

Demographic Monitoring of Wright Fishhook Cactus

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Abstract: Wright fishhook cactus (*Sclerocactus wrightiae* Benson) is a small barrel cactus endemic to the San Rafael Swell in south-central Utah. It was listed as an endangered species in 1979 due to its small population size, threats of over-collecting, and development associated with oil and gas. Demographic monitoring was initiated in 1993 with the following objectives: to establish permanent plots to monitor growth, fecundity, recruitment, and mortality for at least 10 years; to identify habitat factors positively associated with cacti presence; and to identify important insect visitors and predators. Three permanent plots were located throughout the range of *S. wrightiae*, and 93 individuals were followed from 1993 to 2000. In general, diameter size class was significantly different ($P < 0.001$) for all three plots. Size classes 3 and 4 (adults) produced the greatest number of flowers and fruits. Size class 3 produced more flowers and fruits by virtue of its higher density, whereas size class 4 produced more flowers and fruits because of its larger diameter. Mortality exceeded recruitment by a 2.5:1 ratio for all plots. At Hanksville, 21 cacti (68%) were recorded dead in 1994, and the remaining 10 individuals and 5 recruits were recorded dead in 1995. No new recruits have been recorded since 1995 at Hanksville. Ord's kangaroo rats and white-tailed antelope ground squirrels were primary mortality sources at Hanksville, and the cactus-borer beetle was the primary mortality source at Giles and Mesa Butte.

Wright fishhook cactus (*Sclerocactus wrightiae* Benson) is a small, white-flowered barrel cactus endemic to the San Rafael Swell in south-central Utah. It was discovered by Dorde Wright Woodruff in 1961 "near San Rafael Ridge" in Emery County, Utah. Lyman Benson collected it in 1964 at the type location and realized that it formed a link between *Sclerocactus whipplei* and *Coloradoa mesae-verdae*. At that time the genus *Sclerocactus* consisted of just two species. In 1966, Benson expanded the genus *Sclerocactus* to six species and named the novel cactus after Mrs. Wright. Eight species of *Sclerocactus* are currently recognized in the Navajoan, Great Basin, and Mojave deserts (Benson 1982).

On October 11, 1979, *S. wrightiae* was listed as an endangered species (U.S. Fish and Wildlife Service 1979) based on its narrow distribution, its small population size, and the potential threats of commercial collecting and energy development (Mutz et al. 1985). Recent inventories (Welsh 1980, Neese 1987, Kass 1989) have extended its distribution from approximately Ferron in Emery County southwest to Hanksville in Wayne County, Utah (Figure 1).

Conservative estimates of population size range from 50,000 to 100,000 (Neese 1987, Kass 1989). As expected, the accuracy of total population counts is questionable because areas may be overlooked during inventory, and cacti may

actually disappear underground during census periods (S. Welsh personal communication). Accurate counts, which are important for determining population size and dynamics, are fundamental to conservation management (Bradshaw and Doody 1978).

Local populations of *S. wrightiae* typically consist of 50–100 individuals occurring within a 1–2 hectare area. These subpopulations are often clumped on certain geologic strata and are often separated by several kilometers between strata. *S. wrightiae* is most often found on the Morrison, Curtis, and Mancos formations, and is less often found on the Summerville, Dakota, Entrada, and Carmel formations (Figure 2).

To date, the habitat characteristics of *Sclerocactus* have received little attention. Soil tests of *S. polyancistrus* habitat indicate abnormally high calcium carbonate levels (May 1979). Naumann (1989) reported that *S. mesae-verde* is limited to the Mancos Formation, but detected no differences in soil characteristics within the species range. Welsh et al. (1987) and Neese (1987) have suggested that saline or sodic soils are often associated with *S. wrightiae*. Soil surface features such as gravelly pavement may be important to the establishment and growth of *S. wrightiae* (Neese 1987, Kass 1989).

S. wrightiae is found mainly in salt desert shrub at 1378–1460 m (4200–4788 ft) elevation, growing primarily with perennial members of the

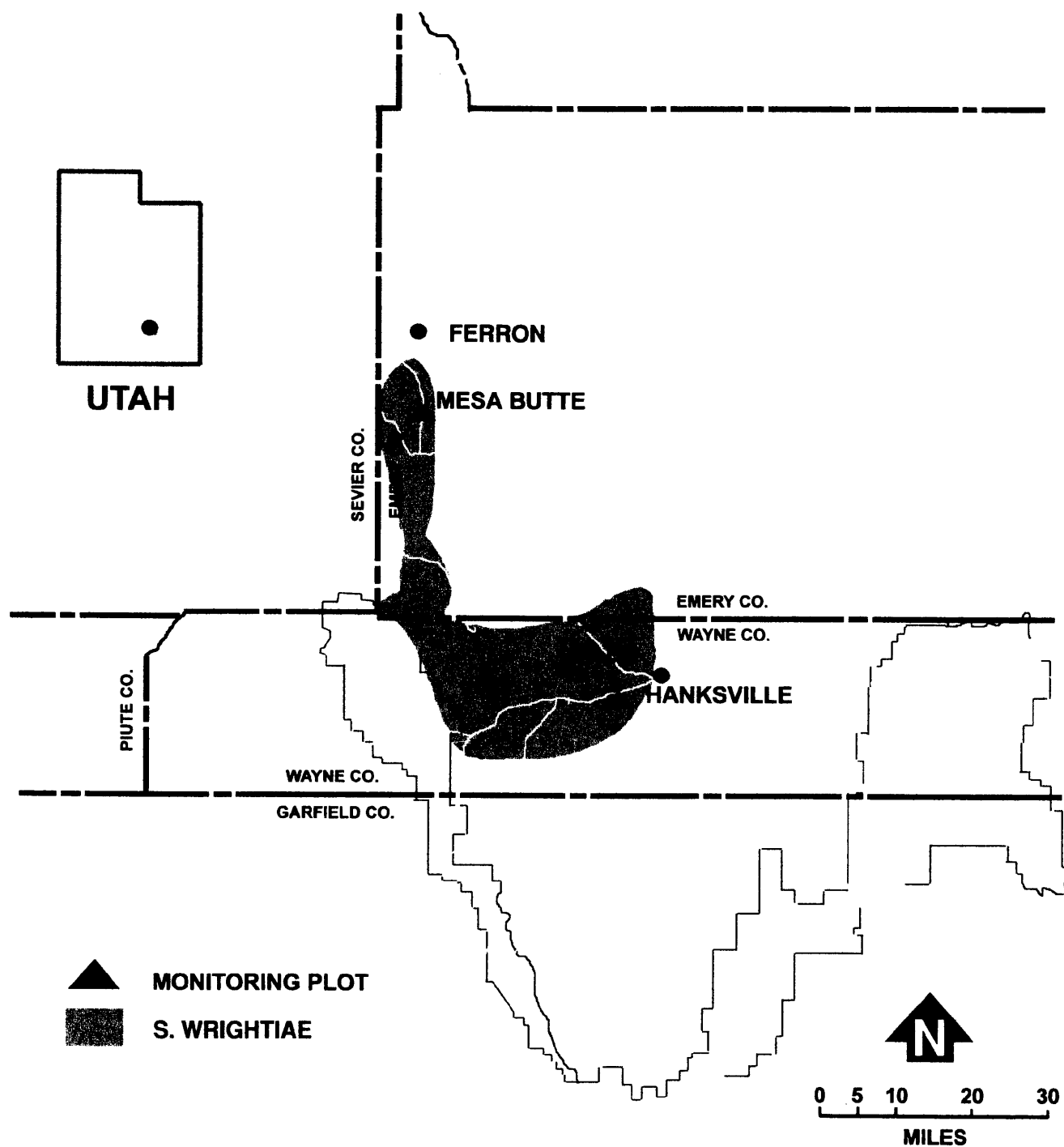


Figure 1. Distribution of *Sclerocactus wrightiae*.

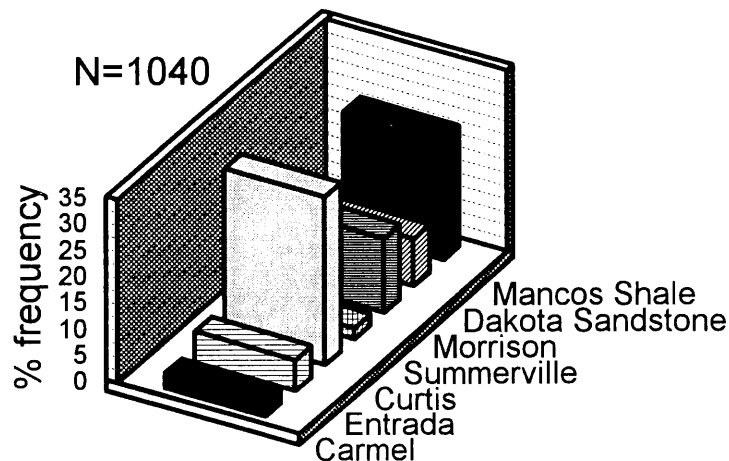


Figure 2. Percent frequency of *S. wrightiae* relative to geologic strata.

genus *Atriplex*. It is most commonly found in association with mat saltbush (*Atriplex corrugata*), Castle Valley saltbush (*Atriplex gardneri* var. *cuneata*), and shadscale (*Atriplex confertifolia*). It also grows at the lower limits of the pinyon-juniper community at 1865–1981 m (6117–6497 ft; Table 1).

Demographic monitoring of cacti has been limited to a few short-term studies. Phillips et al. (1985) and Butterwick (1987) monitored growth and reproduction of the Peebles Navajo cactus (*Pediocactus peeblesianus* var. *peeblesianus*) in Arizona. Warren et al. (1992) monitored *Pediocactus paradinei* for 4 years on the Kaibab Plateau. In Utah, Hughes (1992) is conducting demographic monitoring of *Pediocactus sileri*. Demographic studies of *Sclerocactus* consist of those on *S. mesae-verdae* by Naumann (1989) and Culley et al. (1992) in Colorado and New Mexico, respectively.

To date, demographic information is not available for *S. wrightiae*. Sutter (1996) indicated that demographic monitoring is an essential component of rare plant conservation and is needed to precisely detect changes in populations and management over time. Age structure, establishment history, and optimal reproductive success may be inferred from demographic data (Jordan and Nobel 1982).

Long-term monitoring of *S. wrightiae* was initiated in 1993 with the following objectives: to establish permanent plots to monitor growth, fecundity, recruitment, and mortality for at least 10 years; to identify habitat factors positively associated with cacti; and to identify important insect visitors and predators. A cooperative agreement

between the Bureau of Land Management (BLM) and Intermountain Ecosystems provided project funding.

Methods

Three 0.75 ha (61 × 122 m) rectangular permanent plots were selected throughout the geographic range of *S. wrightiae*. Plots varied with respect to geology, vegetation, elevation, and land use (see Table 1). Plots were selected in high-density cacti areas so the greatest number of individuals could be sampled within a manageable plot size. Eight 30 × 30 m subplots were superimposed on each 0.75 ha plot, and subplot corners were staked with rebar to facilitate location of individual plants.

Thirty-one cacti were randomly selected in each plot and marked with aluminum identification tags attached to large nails located north of each individual. Cacti were located by triangulation, with the two nearest subplot corners serving as permanent reference points.

Height, diameter, vigor, and reproduction (number of flowers and fruits) were recorded for each individual stem annually from 1993 to 2000. Seeds were collected from 20 plants each in Mesa Butte and Giles in 1995 and 1999 to determine the number of seeds per mature fruit. Plants were separated into four size classes based on diameter width. Size class 1 plants were < 2 cm wide and were considered seedlings or new recruits. Size class 2 plants were juveniles > 2 to 4 cm wide, which flowered occasionally but seldom set fruit. Size class 3 were adult plants > 4 cm to 9 cm wide that generally had slightly lower reproductive rates but a higher frequency of occurrence. Size

Table 1. General location and description of *S. wrightiae* plots in central Utah.

	Giles	Hanksville	Mesa Butte
County	Wayne	Wayne	Emery
Elevation	1371 m	1341 m	1731 m
Aspect	East	East	Southeast
Slope	0–10°	0–5°	0–10°
Geology	Mancos shale	Summerville	Mancos shale
Land use	Off-road vehicles	Cattle grazing	Cattle grazing
Vegetation	Castle Valley saltbush	Sand dropseed/galleta grass	Mat saltbush
Precipitation	12.9 cm	13.8 cm	18.5 cm

class 4 were adult plants > 9 cm wide with higher reproductive success.

Kolmogorov-Smirnov goodness-of-fit tests were used to determine if size classes in 1993 fit a normal distribution. Size class data were not normal, so the Kruskal-Wallis non-parametric analog to analysis of variance was used to test for significant differences between means. Spearman's rank correlation analysis was used to show the relationship between size class and number of reproductive structures.

Vascular plant and substrate cover (rock and bare ground) were measured along randomly placed 100 m transects. M2 quadrats were centered at 10 m intervals along the transect. The above procedures were repeated but sampling was centered on *S. wrightiae* individuals nearest the 10 m point on the transect rather than on the transect line itself. Plant-centered versus random-point locations made it possible to test the hypothesis that living cover and substrate cover are no different between cacti and non-cacti habitats. Kolmogorov-Smirnov two-sample t tests were used to test for significant differences in cover between cacti and non-cacti plots. Topographic position was recorded for each plant and was analyzed using a G test.

Three soil samples were collected from each plot (N = 9) in 1995 and analyzed for texture, pH, electrical conductivity, sodium absorption ratio, ppm nitrogen (N), and ppm sodium (Na). Soils samples were taken with an auger inserted to depth of 15 cm and placed in plastic bags. Soils were analyzed by the Brigham Young University Soil Laboratory, Department of Agronomy and Horticulture. Soil data were not tested for significant differences because of small sample size.

Results

Size class varied between sites during the first census in 1993 ($P < 0.001$) and continued to change

in subsequent years (Figures 3–5). In general, the greatest number of individuals was found among size class 3 (young reproductive), followed by size class 2 (juveniles). Size class 1 (seedlings) recorded the fewest individuals, followed by size class 4 (old reproductive). Low recruitment patterns and the small number of older reproductive individuals seem to constitute a species-wide pattern.

Mortality exceeded recruitment by a 2.5:1 ratio for all plots during 1993–2000 (Table 2). After 1995, no live individuals remained in the Hanksville plot. Twenty-one cacti (68%) were recorded dead in 1994, and the remaining 10 adults and 5 recruits were recorded dead in 1995. No new recruits have been recorded since 1995 at Hanksville.

Currently, 6 individuals remain at Giles and 24 at Mesa Butte, a 68 percent decrease from the original population of 93 plants. In 1999 a rare recruitment event added 18 new individuals to Mesa Butte, a 21 percent increase in population size. As of 2000, 15 of those new recruits have survived and are responsible for the bulk of the remaining 24 individuals at Mesa Butte (Table 2).

Mean annual growth pooled for all three plots gradually increased from 1993 to 1995 and then gradually declined from 1996 to 1999, with substantial decreases in 2000. Based on observation of *S. wrightiae* in average precipitation years, seedlings and juveniles grow about 1–2 cm per year, and growth rate declines to about 0.5 cm per year for adults. From these observations, it appears that *S. wrightiae* reaches sexual maturity at about 4 years and probably has a life expectancy of 20 years.

Reproductive Effort

Spearman's rank correlation analysis showed a significant positive correlation ($P < 0.001$) between total number of flowers/fruits and stem diameter. In general, size classes 3 and 4 had the greatest number of flowers and fruits. Size class 3

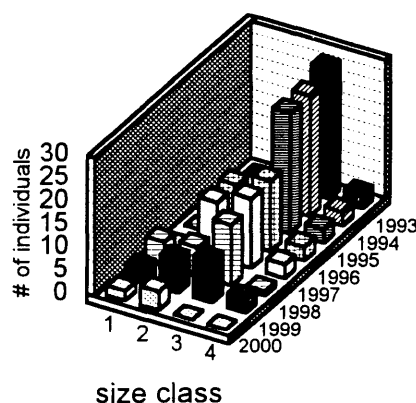


Figure 3. *Sclerocactus wrightiae* size class at Giles (n = 202).

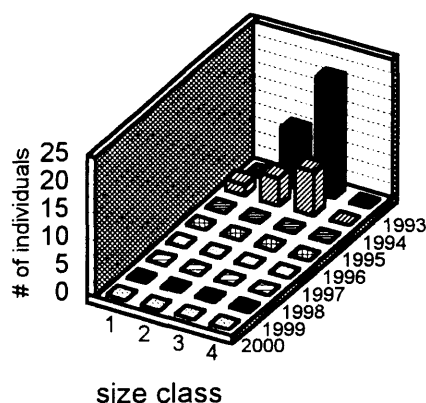


Figure 4. *Sclerocactus wrightiae* size class at Hanksville (n = 46).

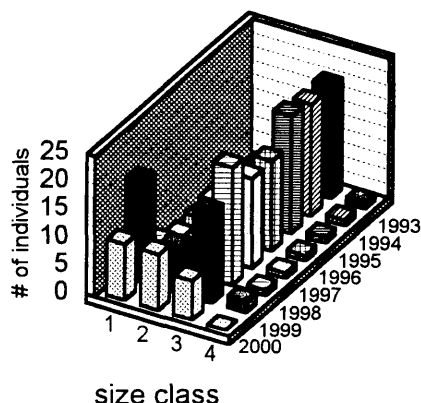


Figure 5. *Sclerocactus wrightiae* size class at Mesa Butte (n = 244).

produced more flowers and fruits by virtue of its larger numbers, whereas size class 4 produced more structures by virtue of its larger size. The reproductive effort for size class 2 was minimal and remained essentially constant throughout the years. Declines in reproductive effort for size classes 3 and 4 resulted from drought and overall mortality of the larger individuals (Figure 6).

The mean number of seeds per fruit averaged for all plots for 1995 and 1996 was 15.6 (SD 7.83). The mean number of reproductive structures per plant and mean number of seeds per plant for 1777 plants were 3.65 (SD 4.49) and 70 (SD 4.43), respectively. Flowering plants produced mature fruit on average 76.4 percent of the time.

Habitat Analysis

Shrub cover was lower and forb and grass cover was higher on cacti than non-cacti plots, but differences were not significant. Total plant cover ranged from 14.7 percent at Mesa Butte to 5.0 percent at Giles (Table 3). Bare ground was slightly higher on cacti plots and percent rock cover showed negligible differences between cacti and non-cacti plots.

The results of G tests indicated that plants are not distributed randomly with respect to topographic position ($P < 0.0001$). Plants occur on long, gradual mid-slopes (79%) and upper mid-slopes (19%) and almost never on abruptly sloping areas or slopes exceeding 11 degrees. Plants occurred on all aspects.

The results of soil analysis at Hanksville indicated electrical conductivity of 15.75 and sodium absorption ratios of 20.76, several times higher than Giles or Mesa Butte (Table 4). Nitrogen was 103.060 ppm at Hanksville, two times lower than Mesa Butte (235.56 ppm) and three times lower than Giles (301.81 ppm).

Soil alkalinity and salinity values were high at the Hanksville plot, suggesting moisture and nutrient limitation problems (Long 1981, Mengel and Kirkby 1982). Nutrient and moisture limitations may explain the smaller stature of individuals and overall poor reproductive performance compared to the other two plots in 1993 and 1994. In general, cacti are not well adapted to growing in high saline or sodic conditions (Benson 1982).

Discussion

The low frequency of occurrence in the smallest size class suggests that recruitment is a rare and episodic event. Only one significant recruitment event was observed in the last 8 years at

Table 2. Mortality and recruitment of *S. wrightiae*, 1993–2000. Values are total numbers of individuals, and values in parentheses represent annual percent mortality and recruitment. Mortality to recruitment ratio is 100:40 or 2.5:1.

Year	N	Plots	Mortality	Recruitment
1993	31	Giles	0	0
	31	Hanksville	0	0
	31	Mesa Butte	0	0
	Total 93		0	0
1994	29	Giles	2	0
	15	Hanksville	21	5
	29	Mesa Butte	4	2
	Total 73		27 (27)	7 (7.5)
1995	29	Giles	0	0
	0	Hanksville	15	0
	31	Mesa Butte	0	2
	Total 60		15 (20.5)	2 (2.7)
1996	29	Giles	0	0
	29	Mesa Butte	2	0
	Total 58		2 (3.4)	0
1997	29	Giles	0	0
	29	Mesa Butte	0	0
	Total 58		0	0
1998	25	Giles	8	4
	31	Mesa Butte	3	5
	Totals 56		11 (19)	9 (15.5)
1999	22	Giles	7	4
	40	Mesa Butte	9	18
	Total 62		16 (28.5)	22 (39)
2000	06	Giles	16	0
	24	Mesa Butte	16	0
	Total 30		32 (51.6)	0
Grand Total	100	40		

Mesa Butte, accounting for the 21 percent increase at that site. Rare and episodic recruitment patterns have been demonstrated for a number of long-lived species, especially cacti. These episodes are most likely related to precipitation events and favorable temperature regimes (Steenbergh and Lowe 1969).

The primary source of mortality at Hanksville was Ord's kangaroo rats (*Dipodomys ordii*) and white-tailed antelope ground squirrels (*Ammospermophilus leucurus*). Kangaroo rat burrows were abundant throughout the area, and antelope ground squirrel activity was observed during the day. It was not uncommon to find both seedling and adult cacti eaten at the ground level within a few nights (Kass, personal observation). Ord's kangaroo rats have been reported eating prickly pear in Idaho, and antelope ground squirrels eat seeds and fruits of cacti as a main dietary item (Zeveloff and Collett 1988). Culley et al. (1992) reported pocket gophers (*Thomomys bottae*) as a

mortality source on *S. mesae-verde* in Colorado and New Mexico.

At both Giles and Mesa Butte, mortality was caused mainly by the cactus-borer beetle (*Moneilema semipunctatum*), a large, black, nocturnal, flightless beetle that ranges from the Great Basin in Nevada and western Utah, south to northern Baja California, and east to the Colorado Plateau in Utah, southwestern Colorado, northwestern New Mexico, and northern Arizona (Linsley and Chemsak 1984).

Linsley and Chemsak (1984) discussed the feeding and mating habits of the genus *Moneilema*. Adult beetles are nocturnal and become active at dusk, at which time they climb up and down the cactus stem. They feed and hide at the bases or in the crowns of stems. Mating occurs at night on top of the plant and may continue throughout the night. The female chooses a suitable ovipositor site near the base of the plant and deposits the egg. After hatching, the larvae attempt to enter the

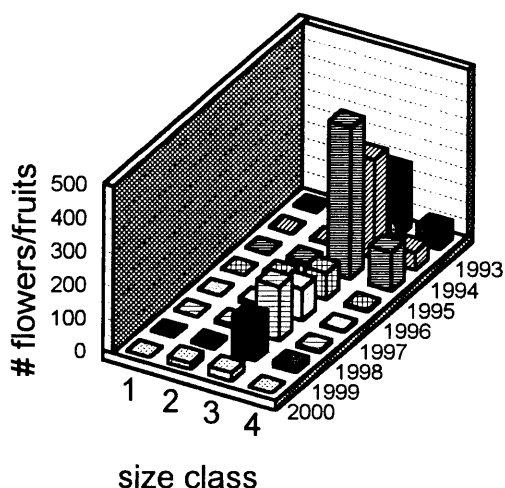


Figure 6. Reproductive efforts for all three plots (n = 1777).

plant, and during the second or third instar the larvae begin to tunnel into the plant. A pupal cell is constructed in the fall, either in the soil or within the hollowed-out stems.

It has been observed that *Moneilema* may select for larger cacti, which may explain part of the decline of larger-sized *S. wrightiae* throughout its range (see Coles and Naumann, this volume). A shift in population structure may result if larger cacti with higher reproductive rates are replaced by smaller cacti with lower reproductive rates.

Conclusions: Threats and Recommendations

Commercial collecting and vandalism are known threats to *S. wrightiae*, and several populations have been extirpated in the Hanksville area (BLM personnel, personal communication). Off-road vehicle (ORV) use is a consistent problem on two of three monitoring plots. Once every 2 years, cacti have been killed by ORVs at Giles. More important, ORVs compact the soil, probably precluding establishment of new recruits. These anthropogenic problems coupled with an overall natural mortality rate of approximately 2.5 to 1 indicate a slow decline for *S. wrightiae*.

BLM management goals for similar endangered species such as *Pediocactus sileri* in southwest

Table 3. Percent cover of vascular plants and substrate components with and without *S. wrightiae*.

	Giles		Hanksville		Mesa Butte	
	Cacti	Non	Cacti	Non	Cacti	Non
Bare ground	48.4	47.2	52.5	50.1	48.7	43.4
Rock	43.9	47.8	38.3	38.6	36.6	38.7
Shrubs	2.7	4.5	1.6	9.0	10.2	11.6
Forbs	3.6	0.5	0.3	0.0	2.5	0.5
Grasses	0.0	0.0	6.8	2.3	1.2	0.5
<i>S. wrightiae</i>	1.4	0.0	0.5	0.0	0.8	0.0
Totals	100	100	100	100	100	100
Live cover totals	7.7	5.0	9.2	11.3	14.7	12.6

Table 4. Mean values for selected chemical and physical parameters for all plots. Standard error shown in parentheses.

	Hanksville loamy sand	Giles loam	Mesa Butte loam
pH	8.6 (0.07)	7.8 (0.06)	7.8 (0.06)
electrical conductivity (mmho/cm)	15.75 (0.10)	2.88 (0.09)	4.35 (0.07)
Na (ppm)	2,144.1 (1.39)	96.48 (1.76)	527.36 (0.57)
N (ppm)	103.6 (0.63)	301.81 (1.23)	235.56 (1.02)
Sodium absorption ratio	20.7 (0.09)	0.97 (0.07)	5.48 (0.07)

Utah are to have about 20 percent of the population in the smallest and largest size classes (Lee Hughes, personal communication). Currently, the *S. wrightiae* smallest size class is at 6.3 percent and the largest size class is at 11.5 percent. Menges (1991) recommended that recruitment must be greater than mortality per year to maintain population viability. These goals are obviously not being met for *S. wrightiae*.

Recommendations for future research include continued monitoring to assess survival of new recruits, mortality sources, and anthropogenic impacts. Probably one of the most important biological factors affecting the narrow distribution of *S. wrightiae* is the apparent lack of long-distance dispersal. Harvester ants (*Pogonomymex* spp.) were observed carrying seeds of *S. mesae-verdae* in New Mexico (Culley et al. 1992). Most 1999 recruitment at Mesa Butte was observed around harvester ant mounds. Further research into this phenomenon would elucidate the nature of the limited distribution of these cacti.

Because members of the genus *Sclerocactus* are highly self-incompatible, identification of effective pollinators is important. Maintenance of genetic diversity appears to be totally dependent on animal pollinators in this species. Both pollinators and seed dispersers may need to be considered for the conservation and protection of *S. wrightiae*.

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