Five-Year Monitoring Study of Siler's Pincushion Cactus (*Pediocactus sileri*) in Kane County, Utah

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Abstract: Siler's pincushion cactus (*Pediocactus sileri*) occurs primarily on Bureau of Land Management (BLM) lands in Washington and Kane Counties in southwestern Utah and across the border in northwestern Arizona. This 5 year (1993–1997) monitoring study was set up as a challenge cost-share project between Red Butte Garden and the Utah State BLM Office in Salt Lake City. A permanent study plot was established about 10 miles east of Kanab, in Kane County, to annually monitor growth, reproduction, recruitment, mortality, and threats to the species. The cactus grew an average of 0.42 cm in height and 0.33 cm in width per year. Plants were about 10 years old before they produced fruit. Four demographic patterns were observed: (1) the total number of individuals nearly doubled, (2) the average annual recruitment rate was approximately four times greater than the average annual mortality rate, (3) the population appeared young, vigorous and viable, and (4) the cactus population may have responded to above-normal precipitation at the study site. Livestock and off-road vehicle tracks were observed in the study area but apparently are not major threats to the species. The Kane County population may be the most viable of all the populations currently under study in Utah and Arizona.

Siler's pincushion cactus (*Pediocactus sileri*) has been listed as endangered by the U.S. Fish and Wildlife Service since 1979 under the Endangered Species Act of 1973 (U.S. Fish and Wildlife Service 1979). Most of the known or potential cactus habitat is managed by the Arizona Strip and Cedar City BLM Districts (U.S. Fish and Wildlife Service 1993a). It is BLM policy to implement appropriate conservation programs for endangered, threatened, and other sensitive plant species ("special status species") that occur on their lands. To accomplish that goal, the BLM has extensively studied the species in-house and under contract for 20 years (Bureau of Land Management 1985, 1987, 1990a, 1990b, Cormier 1985, Gierisch 1980, 1981, 1989, Gierisch and Anderson 1980, Hughes 1991, 1996, 1993–1998, Swapp 1985, Woodbury 1985).

Since it was listed as endangered, botanists hired by the U. S. Fish and Wildlife Service (Phillips et al. 1979) have also studied the species. After careful consideration of current information on the species, the U.S. Fish and Wildlife Service (1993a) proposed to downlist the cactus species to threatened, provided that the following five criteria could be met: "(1) known populations should be censused and mapped, (2) the BLM should establish permanent monitoring plots that are surveyed annually, (3) the BLM should develop an approved habitat management plan which includes steps to ensure the protection of the species, (4) the BLM should develop a mineral feasibility report assessing the present and potential value of the cacti's habitat for mining of gypsum, selenites and uranium and (5) the BLM should administer mining claims within known populations, mitigate adverse affects and initiate Section 7 consultations when necessary."

To meet the first two reclassification criteria listed above, the BLM entered into a cost-share agreement with Red Butte Garden to conduct an in-depth distribution and demographic survey of Siler's pincushion cactus on BLM lands in Washington and Kane Counties, Utah (Hreha and Meyer 1994). Red Butte Garden established a monitoring plot at Muggins Flat about 10 miles east of Kanab in 1993. Since the study was initiated, the U.S. Fish and Wildlife Service (1993b) has downlisted the species from endangered to threatened. This is the final summary of that monitoring study and is supplemental to the study by Hreha and Meyer (1994).

The species has been monitored at the Warner Ridge population in Washington County, southwestern Utah and in northwestern Arizona at the Atkin Well, Johnson Springs, and Yellowstone populations since 1985. However, no monitoring studies had been conducted at Muggins Flat, the only known location of the cactus in Kane County, Utah. Therefore, a permanent plot was established at Muggins Flat to monitor cactus population parameters such as growth, reproduction, recruitment, mortality, and impacts to the species (Lesica and Steele 1997). The results of the Muggins Flat study, along with data gathered at the other monitoring plots established by the BLM throughout the range of this threatened cactus in both southern Utah and northern Arizona, will be used by the BLM to establish management guidelines for this species and its habitat.

Even after the species was downlisted, the Bureau of Land Management has continued to monitor populations on BLM lands at Muggins Flat and Warner Ridge in southern Utah and at Atkin Well, Yellowstone, and Johnson Springs in northern Arizona. Bureau of Land Management efforts are directed toward restoring habitat and stabilizing or increasing populations to the point that the provisions of the Endangered Species Act will no longer be necessary (U.S. Fish and Wildlife Service 1986, Bureau of Land Management 1987).

Methods

A 0.25 hectare plot was established at Muggins Flat about 10 miles southeast of Kanab, Utah. The plot was 50 m square and was divided into 100 subplots of 5 sq m each. Monitoring was initiated in 1993. Cacti occurring on the plot were tagged and numbered in 1994. Annual monitoring was conducted at the end of the growing season, usually at the end of September, and continued through the 1997 field season. Cactus height, width, age, vigor, reproductive status, threats, and damage were recorded annually for all tagged cacti. Vigor was assessed by subjective observation: dead, poor, fair, good, or excellent. Recruitment and mortality were also tracked for the duration of the study. New recruits were tagged and numbered the year they were first observed on the plot.

Results

Population Structure

The trend in the monitoring plot was generally toward shorter (< 1.9 cm) rather than taller (> 6.0 cm) cacti. Most (41.9%) cacti on the plot fell into the shortest height class, made up almost entirely of new recruits. The percentage of individuals in the recruitment class ranged from 28.5 to 53.3 percent of the population over 5 years. The recruitment class made up more than half (53.3%) of the population in 1995.

Most cacti (34.2%) in the plot were between 2.0 and 3.9 cm wide, and a few (5%) cacti were more than 8.0 cm wide. The remaining three width classes had about equal representation in the population at about 20 percent.

To evaluate and better compare size classes of the cacti, height and width were combined to estimate volume for each individual. Cactus volumes were calculated using the formula for a cylinder:

$$\text{Volume} = ((1/2 \text{ width})2 \times p) \times \text{height}.$$

Plant volumes were graphed as histograms on a semi-log scale to better illustrate the smallest size class and to show size distribution (from 10 to 1400 cubic cm) in the population (Figure 1).

Size class distribution was relatively stable from year to year. The general trend in cactus architecture tended to be toward short/slender rather than taller/stouter plants, representing a demographic shift toward the juvenile recruitment class and away from the mature senescent class.

The histograms show a gradual increase in size for each successive year as cohorts grew into the next size class. The smallest size class usually held the greatest proportion of the plants due to recruitment. Assuming that larger plants were generally older than smaller plants, Figure 1 also shows that the population was mostly younger rather than older plants.

Average growth rates were calculated by using increases in height and width measurements for tagged individuals on the plot. The increases in these measurements over the last 3 years of the study were tallied and an average was calculated for each parameter. Growth rates were relatively stable from 1993 through 1997. Some individuals occasionally decreased in size, probably due to shrinkage after a period of little or no rain.

Phillips and Phillips (1996) found that *Pediocactus peeblesianus* var. *peeblesianus* retracted beneath the soil surface in June after seed set and did not resurface until the fall. Hughes (1996) reported that larger individuals of *P. sileri* retracted underground less frequently than smaller individuals, but larger individuals did retract underground during long dry spells.

Cactus age classes were estimated using methods similar to those used by Culley et al. (1993) and Gibson and Nobel (1986). In both of these studies, each height class was converted into an age class based on observation of growth rates and onset of reproduction.

The average height growth rate for *P. sileri* in our study was 0.42 cm per year and the average width growth rate for cactus was 0.33 cm per year during the study. For convenience, we used the

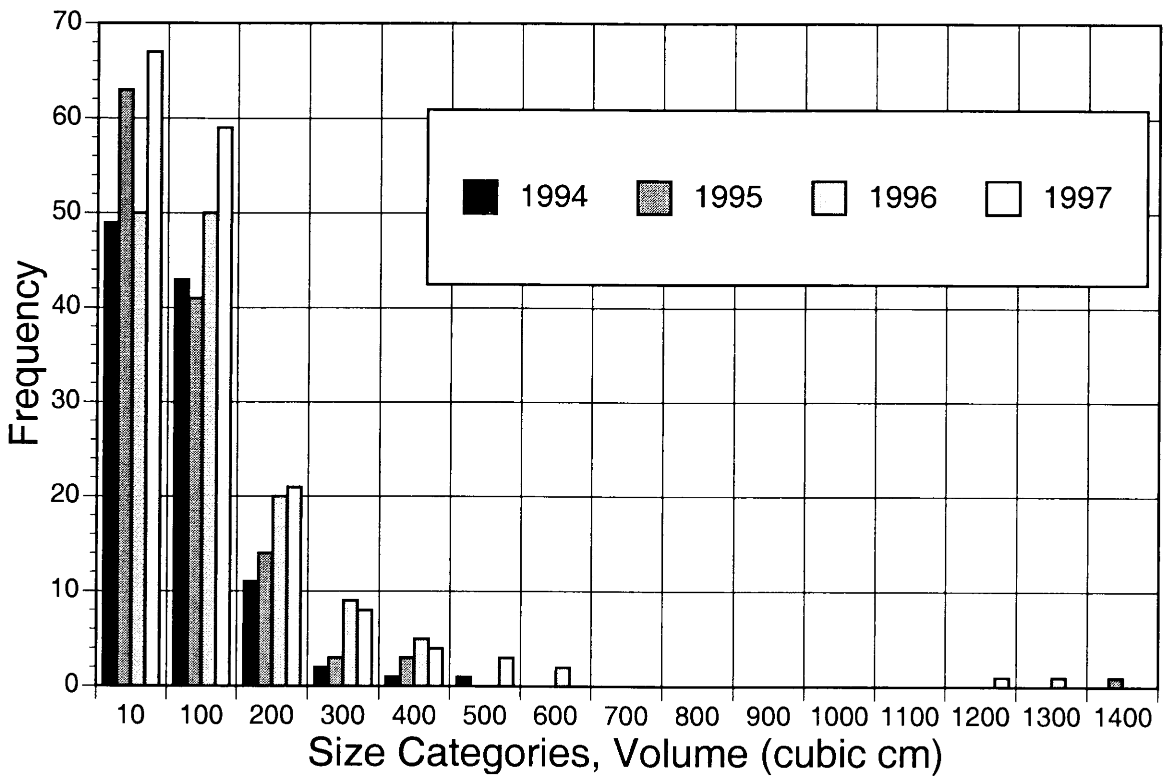

Figure 1. *P. sileri* plant size based on cylindrical volume calculated as a function of the width and height of all plants observed for each year (volume = $\pi(1/2 \text{ width})^2 \times$ height). The chart uses a semi-log X-axis for the smallest size category in the range of 0 to 100 cubic cm, to better illustrate that size category. Thereafter, the size categories are linear. The Y-axis shows frequency (percentage) of individual plant stems in each size category. The smallest size cohort holds the greatest number of individuals, due presumably to seedling recruitment. A single very large individual tripled in volume between 1994 and 1995.

average height growth rate of 0.5 cm per year to calculate the age estimates reported here. For example, a cactus that was 2.0 cm tall would be about 4 years old. Juveniles were probably 1–4 years old, and intermediate aged cacti were probably 4–8 years old. Mature cacti were probably more than 8 years old.

Phillips and Phillips (1996) reported that *Pediocactus peeblesianus* var. *peeblesianus* took about 8 years to reach sexual maturity. We also estimated that *P. sileri* might take 8 years to reach sexual maturity by using the shortest (4 cm) fruiting cacti on the plot. The average fruiting age was about 10 years and was calculated by using the average (5.35 cm) height of fruiting cacti on the plot. Individuals may live at least 26 years and evidently may produce fruit for about 16 years. We calculated this age by using the tallest fruiting individual (13 cm) on the plot.

We tallied almost twice as many juvenile (38.8%) and intermediate (35.8%) age cacti as mature (20.8%) cacti; nearly 75% of the population was younger, non-reproductive plants. The average recruitment rate (38.8%) of individuals into the juvenile age class was approximately 10 times greater than the average mortality rate (4.4%) observed during the study.

Reproduction

The number of fruiting plants on the plot ranged from 11 to 17, and the average over the 5-year period was 15 plants. The percentage of fruiting plants on the monitoring plot dropped from 19 percent in 1993 to 8 percent in 1997. This proportional decrease in fruiting individuals was due, however, to the increase in new recruits over the course of the study. As new recruits were added to the population, the population base number rose and consequently the percentage of reproductive individuals in the population decreased. This shift from larger to smaller individuals suggested that the proportional reproductive potential of the species was temporarily reduced.

The actual reproductive output did not decrease, as evidenced by the fairly constant number of plants fruiting each year (about 33–50% of the reproductive plants fruited each year; 11–18 plants out of a cohort of 28 plants over the 5-year study period). As smaller (younger) individuals reach reproductive maturity, the reproductive potential of the population may gradually increase over time.

The average number of fruits produced per year on the monitoring plot was 38.6 and the average number of fruits per fruiting plant was 2.61. The number and the timing of flowering, along with differences in fruit production per individual plant, were probably due to moisture availability. Cacti may have to achieve a certain size before they have enough water to sustain flowering and subsequent fruit development (Gibson and Nobel 1986). Hughes (1996) reported that high fruit production years coincided with years of above-average precipitation.

The availability of moisture affects many stages of the reproductive cycle of cacti. Seed production may be affected by low rainfall (Gibson and Nobel 1986). Phillips and Phillips (1996) found germination to be strongly correlated with rainfall. In their study of *Pediocactus peeblesianus* var. *peeblesianus*, germination events appeared to track favorable periods of precipitation. *Pediocactus peeblesianus* var. *peeblesianus* takes advantage of both spring and summer rains and can germinate in summer or fall after favorable rainfall.

In another study, Frye (1996) was unable to correlate higher recruitment rates of *Pediocactus paradinei* on his study plots after the highest levels of precipitation recorded at the site. Apparently, even with this record moisture, the threshold necessary to produce a favorable germination response in the species was not attained. Water relations are critical during the cacti seedling stage. Jordan and Nobel (1982) found that rainfall was correlated with seedling establishment and cacti growth (height) in the Sonoran Desert. Many cacti typically germinate seeds in late summer after the monsoon season and can be killed by autumn or spring droughts. Seedlings are not tolerant of extremes in temperatures and this intolerance could be responsible for seedling mortality.

High temperatures can cause drought conditions that can limit successful cacti establishment. Seedlings not killed by extreme summertime temperatures are often killed by severe cold during winter (Gibson and Nobel 1986).

Fruiting individuals ranged from 2.0 to 13.0 cm tall and from 5.0 to 12.0 cm wide. Average fruiting plant size was 5.35 cm in height and 7.25 cm in width. Average fruiting plant volume increased from about 125 to 265 cubic cm from 1994 to 1997, respectively (Figure 2).

Average size of reproductive versus nonreproductive individuals was 214 cubic cm and 30 cubic cm, respectively. Reproductively mature individuals were about seven times larger in size (volume) than non-reproductive individuals. Larger plants tended to produce more flowers and fruits than smaller plants. Larger plants contributed the majority of resources to the reproductive effort of the species. Fruits per plant ranged from 1 on the smallest to 12 on the largest individuals. Hughes (1996) reported that larger *Pediocactus peeblesianus* var. *peeblesianus* usually produced more fruit than smaller ones. Culley et al. (1993) also reported that larger cacti were responsible for most of the reproductive effort in their study of the Mesa Verde cactus (*Sclerocactus mesae-verdae*) in Colorado and New Mexico.

Older plants in our monitoring study produced more flowers and fruits than younger plants. On average, most (78.2%) of the fruiting individuals were 8 years or older (mature age class), whereas 21.8 percent were between 4 and 8 years old (intermediate age class).

Plant Condition

Overall, cacti appeared to be in pretty good condition for the duration of the study (Figure 3). The study means for cacti vigor were excellent (43.6%), good (28.9%), fair (17.8%), and poor (4.6%). Average cactus mortality was low (4.3%) on the monitoring plot during the 5 years.

The two major threats to the study plot cacti were trampling and off-road vehicles. In 5 years, livestock trampled eight cacti and seven cacti were driven over by vehicles. Most of this damage probably occurred when ranchers entered the grazing allotment near the study site. Culley et al. (1993) and Hughes (1996) also reported that the two major threats to the cacti populations they were studying in the Southwest were livestock trampling and off-road vehicles.

Rare-plant researchers also undoubtedly impact the populations they are studying. In our study plot we were primarily concerned with

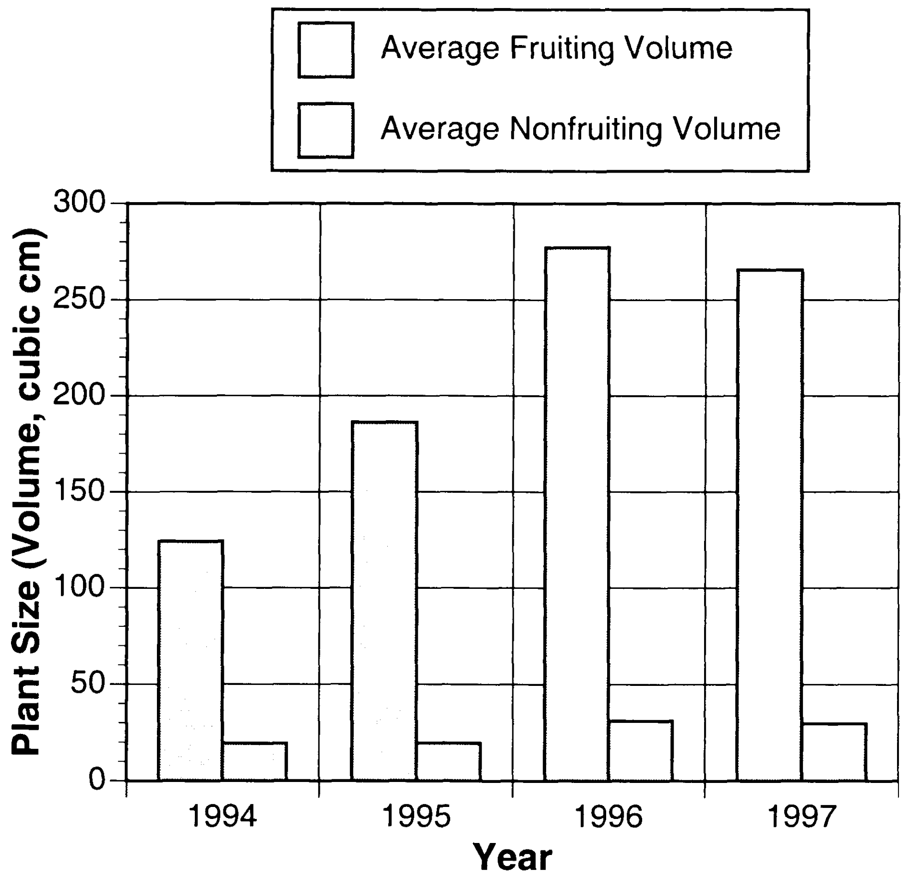

Figure 2. The entire fruiting cohort (n = 28) was averaged each year, even though not all plants in the cohort fruited every year of the study. Only two plants fruited all 5 years; their average size was 732 cubic cm over the 5 years.

disturbance of cryptobiotic crust in the cacti's habitat. During the 5-year monitoring study of this species, we attempted to walk in small, eroded ravines and on rocks, rather than on the cryptobiotic crusts, but at times it was necessary to step on crust soil. We did not evaluate the result of our impacts on the study plot and the species.

A recently reported threat to Siler's pincushion cactus was the spraying of insecticides to control grasshoppers in the cacti's habitat (Peach et al. 1993). Insecticides could indiscriminantly kill the species' pollinators and reduce their numbers. This could result in decreased pollination, fertilization, fruit production and seed set in the species. Ultimately, cacti population numbers could decline, thus threatening the species. Peach et al. (1993) recommended spraying for grasshoppers after the flowering period of the cactus, which starts the last week in March and continues through the first week in May.

Population Demographics and Trends

In 1993, we initially counted and permanently tagged 88 cacti on the monitoring plot. The population experienced a 46 percent increase in plants over the 5-year study period. The number of individuals increased to 162 cacti by 1997 (the last year of the study). The mean annual number of individuals in the population was 122 plants.

Initially, 33 percent of the subplots had cacti present in them; by the end of the study 54 percent of the subplots were observed to have cacti growing in them. Cacti frequency experienced a net increase of 21 percent.

Recruitment and Mortality

Recruitment ranged from 16 plants (1996) to 26 plants (1997) during the study. Mean annual recruitment was 21 plants on the study plot. Recruitment was recorded as zero during the first year of the study because we were unable to determine

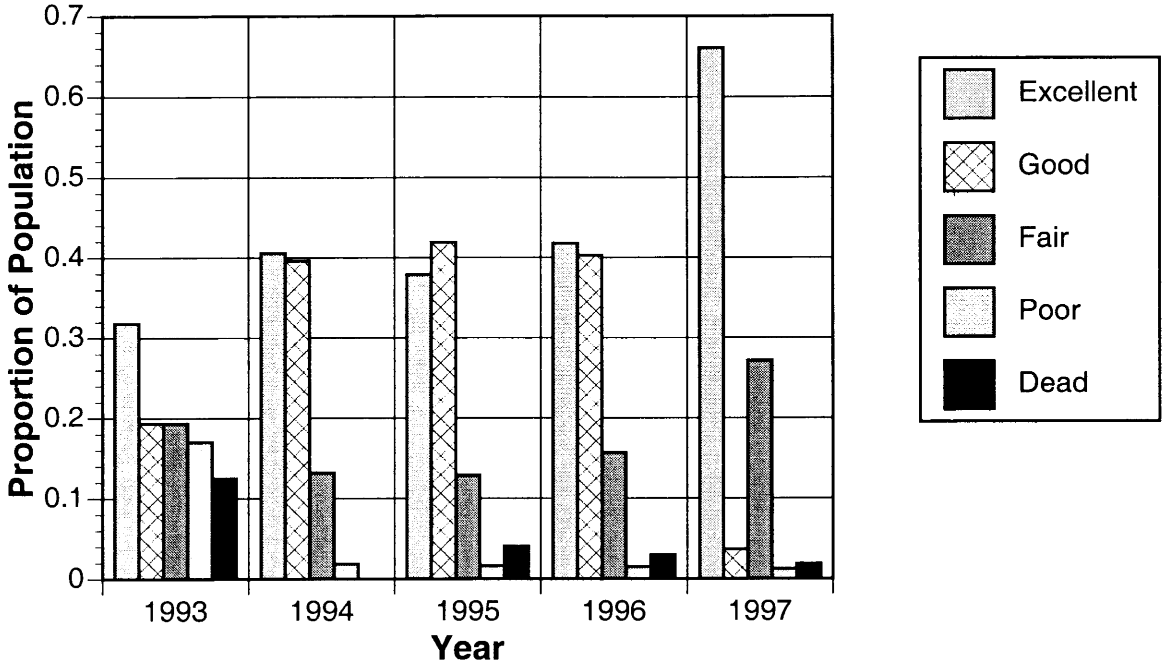

Figure 3. Vigor classes over 5 years. The 1993 "mortality" class overestimated the actual rate for the year, as it was cumulative of previous years.

the number of new recruits without data from the previous year.

Mortality ranged from 11 plants (1993) to zero (1994) during the study. Mean annual mortality was five plants on the study plot. Mortality was recorded as 11 the first year, but this number was probably high because it may have included individuals that died prior to the beginning of the study. In general, cactus mortality declined slightly during the monitoring study from 11 plants in 1993 to 3 plants in 1997. In comparison, recruitment was four times greater than mortality; this will assure that dead cacti are replaced at a ratio of 4:1.

There are many possible causes of mortality in cacti populations including rot, disease, desiccation, drought, rodent depredation, herbivory by insects, senescence (old age), off-road vehicles, and livestock trampling (Kass 1992, Culley et al. 1993).

The cause(s) of death for the cacti that died on the plot could not be determined. Some individuals simply disappeared from the plot and were not relocated. All deaths may be attributable to natural causes such as desiccation and senescence.

Most of the cacti that died belonged to the juvenile (recruit) class except for one that was mature (senescent). The very small cacti are particularly susceptible to all of the causes of mortality listed above, in particular desiccation and root rot infections from pathogenic fungi, particularly following rodent depredation, as young cacti lack central spines and are therefore poorly defended (personal observation, T. M.). Rodents, birds, and harvester ants may be responsible for herbivory of seeds and seedlings (Gibson and Nobel 1986). Excessive herbivory may contribute to mortality.

Comparison of Results with Hughes (1993–1998)

Hughes (1991) has studied *P. sileri* since 1985 and continued to record annual observations (1993–1998). Hughes (1996) also studied other members of this genus along with Butterick (1986), Frye (1996), and Phillips and Phillips (1996). Hughes's records indicate that Siler's pincushion cacti populations throughout its range have variable age distributions. Other researchers have also reported variability in population age distributions over their ranges (Culley et al. 1993, Frye 1996, Hughes 1996, Kass 1996, Phillips and Phillips 1996, Warren et al. 1993).

Hughes (1991) also reported that fruit production was variable (0–63% annually between 1985 and 1990) on his plots and that this variability probably was the result of differences in precipitation received in the cacti's habitat from year to year. Fruiting percentages appeared to increase in years with above-normal precipitation and decrease when precipitation was low. Butterick (1986) and Hughes (1996) reported variable fruit set in the populations of *Pediocactus peeblesianus* var. *peeblesianus* that they were studying in Arizona.

Hughes (1991) also reported that *P. sileri* had variable annual recruitment (0–26 plants) and mortality (0–56 plants) from 1985 to 1990. The highest mortality (56 plants) reported in 1990 at the Johnson Springs plot was due to herbivory, probably by rabbits.

When we compared our results at Muggins Flat, Utah with Hughes's results at Johnson Springs, Arizona, we found that both sites had similar demographics during the survey period between 1993 and 1998 (Table 1). Both sites had young populations. Johnson Springs had an annual average of 86.4 percent and Muggins Flat had an average of 89.1 percent of the population in the shortest height class (0–4.9 cm).

Average annual fruit production was similar at the two sites: Johnson Springs averaged 18 percent plants fruiting and Muggins Flat averaged 11.7 percent plants fruiting per year. Average annual recruitment at Muggins Flat (16%) was nearly 10 percent higher than at Johnson Springs (6%) per year. However, average annual mortality at Muggins Flat (3%) was similar to that reported at Johnson Springs (2.3%).

The Muggins Flat cacti population, which increased from 88 to 162 plants during the study, was more than twice as large as the Johnson Springs cacti population, which fluctuated from 66 to 77 plants during the study. By the end of the study period the Muggins Flat population had approximately doubled in size and the Johnson Springs population had increased by about 6 percent.

The Muggins Flat population appeared to be more vigorous than the Johnson Springs population because of its reproductive capacity, high recruitment rate, successful establishment rate, low mortality rate, and overall population viability. Finally, when compared to the other monitoring sites for this species, the Muggins Flat site may be one of the most productive sites in the entire range of this cactus species.

Conclusions

Four general life history trends or patterns emerge from this study: (1) the number of plants increased over the 5-year study period, (2) the number of recruits was similar over the 4 years that recruits were tallied, (3) the number of dead

Table 1. *Pediocactus sileri* population monitoring results of Hughes (1993–1998, Johnson Spring) and Hreha and Meyer (1993–1997, Muggins Flat).

	1993	1994	1995	1996	1997	1998	Average
No. of plants (%) in 0–4.9 cm height class:							
Johnson Spring	55 (83.3)	54 (80.5)	55 (80.8)	75 (97.4)	—	63 (90.0)	60.4 (86.4)
Muggins Flat	79 (89.7)	101 (95.3)	114 (91.9)	111 (82.8)	139 (85.8)	—	109 (89.1)
No. of plants (%) producing fruits:							
Johnson Spring (F)	11 (16.7)	2 (3)	25 (36.8)	—	—	11 (15.7)	12 (18)
Muggins Flat	17 (19.3)	11 (10.4)	16 (12.9)	16 (11.9)	13 (8)	—	15 (11.7)
No. of recruits (%) in population:							
Johnson Spring	7 (11)	2 (3)	5 (7)	7 (9)	—	0	4 (6)
Muggins Flat	—	18 (16.9)	24 (19.4)	16 (11.9)	26 (16)	—	21 (16)
No. of deaths (%) in population:							
Johnson Spring	4 (6)	1 (2)	1 (1)	1 (1)	—	1 (1.4)	2 (2.3)
Muggins Flat	11 (12.5)	0	5 (4)	4 (3)	3 (1.9)	—	5 (3)
Total no. of plants in plot for the year:							
Johnson Spring	66	67	68	77	—	70	
Muggins Flat	88	106	124	134	162	—	

Johnson Spring data from annual reports on *Pediocactus sileri* by Lee Hughes (1993–1998).

plants decreased slightly over the 5 years that mortality was counted, and (4) the number of recruits was about four times greater than the number of plants that died each year in the plot.

The 100-year average precipitation for a region is typically positively correlated with elevation. In Figure 4 we regressed average annual precipitation spanning the 5 years of our monitoring study, as well as the 100-year average precipitation, versus elevation for the weather stations nearest our monitoring plot. The data was from the five nearest regional weather stations collected by the Utah State Climate Center (Ashcroft 1992, Utah State University 1999). We calculated total annual precipitation from May through April of the following year as our "water year" because we assumed that this would be the precipitation cycle impacting the current growth and flowering. The regression equation was

$$Y = 124.65 + 0.0864 (X)$$

where Y is the predicted rainfall in millimeters and X is the elevation in meters. The R^2 of the regression of 100-year average precipitation vs. elevation was 0.18; therefore, elevation accounts for only 18 percent of the variation in rainfall. The chart demonstrates that the Kanab weather station registered higher precipitation for the 5 years of the study than would normally be predicted on the basis of either elevation or long-term weather patterns. The higher value was due primarily to very high precipitation in the early months of our study, and to a single month, September 1997, that registered 232 mm precipitation (9 inches) at the station.

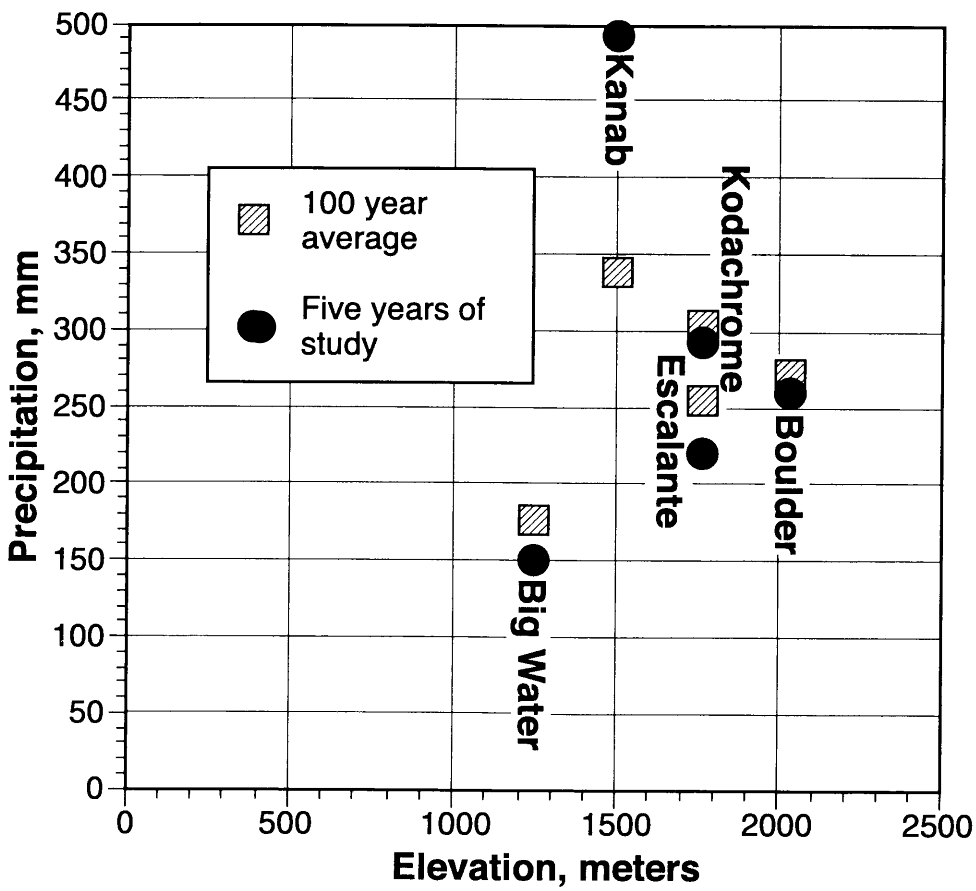

Figure 4. Regression of average annual precipitation during the 5 years of monitoring, as well as the 100-year average precipitation, versus elevation for the weather stations nearest our monitoring plot. Data from the five neareste regional weather stations, Utah State Climate Center (USU 1999). We calculated total annual precipitation from May of one year through April of the following year as the "water year," assuming that to be the precipitation cycle impacting current growth and flowering.

Although high, the precipitation records were included because we assumed they were accurate. During the study, Escalante and Big Water were slightly below their 100-year averages, whereas Kodachrome and Boulder were quite close to their 100-year averages.

We used the long-term weather records of Kanab, Utah for our *P. sileri* site, as it was geographically closest and at a similar elevation. Kanab receives an average (100-year norm) 337.5 mm (13.5 inches) of precipitation per year (Pope and Brough 1996, Utah State University 1999).

This Siler's pincushion cactus population may have responded to above-normal precipitation at the study site, which was favorable for recruitment and may be a major driving force in population growth (Figure 5). The above-normal (4 years out of 5) precipitation over the course of the study may also account for the slight drop in mortality.

Major weather events occur over the whole area and individual storms may be spotty in distribution, especially in summer, resulting in differences in precipitation and temperature between Kanab and the study site. By refining our study design (cf. Phillips and Phillips 1996), it may be possible to correlate weather data with cactus population data such as seedling establishment, recruitment events, age classes, and mortality.

Several authors have discussed population viability analysis (PVA) and minimum viable pop-

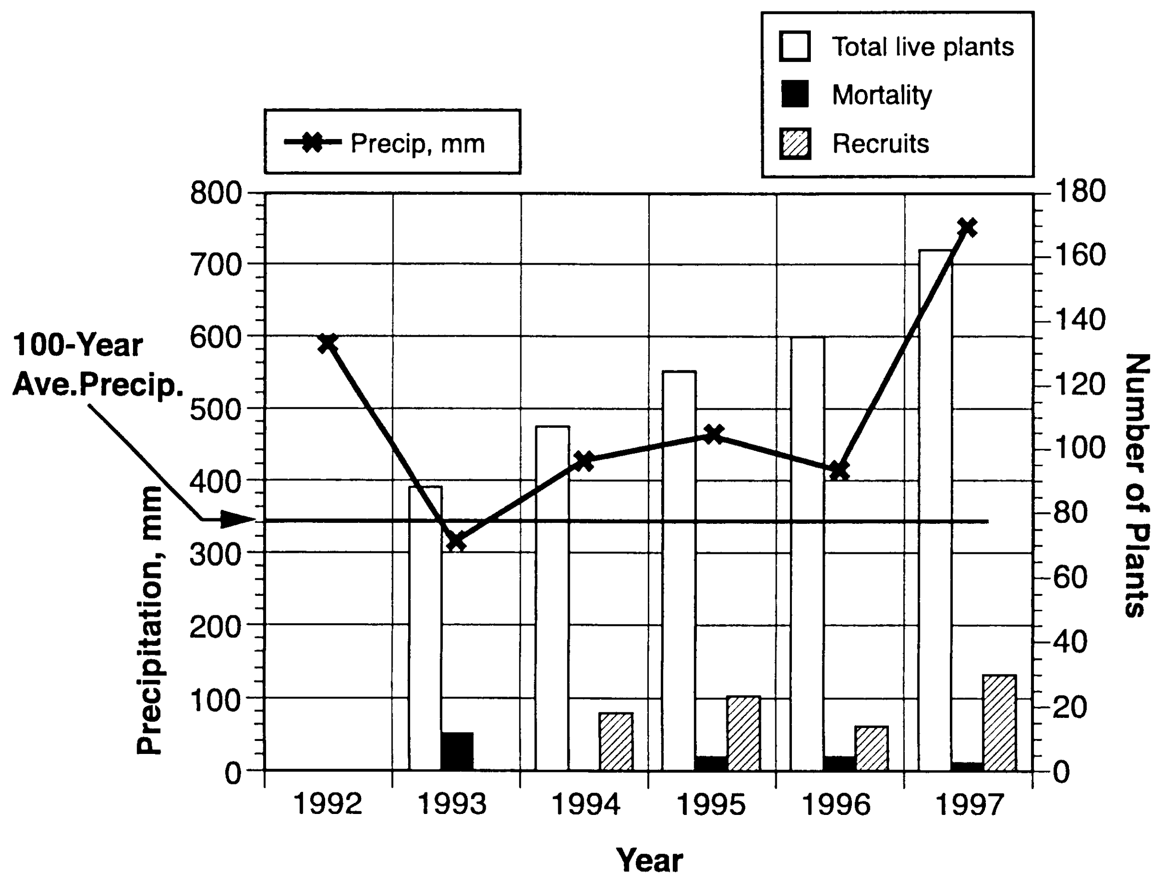

Figure 5. Demographic trends in *Pediocactus sileri* and precipitation. Precipitation (mm, left Y-axis) plotted next to numbers of plants in three life stages: total live plants, mortality, recruits (also included in total live plants column). As in Figure 4, precipitation "water year" is calculated from May through following April. Average precipitation 1992–1997 (not shown): 492 mm, which is 155 mm (6 inches) above 100-year average.

ulation (MVP) size in conjunction with rare plant populations (Boyce 1992, Crone and Gehring 1998, Gilpin 1989, Menges 1986, 1990, 1991, Nunney and Campbell 1993, Shaffer 1981). Menges (1990) was probably the first to bring a rare plant case study to the forefront when he reported his findings on Furbish's lousewort (*Pedicularis furbishiae*).

Height and width measurements, as well as age, reproduction, and vigor observations, may be used to assess population viability (Hughes 1991, Menges 1991). Both height and width distributional patterns remained constant over the 5 years of this study.

Hughes (1991) reported that a healthy cactus population should have as many smaller, younger recruits as larger, older (senescent) individuals. The study plot had about eight times as many younger (39%) recruitment size plants than older (5%) senescent plants.

There was relatively equal representation (19–34%) in each width class except the largest, which averaged only 5 percent of the population.

The 1997 *P. sileri* population size class distribution is consistent with the habitat management plan objectives set for the species (Bureau of Land Management 1987). Nearly 75 percent of the population were juvenile or intermediate in age (< 8.0 years old). Younger (juvenile) plants are usually healthier than older (senescent) individuals. The vigor of about 75 percent of the population on the monitoring plot was observed to be excellent or good. Vigorous plants are usually healthier and more viable.

Potential causes of extinction in plant populations include environmental, demographic, and genetic stochasticity, plus natural catastrophes (Shaffer 1981). To this list we can add man-made alterations to their habitats such as fragmentation, introduction of alien flora and fauna, and disruption of ecosystems from pollution or spraying of insecticides.

Impacts to a species and changes in its population dynamics may be detected at the habitat level, the population level, and the individual level (Menges and Gordon 1996). To detect variations in rare plant populations, population parameters need to be monitored annually to ascertain demographic trends. The simplest way to assess population viability is to measure the population's growth from one year to the next over a period of several years for at least 10 years but preferably for 20 years (Menges 1986). A viable population is usually stable if recruitment equals mortality and increasing in size through time if recruitment exceeds mortality.

Menges (1991) noted that recruitment should be greater than mortality per year to maintain population viability. Reproduction was successful on the monitoring plot, producing about 20 new recruits per year. Recruitment was four times greater than mortality on the plot.

According to Frye (1996), even with very low mortality rates a population with little or no recruitment would most likely decline. A population that lives for 25 years may need one or two good years of reproduction to replace itself. A short-term sampling period (less than 10 years) might miss a favorable reproductive year and thus overestimate the risk of extinction.

The Muggins Flat cacti population appears young, vigorous, and viable. This population may enjoy optimal site conditions for cactus growth and survival, possibly in contrast to the remainder of its range. However, the duration of this study did not capture any environmental catastrophes such as drought, fire, temperature extremes, and excessive depredation by rodents, herbivory by insects, or plant disease. In managing rare plant populations we often have to make decisions using incomplete data sets. Therefore, our ability to use the available data effectively is critical to our success as managers of rare plant species such as *P. sileri* (Crone and Gehring 1998).

Management Recommendations

1. Continue to protect the monitoring plot near Muggins Flat. Make sure grazing activities in the vicinity of the site do not threaten the species or its habitat.

2. Refine the monitoring study to include precipitation data for Kanab, Utah and correlate precipitation data at the site with demographic data for the cactus population.

3. Continue to monitor the Muggins Flat population every year or at least every other year starting in 2000.

4. Continue to compare the Muggins Flat population demographics with the other BLM sites monitored by Lee Hughes (BLM, Arizona Strip Field Office, St. George).

5. Monitor the timing of spraying for grasshoppers. Spraying insecticides to control grasshoppers in the cacti's habitat could kill the species' pollinators. According to Peach et al. (1993), spraying for grasshoppers should be later than the flowering period of the cactus, which starts the last week in March and proceeds through the first week in May.

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