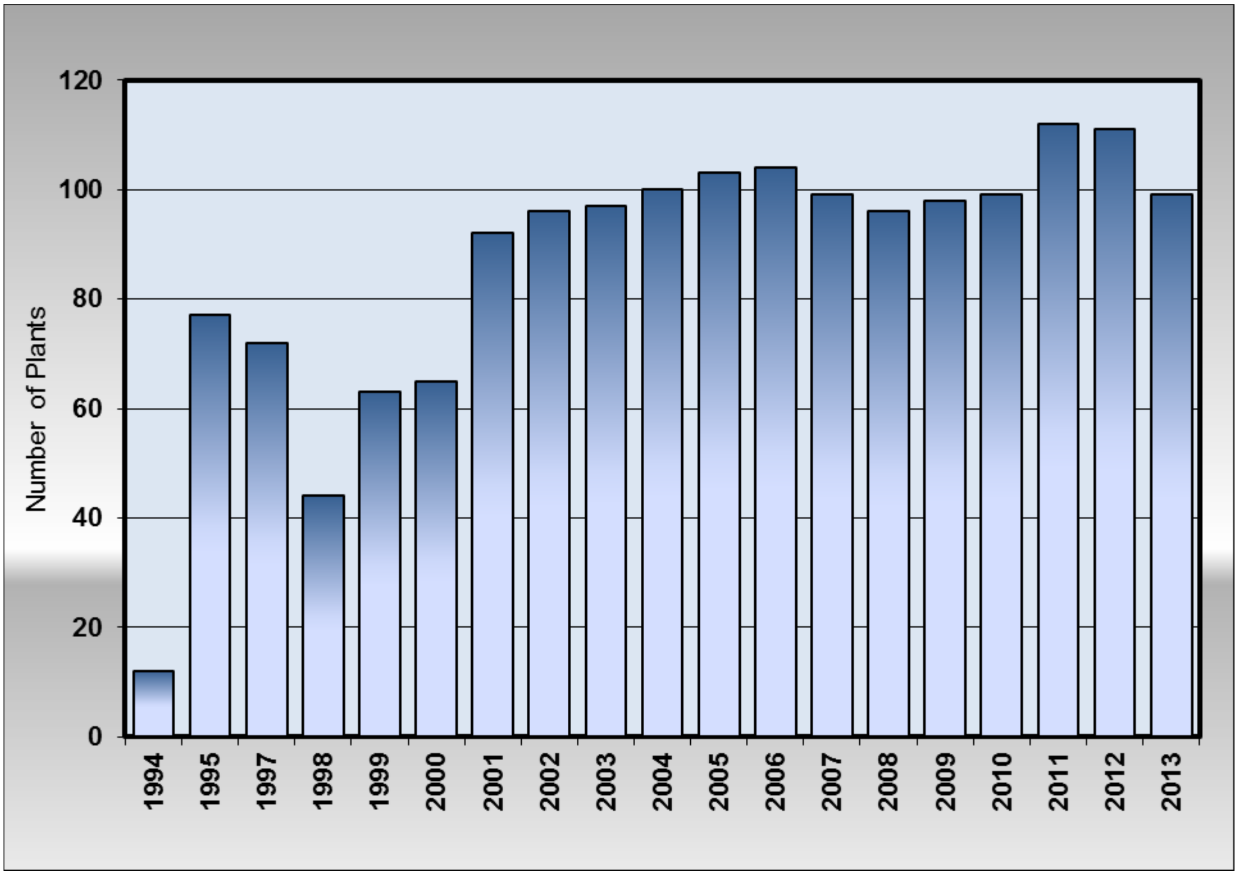

Figure 6. Number of *Pediocactus knowltonii* plants started from 2,250 seeds at 3 BLM seed plots in San Juan County, NM.

<u>Size Class Distribution and Stem Diameter</u>

Analysis of diameter size class distribution of plants growing from seeds shows that 19 years after planting, the distribution of size classes is approaching the general distribution of a natural occurring populations, although the percentage multi-stemmed individuals remains lowest among the three monitored populations (Figure 5). The majority of plants are located in the young adult size class of 1.1 – 2.0 cm, which is consistent with results from the type locality and transplanted populations. In 2013 the mean diameter of *Pediocactus knowltonii* plants in all 3 BLM seed plots was 1.61 cm, which is similar to the mean diameter to plants in the natural population at the type locality (1.58 cm).

Reproductive Effort

The first flowering plant was found in the monitoring plots in 2000, six years after seeding (Figure 7). The percentage of plants reproducing in the BLM Seed Plots has increased steadily since and has surpassed the percentage of reproducing plants in the natural population in all years since 2005, except 2012 and 2013. Fifty-seven flowers and fruits were produced by 39 reproductive plants in 2013.

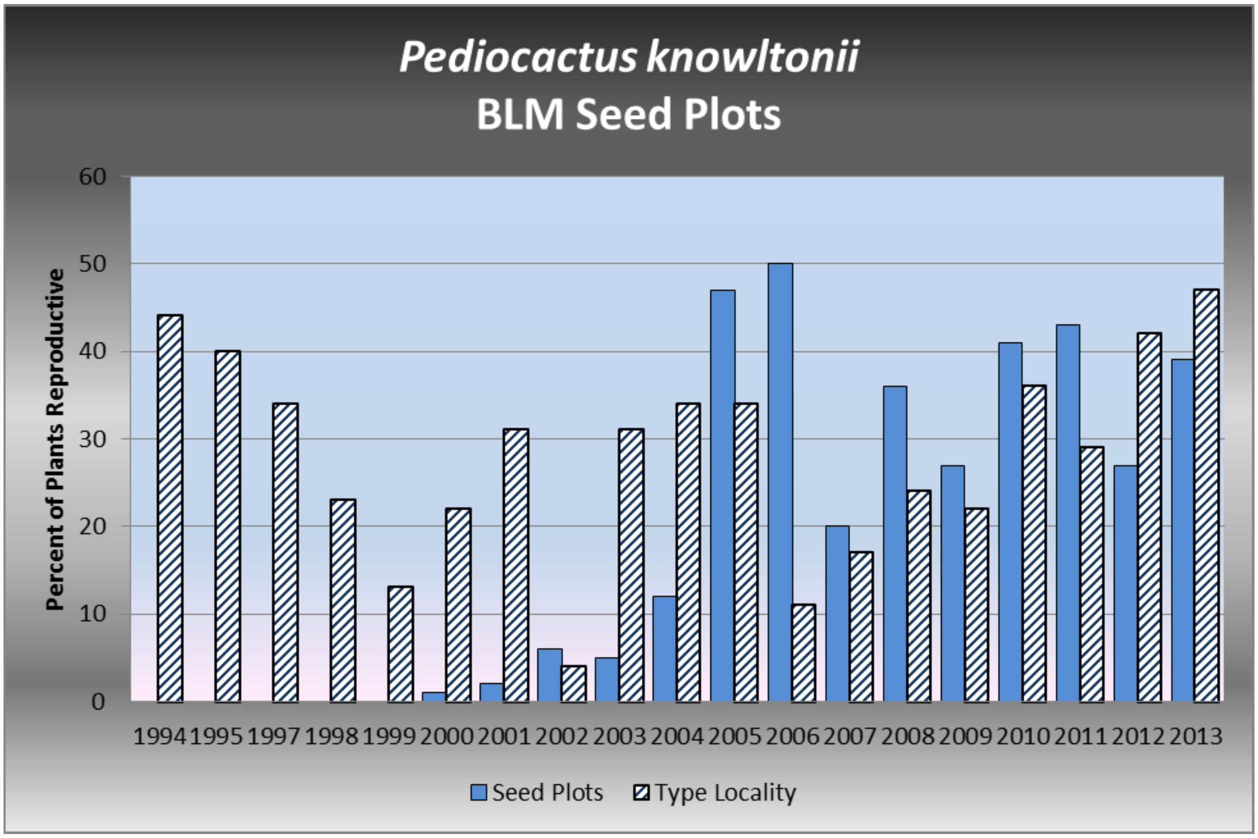

Figure 7. Percent of *Pediocactus knowltonii* plants reproducing at the natural population (type locality) and the BLM Seed Plots from 1994 to 2013.

Treatment Results

In 2005, eleven years following seeding and plot treatment, an analysis of variance for the random block design of this experiment showed no significant differences in the number of plants between plot treatments (F=2.88 with 2 and 4 degrees of freedom)(Table 4)(Sivinski 2005). Seedbed preparation is unnecessary and will, in fact, increase soil erosion when seed plots are placed on a slope.

Table 4. Total number of *Pediocactus knowltonii* seedlings in three replicate plots at the BLM Seed Plot site. Each plot has No Treatment, Brushed, and Cultivated blocks.

	No Treatmet	Cultivated	Brushed
1994	8	2	2
1995	36	31	10
1997	26	23	23
1998	17	21	6
1999	24	23	16
2000	28	20	17
2001	38	30	25
2002	38	29	29
2003	40	28	29
2004	39	28	33
2005	42	29	32

CONCLUSIONS

Although the number of *Pediocactus knowltonii* plants in the monitoring plots fluctuates from year to year, the overall trend after 27 years of monitoring at the type locality is a slow decline. This trend is consistent with other species of *Pediocactus* monitored on the Colorado Plateau (Clark & Clark 2008, Hazelton 2011, Phillips & Phillips 2004, Roth 2008, USFWS 2012). Declining trends are largely attributed to prolonged drought impacts and global climate change. Climate change impacts may include changes in pollinator availability and therefore successful pollination among *Pediocactus* plants, increase in predation by beetles and rodents, desiccation, increased resource competition of seedlings with annual invasive species during years of high rainfall, decreased reproductive effort and therefore decreased germination and establishment.

The natural population increased in numbers during the late 1980s and early 1990s, and then gradually declined 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. The decline represents a confluence of low reproduction and recruitment, likely influenced by drought conditions, and predation by rodents or rabbits. Small gains in the number of plants since 2009 at the natural population and may signal a reverse in the trend of continuous decline.

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. No further acts of vandalism have been observed since.

Survivorship and reproductive effort of *Pediocactus knowltonii* 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. However, transplanted clones comprise an aging population with little or no recruitment. These plants are relatively long-lived for small cacti, but as they decline in numbers through time they are not being replaced by new recruits. The entire transplant population at Navajo Lake suffered catastrophic decline from rodent predation in 2006 and the transplant population was abandoned and judged a failed effort in 2007. The BLM #1 transplant population has also been declining through 2008, but appears to be stable or slightly increasing over the past 5 years.

Direct seeding into new locations is a viable alternative 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. In addition, a large quantity of seed is required to ensure adequate germination and establishment. Plants in the BLM seed plots are moving towards a natural size class distribution similar to the natural population. 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 since 2009 appear to constitute a small, but stable or growing, population.

The longevity of *Pediocactus knowltonii* seed in the soil seed bank is not known, but it seems likely that seed viability of the original seeds planted declined after 8 years in the ground. Although subsequent years' recruits are likely supplemented by the offspring of reproductive cacti in the plots, the percentage of plants in the seedling/juvenile size class has been highest in the seed plots over the natural population and transplanted populations, except for 2013. Therefore it is possible that at least some of the original 1994 seeds may continue to contribute to the population of newly recruited individuals in the BLM seed plots. A seed bank viability study to establish how long seeds can persist in the soil in their natural environment would shed further light into our understanding of recruitment levels. In addition, it would be helpful to know what percentage of *Pediocactus knowltonii* seeds are viable and therefore contribute to the viability of the seed bank. If a large percentage of seeds are not viable, what is the cause? Lack of pollinators or pollination success? Inbreeding depression? Similarly, what percentage of seeds are carried off by seed predators and therefore become lost to the population?

Whether establishing new populations of *Pediocactus knowltonii* by transplanting clones or direct seeding can be successfully accomplished has yet to be seen. Natural recruitment to these new populations has been an exceedingly slow process. Overall, it appears that that direct seeding large quantities of seeds is more likely to succeed in establishing self-sustaining populations than those started from clones.

After many years of studying the feasibility of transplanting clones and seeding plants directly into habitat we have some understanding of the complexities of establishing new populations. Low levels of recruitment appear to be the largest threat to the natural and experimental populations. Further studies are needed to understand the root causes low recruitment levels, including pollinators and pollination success studies, climate change impact studies, seed and seed bank viability studies, and genetic studies to analyze for potential deleterious effects caused by inbreeding depression.

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