Integrated Conservation Strategies for Recovery of Sentry Milkvetch at the South Rim of Grand Canyon National Park

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Abstract. The endangered plant, sentry milkvetch (*Astragalus cremnophylax* var. *cremnophylax*), is known only from the south rim of Grand Canyon. To mitigate declines in the population, personnel from the U.S. Fish and Wildlife Service, Grand Canyon National Park, and The Arboretum at Flagstaff have used several strategies. These include monitoring mortality and natality in the population, protecting the population by erecting a fence, surveying for new populations, and conducting basic research and reintroduction studies. Greenhouse germination studies indicated that an average of 49% germination could be expected under high watering conditions. Transplanted seedlings had greatest survival in soils of high limestone composition. Using this information from greenhouse studies, 196 seeds were reintroduced into four different microsite types at Maricopa Point in 1990. Despite the good rains received at Maricopa Point in summer 1990, seed germination and survival in experimental microsites was poor. Although 10% of seeds germinated, only 1% of the seedlings successfully survived until fall, and 0.5% of the seeds survived winter 1990–91. Thus, field germination was below expected. Ongoing tests of natural germination may give insights into requirements for natural establishment and reasons why the seedling establishment failed in the chosen microsites.

Key words: *Astragalus*, conservation, endangered plants, endangered species, Grand Canyon National Park, reintroduction, sentry milkvetch.

Several strategies are needed for conservation of plant species threatened with extinction. These include identifying and protecting the species' habitat, introducing or reintroducing propagules into habitats where they are likely to survive, propagating and maintaining the species in public gardens or seed banks (Westman 1985), and conducting basic research to increase knowledge of species biology. Usually, an integrated conservation strategy involving federal agencies and private institutions must be undertaken to achieve the goal of plant recovery (Falk 1990). Private institutions can fill the necessary role of conducting research and propagating rare plants to elucidate the conditions required for seed germination, growth, and survival and to generate seed or plant propagules for reintroductions.

Integrated conservation strategies between private botanical gardens and federal agencies have aided the recovery of several endangered plants, including Menzies wallflower (*Erysimum menzeisii*; Ferreira and Smith 1987), Arizona agave (*Agave arizonica*; Delamater and Hodgeson 1987), Knowlton's pincushion cactus (*Pediocactus knowltonii*; Olwell et al. 1987; Milne 1986), and Malheur wire-lettuce (*Stephanomeria malheurensis*; Falk 1990).

Here I report on the integrated conservation strategies undertaken by the U.S. Fish and Wildlife Service, Grand Canyon National Park, and The Arboretum at Flagstaff to protect, manage, and restore the endangered sentry milkvetch (*Astragalus cremnophylax* var. *cremnophylax*).

Study Organism

Sentry milkvetch is a federally listed endangered plant that grows on the south rim of the Grand Canyon in Grand Canyon National Park. The plants are small, rock-hugging herbs, less than 1 cm tall and spreading up to 10 cm along the ground. Their silver-haired leaves and delicate purple flowers are stunning, yet minute. The plants grow in shallow soils (<5 cm deep) or in cracks in flat pavements of Kaibab limestone. The plants seem to occur on Kaibab limestone where the limestone forms minimum-sized platforms (U.S. Fish and Wildlife Service 1990).

The first step taken toward conservation of this species was to establish and monitor long-term demographic plots. In 1988, Sue Rutman from the U.S. Fish and Wildlife Service began monitoring the largest-known population at Maricopa Point. She documented that the population has undergone a 33% decline over the past 4 years; numbers of individuals within permanent monitoring plots have dropped from 359 plants in 1988 to 240 plants in 1991 (Maschinski and Rutman 1993). Historical records indicate that the plant was once common along sandy ledges of the south rim of the Grand Canyon (Phillips et al. 1982), but within the last 45 years, numbers of extant individuals have diminished. The declining status of sentry milkvetch is tied to its apparent restriction to its picturesque habitat on the rim of Grand Canyon. Trampling by park visitors and degradation of the limestone habitat are believed to have endangered the species (U.S. Fish and Wildlife Service 1990).

Surveys in the general area for potential habitat have been largely unfruitful. Although searches have been conducted for many miles west and east of Maricopa Point (U.S. Fish and Wildlife Service 1990), no new plants were discovered until June 1991, when Kathy Warren of the National Park Service discovered three more individuals east of Grandview Point. Thus, the current known populations consist of approximately 400 plants growing at Maricopa Point and three additional plants growing east of Grandview Point.

In contrast to the Grandview Point population, which is largely inaccessible to the public, the population at Maricopa Point is extremely vulnerable to human trampling. There is a parking lot and overlook at this site, where shuttle buses stop throughout the year and private vehicles can stop from September through May. As one of the most popular sites along the south rim of the Grand Canyon, hundreds of thousands of people have access to the sentry milkvetch habitat each year. In spring 1990, the National Park Service took steps to protect the population at Maricopa Point by erecting a fence enclosing the entire population. In addition, they removed social trails that ran through the exclosure and rerouted public traffic around the fragile population.

Because population numbers are small and the distribution of the plant is limited, another conservation need is to reintroduce propagules to existing and new locations. To accomplish this goal, the basic biology of the species had to be researched. To learn about the reproductive biology of the species and to reintroduce propagules to wild populations, The Arboretum of Flagstaff began a series of studies under contract with the U.S. Fish and Wildlife Service in cooperation with the National Park Service.

Methods

Germination Studies

Seeds collected from 53 plants growing in one of four subpopulations at Maricopa Point were tested for germination potential to determine germination requirements and seed viability of the sentry milkvetch. The subpopulations are isolated by 100–150 m, have experienced varying degrees of foot traffic, and may or may not be reproductively isolated. On 31 July and 1 August 1989, seeds were placed in a potting medium (50% peat moss, 50% #20–30 sand) on an open bench in a greenhouse, where they received water every 1–3 days. The germination success of individual parents and plants from one of four subpopulations was recorded on 7 September 1989. Percent germination success among the subpopulations was analyzed using a Kruskal–Wallis test.

This nondestructive method of testing seed germination was used, rather than destructive chemical viability tests, because the rarity of the species dictates that each propagule is vital to the species conservation and no seeds can be sacrificed.

Transplanting and Soil Requirements

To test the soil requirements of the sentry milkvetch, a subsample of 50 germinated seedlings was transplanted into one of two different soil media. Two replicates of 10 seedlings each were transplanted into potting media containing mixtures of limestone, sand, perlite, or peat moss, and three replicates of 10 seedlings were transplanted into unaugmented limestone soils. Survivorship was measured on 12 December 1989 and 14 May 1990 and was analyzed using a Mann–Whitney test.

Experimental Seed Introduction

To examine field germination requirements, 196 seeds collected from the population in 1989 were reintroduced to Maricopa Point on 3 July 1990. Seven seeds were sown into each of seven replicates of four different microsites. The microsites were (1) unshaded pockets in the bedrock holding powdered limestone or fine gravel at least 1 cm deep, (2) unshaded cracks in the bedrock, (3) soil on the east side of trees or shrubs, and (4) soil on the southwest side of trees or shrubs. Germination, seedling establishment, and survival were assessed every 2–4 weeks until November 1990. Overwintering survival was assessed in spring 1991.

Field Observations of Seed Germination and Dispersal

Germination and seedling establishment at Maricopa Point were recorded to determine patterns of natural germination. Because dispersal of sentry milkvetch seeds appeared to be limited, 12 adult plants known to have flowered the previous spring were used as focal points from which germination and seedling establishment could be examined. Adult plants were marked with aluminum tags, taking care not to damage roots. Seedlings were recorded by marking nearby pebbles with nail polish. For 10 months, germination and survival of seedlings near the 12 test plants were recorded.

Results

Germination Studies

The average germination of seeds was 49%; however, germination success of seeds from individual parents ranged from 0 to 100%. Mean germination across subpopulations varied from 14.3 to 53.2% (Table 1).

Table 1. Mean seed germination from greenhouse studies of four subpopulations at Maricopa Point.[a]

Subpopulation[b]	Mean germination (%)
M1	32.4 ± 0.06
M2	49.3 ± 0.005
M3	53.2 ± 0.09
M4	14.3 ± 0.00

[a] Numbers are means ±1 SE.
[b] M1, M2, and M3 germinations did not differ significantly (Kruskal–Wallis = 0.23, $P = 0.89$).

Thus, the majority of sentry milkvetch seeds tested were viable and germinated at percentages experienced by other species (e.g., Harper 1977) when given adequate water.

Transplanting and Soil Requirements

Seedlings transplanted readily. For the first 5 weeks after transplanting, mortality was low and there was no significant difference between seedlings transplanted into augmented versus unaugmented media ($U = 2$, $P > 0.05$). However, in the next 5 months, mortality increased markedly (Table 2). Survival was significantly greater in unaugmented limestone soils than in augmented soils ($U = 6$, $P = 0.1$; Table 2). In augmented soils, seedlings died from desiccation, rather than disease. These results suggest that water retention of the unaugmented limestone soils is greater than in augmented soils and sentry milkvetch seedlings are intolerant to slight water loss.

Experimental Seed Introduction

Despite the good rains received at Maricopa Point in summer 1990, seed germination and survival in experimental microsites were not successful. Although 10% of seeds germinated, only 1% of the seedlings successfully established (Table 3). Seedlings germinated in all four microsites; however, only a single seedling that germinated in a crack in the limestone survived through winter 1990–91. One seedling that germinated on the east side of a

Table 2. Comparison of seedling survival in augmented and unaugmented limestone soils.[a]

Planting date	Soil media	Replicate	Survivors 12-19-89	Survivors 5-14-90
11-9-89	Limestone augmented	1	9	0
	with sand, perlite, peat	2	10	0
11-9-89	Limestone	1	5	3
		2	9	4
		3	9	4

[a] Ten seedlings were transplanted into each replicate.

Table 3. Seed germination and survival in experimental microsites.

Microsite	Total seeds introduced	Number germinated	Number survived to May 1991
Unshaded pockets	49	1	0
Unshaded cracks	49	2	1
East side of shrub	49	1	0
West side of shrub	49	7	0

shrub survived through November 1990 but did not survive winter 1991. Frost heaving was evident in many of the microsites. The notable exception was the crack containing the lone surviving seedling.

Field Observations of Seed Germination and Dispersal

Natural seed germination primarily occurred in fall (Table 4) in soils at least 3 cm deep. Most of the seedlings germinated within 10 cm of adult plants. Seedling mortality was highest in fall 1990, whereas winter mortality ranged from 20 to 33%. If seedlings persisted until April 1991, they had high survivorship. Seedling survival also tended to be higher for those seedlings that established near potential nurse plant species, such as snakeweed (*Gutierrezia* spp.) and cliffrose (*Purshia stansburiana*).

Discussion

The experimental introduction of seeds to Maricopa Point had low success. The greenhouse germination studies indicated that an average 49% germination could be expected. Field germination in 1990, however, was only 10%, and survival was only 0.05%. Although studies of other plants have reported recruitment percentages as low as 1%, many species have much higher recruitment (e.g., Harper 1977). This begs the question of why germination was so much lower than expected.

My observations of natural seedling germination suggest several reasons why the microsites chosen for reintroducing seeds may not have been ideal. First, soil depth seems to be critical to seed germination. Natural germination occurred in soils at least 3 cm deep but not deeper than 5 cm. Soils 3–5 cm in depth were uncommon in the experimental microsites. The experimental

Table 4. Seed germination and seedling survival in natural population of sentry milkvetch (*Astragalus cremnophylax* var. *cremnophylax*).

Date	Number of seedlings[a]			Mortality[b]
	Births	Survivors	Deaths	(%)
9-7-90	14			0
9-27-90	1	6	8	57
10-11-90	39	5	2	33
11-02-90	14	26	12	27
2-13-91	0	36	8	20
4-15-91	1	30	6	17
5-30-91	0	30	1	3

[a] Total births, survivors, and deaths of seedlings recorded near 12 adult plants over 9 months.
[b] The percentage of mortality between each observation date.

microsites near shrubs had deeper soils, whereas those associated with limestone platforms had shallower soils. Soils deeper than 5 cm may have experienced frost heaving, which may have contributed to overwintering seedling mortality. In contast, soils less than 3 cm in depth may have a tendency to dry rapidly, causing seedling mortality. Greenhouse studies indicated that sentry milkvetch seedlings had surprisingly low drought tolerance, especially in loose-textured augmented limestone soils. Limestone bedrock may play a role in storing and providing water for seedlings at Maricopa Point, because the habitat where the seedlings grow has extremely shallow soils that have potentially low soil moisture retention capabilities (U.S. Fish and Wildlife Service 1993).

A second reason why the experimental microsites may have failed is that natural germination often occurred near other plants, suggesting that seedlings may need nurse plants in order to become established. Nurse plants may provide protection from wind and sun and provide microclimates with slightly elevated humidity and moisture that can protect seedlings from drought.

Third, it is possible that the 1-year-old seeds used in the reintroduction had reduced viability. This remains a strong possibility because nothing is currently known about seed longevity of sentry milkvetch. Future tests using seeds stored for known time periods can resolve this question.

Fourth, genetic inbreeding may be affecting various aspects of seed and seedling health because the numbers of individuals at Maricopa Point are so few. It is possible that abnormalities in seeds or seedlings affected germination rates and survival. Tracking germination success for individual parents through time is a possible avenue for evaluating the genetic health of the population.

Future reintroduction efforts will incorporate the findings of this study to attempt to improve germination and establishment success. Because the sentry milkvetch population is vulnerable to extinction due to its low population and limited distribution, it is imperative that efforts on its behalf be continued by federal agencies and private institutions.

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