Populations of *Amsinckia grandiflora* (Large-flowered Fiddleneck): Growth and Decline Under Different Management Regimes

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Plant Conservation Program
California Department of Fish and Game
1416 Ninth Street
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Abstract

The present study is part of an ongoing recovery effort for *Amsinckia grandiflora* , emphasizing the creation, enhancement, and evaluation of self-sustaining populations. The specific objectives included; 1) evaluation of the seven-year-old reintroduced population at Lougher Ridge under an "enhanced" (manipulated) management regime, 2) ongoing monitoring of the natural populations, 3) sixth year evaluation of the reintroduced populations at Black Diamond II, Los Vaqueros I, Connolly Ranch, and Corral Hollow and 4) determination of a nutlet source (genetic) effect using a common garden experiment at Lougher Ridge and Corral Hollow.

The reintroduced population of *Amsinckia grandiflora* at Lougher Ridge was comprised of only 30 reproductive plants in 1996, a decrease of 93 % since 1995. The decrease was due in part to unknown factors that inhibited germination, especially of Davis source nutlets. Davis nutlets were the garden-propagated descendents of nutlets collected by Dr. Robert Ornduff from the Site 300 Droptower in the mid-1960's. Plant size (and presumably nutlet output) remained high compared to most other years, but low population size significantly reduced potential for continued growth and self-maintenance.

The natural Droptower population at Site 300 consisted of 1949 reproductive individuals in April of 1996, a 76% increase over the previous year. The plants were generally smaller than usual, even with habitat enhancement treatments. Nevertheless, the data strongly suggest that the Droptower population has considerable resilience in the face of large variations in environmental variables (e.g. rainfall, temperature). Ongoing manipulation of the annual grass cover, both with dilute herbicide and controlled burns, is necessary. The size of the untreated, natural population in Draney Canyon decreased to 9 plants and plant size remained small. In the absence of management intervention, the Draney Canyon population is likely to be extirpated in the near future.

The reintroduced Black Diamond II, Los Vaqueros I, and Connolly Ranch populations were apparently extirpated in 1995-96, with no reproductive plants found at any of the sites. Previous disturbance by gophers probably increased mortality of established plants and kangaroo rats (especially *Dipodomys heermanni*) cleared large patches of plant cover by chewing off the stems of grasses and forbs alike (including *A. grandiflora*) and probably foraged for seeds. Although it is only speculation at this time,

stem clipping and seed collection by kangaroo rats may be having a large impact on some populations of *A. grandiflora* . A study of nutlet mortality with respect to nocturnal rodents is currently being conducted to help explain the unexpected decline of *A. grandiflora* at Connolly Ranch, and to provide data for demographic simulation models.

The original population reintroduced to Corral Hollow Ecological Reserve decreased to 18 plants, but the surviving plants were large with high nutlet output per plant. The decrease was due in part to unknown factors that inhibited germination, especially of Davis source nutlets (see below). Although the CH population remains small, it has a potential for growth and may contribute to the recovery of the species.

The new population (Carnegie Canyon) east of Connolly Ranch decreased in size and extent in 1995-1996, although plants still number in the thousands. Mean size and mean maximum size were above average, and at least 80 nutlets were produced per plant.

In most years at Lougher Ridge and Corral Hollow, no significant differences in demographic performance could be detected between the Davis and Carnegie nutlet sources. Year-to-year and site differences appeared to be more important than source differences. However, a significant difference in total germination was detected at both sites during 1995-1996. Germination was very low overall, but germination of Carnegie nutlets was at least twice that of Davis nutlets. Even though few plants were thus produced, Carnegie plots were relatively showy at flowering time and attracted more pollinators than Davis plots. This difference could only be detected when most nutlets remained dormant. The conditions during 1995-1996 which constrained germination are difficult to identify.

Acknowledgments

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Populations of *Amsinckia grandiflora* (Large-flowered Fiddleneck): Growth and Decline Under Different Management Regimes

Bruce M. Pavlik

The recovery of endangered plants requires the creation of new, self-sustaining populations within historic range and the enhancement of natural populations *in situ* (Pavlik 1994a). In the case of *Amsinckia grandiflora* Kleeb. ex Gray, new, reintroduced populations and enhanced natural populations are required by the draft recovery plan (U.S. Fish and Wildlife Service 1987). The present study is part of an ongoing recovery effort for the species (Pavlik 1988, Pavlik and Heisler 1988, Pavlik 1990, 1991a, 1991b, 1992, Pavlik et al. 1993, Pavlik 1993, 1994b, 1995a, 1995b) that emphasizes the creation, enhancement, and evaluation of self-sustaining populations.

The specific objectives of the present study included; 1) evaluation of the seven-year-old reintroduced population at Lougher Ridge under a enhanced management regime, 2) ongoing monitoring of the natural populations at the Droptower on Site 300, and the large, natural population in Carnegie Canyon, 3) sixth year evaluation of the reintroduced populations at Black Diamond II, Los Vaqueros I, Connolly Ranch, and Corral Hollow, and 4) an extension of a three year common garden experiment conducted at Lougher Ridge and Corral Hollow.

Methods and Materials

Managing and Evaluating the Reintroduced Population at Lougher Ridge

The Lougher Ridge reintroduction site was manipulated to reduce annual grass cover during spring 1996, allowing evaluation of its performance under an "enhanced", seven year management regime (Pavlik 1995a). Light, patchy application of a 1/10th strength, grass-specific herbicide (Fusilade) was made on 12 January 1996, centered on the 20 original treatment plots of the 1989-90 reintroduction (Pavlik et al. 1993). *Amsinckia* seedlings were in the two leaf stage and the annual grasses were dense and between 4 and 8 cm tall. Just enough spray was used to wet the annual grass leaves while those of native perennial grasses were avoided.

The site was inspected on 4 November, 8 November, 13 November, 18 November, 21 November, 29 November, 12 January, 10 April, and 23 April to observe seedlings, record phenology, read the raingauge and to fix the fence. Census of the population took

place on 23 April 1996, when *Amsinckia* plants were at the peak of floral display. Each of the 20 treatment plots from 1989-1990 (see Figure 2, Pavlik 1991b) served as a reference for counting plants, since it appeared that most nutlets did not disperse far from their place of origin. All plants within a 2 X 2 m area centered on each treatment plot were counted as progeny of the previous generation that originated in that particular plot. Plants that grew between the 2 X 2 m areas were counted as part of the census but their origins were not assigned to plots. Finally, outlying plants that dispersed and grew beyond the original fenced area were tallied according to floral morph (pin or thrum) and their heights measured. The distance of each outlier to the fence was also determined.

In order to estimate nutlet production of the 1995-96 population, all plants were measured for shoot length on 23 April 1996. Shoot length was translated into nutlet output per plant using a new correlation developed from plants growing at Lougher Ridge in 1992 (Pavlik 1992). Methods for determining the relationship between nutlet output and shoot length and estimating nutlet production of the population are described in Pavlik (1991a).

Evaluating the Natural Populations at Site 300

The Droptower population at Site 300 was manipulated to reduce annual grass competition during 1995-1996, allowing evaluation of its performance under an "enhanced", management regime (Pavlik 1995a). Light, patchy application of a 1/10th strength, grass-specific herbicide (Fusilade) was made on 23 January 1996, centered on patches a through f as designated during the first treatment in 1991 (Pavlik 1991b). *Amsinckia* seedlings were in the two leaf stage and the annual grasses were sparse and between 6 and 8 cm tall. Just enough spray was used to wet the annual grass leaves while those of native perennial grasses were avoided.

A census was conducted on 9 April 1996 and included total population size, pin/thrum ratio, and spatial distribution. In order to estimate nutlet production and to determine the effects of controlling annual grasses on plant growth, 100 plants were randomly selected and measured for shoot length. Four reference stakes were located *a priori* near the top and bottom of the fenced area (two towards the west side, two towards the east). At each stake a random numbers table was used to generate 25 compass bearings (0 to 360^{o}) and 25 distances in centimeters (0 to 400 cm). The plant nearest to a point described by each pair of bearing-distance coordinates had its shoot length measured and its floral morph (pin/thrum) determined. Shoot length was

translated into nutlet output per plant using the equation developed at Connolly Ranch in 1991 (#nutlets/plant = 3.42 (shoot length in cm) - 65.46, $r = 0.86$ $P<0.01$, Pavlik 1991a).

The Draney Canyon population at Site 300 was censused on 15 April 1996 by staff of Lawrence Livermore National Laboratory (supervised by Tina Carlsen). Every plant was counted and recorded as to floral morph. Never having been treated with herbicide, this population serves as a control for comparisons with the Droptower population.

Evaluating Reintroduced Populations at Black Diamond II, Los Vaqueros I, Connolly Ranch and Corral Hollow

In the sixth year after reintroduction, the Black Diamond II, Los Vaqueros I and Connolly Ranch populations were not manipulated to reduce annual grass competition during 1995-1996, and were thus under a "natural" management regime (Pavlik 1995a). Final census of the Connolly Ranch (CR) site was conducted on 24 April 1996 and included total population size, pin/thrum ratio, and spatial distribution. Final census of the Black Diamond II (BD II) and Los Vaqueros (LV) sites was conducted on 23 April and 2 May 1996, respectively.

Census of the Newly Discovered Natural Population

This population was mapped, described, censused for density, pin/thrum ratio and plant size on 16 May 1996. It has tentatively been named the "Carnegie Canyon" population.

Common Garden Experiment at Lougher Ridge and Corral Hollow

Using nutlets from two sources with different levels of electrophoretically-detectable variation, Pavlik et al. (1993) created an experimental population of *A. grandiflora* at Lougher Ridge. Despite intense demographic monitoring of nutlets and plants derived from the two sources, no differences in germination, survivorship, pin/thrum ratio, or nutlet output could be detected. In general, genetic considerations are currently viewed as less important in population establishment and persistence than environmental stochasm (Menges 1992, Guerrant and Pavlik 1997). Few rigorous tests of genetic effects *in situ*, however, are found in the published literature on rare or endangered plants. Such effects may determine the success of recovery efforts that involve the creation or enhancement of populations in the wild. I tested for genetic effects from two different

source populations of *A. grandiflora* at two different sites in two growing seasons, using a Turreson-type common garden experiment. Not only was a statistically-significant genetic effect detected in one of the years, the poor performance of some populations in 1995-1996 could be explained by an examination of the same demographic data.

One of the two nutlet sources was the 1989 crop of *A. grandiflora* plants grown in a garden at UC Davis (Pavlik 1990). Davis nutlets were the garden-propagated descendents of nutlets collected by Dr. Robert Ornduff from the Site 300 Droptower in the mid-1960's. The other source was the 1993 or 1994 collections made from the large, natural population in Carnegie Canyon (Pavlik 1993, 1994b). Although electrophoretic studies were not made on these particular nutlet cohorts, other cohorts from Davis and Carnegie Canyon differ in the amount of detectable genetic variation (Pavlik et al. 1993, unpublished data). The cultivated nutlets from Davis have low variation (percentage of polymorphic loci, number of alleles per locus, heterozygote frequency) compared to nutlets from any natural population. Otherwise, gross phenotypes of plants from the two sources appear similar. All fresh nutlets were air-dried at room temperature prior to storage in paper envelopes at 4 C. Laboratory tests conducted under near-optimum conditions (Pavlik 1988) over several years demonstrated 60-73 % germination for Carnegie Canyon 93 or 94 nutlets and 73-92% for Davis 89 nutlets.

The two sites selected for common gardens lie at the northern and southern edges of the historic distribution of *A. grandiflora* . Lougher Ridge, in Black Diamond Mines Regional Preserve near Antioch, Contra Costa County, is the site of the first *A. grandiflora* reintroduction. Corral Hollow Ecological Reserve is along Corral Hollow Road in San Joaquin County, less than an aerial mile from the natural Droptower and Carnegie Canyon populations. Both have been ecologically characterized in previous reports (Pavlik 1990, 1992).

Nutlets from the two sources were sown into replicate plots that varied in number and size depending on nutlet availability. During the 1993-1994 experiment, six replicates of each nutlet source were sown with 70 Davis 89 or 30 Carnegie 93 nutlets. This means that 420 and 180 nutlets, respectively, were sown at each garden site. During the 1995-1996 experiment, four replicates were sown with 100 nutlets each for each source (a total of 400 nutlets of Davis 89 and 400 of Carnegie 94 at each site). An additional experiment was conducted in 1994-1995 at Corral Hollow, using four replicates of 50 nutlets from each source (Davis 89 and Carnegie 94). In all years, sowing utilized the removable wooden plot frames and techniques described in Pavlik et al. (1993), and took place just before the first significant rains of the fall season (by mid-November). The position of each plot was randomly selected within a subjectively-determined patch of suitable

habitat. No supplements of water or nutrients were added, and existing grass cover was left in place. Competition from annual grasses was reduced in all plots by spraying with a dilute solution of a grass-specific herbicide (Fusilade) according to methods described in Pavlik et al. (1993) and Pavlik (1995a). Applications took place after grass emergence, usually by mid-January.

Plots were checked for initial germination of *A. grandiflora* between mid-December and mid-January using the planting frames fitted over permanent metal stakes. Encoded data sheets that resembled the plot frames facilitated the task of recording information. Each plant was marked with a wooden potsticker so that subsequent germination could be detected and added to initial germination (the sum represents total germination for the year). Survivorship to reproduction was determined by the ratio of flowering plants (in early to mid-April) to total germination. At this time, pin-to-thrum ratio and plant size could also be determined (Pavlik et al. 1993).

Evaluation of the demographic performance of nutlets from the two sources in two gardens during different years was made by comparing total germination, survivorship to reproduction, and reproductive plant size between sets of replicate plots (Pavlik 1994a). Statistical analysis of differences was made using ANOVA with arcsine transformation where appropriate.

Results and Discussion

Weather Patterns and Phenology During 1995-1996

In northern California the 1 November to 31 May growing season of 1995-96 had a slightly above average amount of precipitation. Records for San Francisco, Oakland, and Sacramento indicate that rainfall was 103-116 % of normal during the 1 Nov to 31 May period, with an overall regional surplus of about 9 % (compared to a 66% surplus during 1994-1995, a 28% regional deficit during 1993-1994, a 42% regional surplus during 1992-1993 and a 5-25% deficit during the previous three growing seasons). The total precipitation actually received at Lougher Ridge during the October to May period of *Amsinckia* activity was 528 mm (724 mm in 1994-95, 268 mm in 1993-94, 489 mm in 1992-93, 296 mm in 1991-1992, 271 mm in 1990-91, and 289 mm in 1989-90).

In terms of temporal pattern of precipitation, 1995-96 was unusual (Figure 1). The first significant storm dropped 54 mm of rain on 11 December. Prior to this, only 2.8 mm fell on 4 December, with no prior measurable precipitation. Additional rainfall came frequently throughout the winter and spring, but monthly totals progressively declined

from 188 mm in December to 109 mm in January, 95 mm in February, 75 mm in March and 37 mm in April. In previous years, precipitation started earlier (except in 1990-91) and peaked between January and March.

The phenology of the Lougher Ridge population was not closely observed during this wet growing season. *Amsinckia* germinated in response to the precipitation received in mid-December. Annual grasses had also germinated and grew vigorously at that time. It is likely, therefore, that competition between *Amsinckia* and the annual grasses was intense during the early portion of the growing season (Pavlik et al. 1993). The final census at Lougher Ridge was conducted on 23 April. The plants were above average in size, often branched and some calyxes contained fully formed, green nutlets. By 12 May plants were completely senescent, with mature nutlets that had already dispersed from the dry inflorescences. The patterns of rainfall and *Amsinckia* phenology at other sites with natural and reintroduced populations were similar to those at Lougher Ridge.

Status of the Reintroduced Population at Lougher Ridge

A total of only 30 flowering plants of *Amsinckia grandiflora* were counted at Lougher Ridge on 23 April, 1996, a large decrease from the 446 reported in 1995 and the 1106 reported in 1994 (Table 1). Most plants were still found in or near the 20 original reintroduction plots. Overall, the floral display was overwhelmed by the dense grass canopy. The pin/thrum ratio was 1.33 inside the fence, but even outside the fence.

The 1996 plants at Lougher Ridge were slightly larger than usual, as indicated by their mean and maximum sizes (Table 2). However, there were fewer plant size-classes represented in the 1996 population (13 classes vs. 25 in 1995, 14 in 1994, 17 in 1993, 14 in 1992 and 10 in 1991), with no individuals found in the largest (52-90 cm) reproductive categories (Figure 2). Unlike in 1995, the 1996 plants were well branched (commonly 4-8 branches, with a maximum of 17) with many flowering stems. This may have been a response to the reduction in annual grass cover caused by the herbicide treatment. The nearest neighbors to 83% of the reproductive *A. grandiflora* individuals were the native forbs *Montia perfoliata* and *Galium* sp. and not the dominant annual grasses observed in the previous year.

Table 1. Comparison of characteristics of the Lougher Ridge population of *Amsinckia* , March or April census, 1990 - 1996.

	reproductive plants			population growth			pin / thrum ratio		
year	inside fence (# pl)	outside fence (# pl)	Σ (#pl)	inside fence (%)	outside fence (%)	Σ (%)	inside fence (dimensionless)	outside fence	Σ
1990	1101	---	1101	---	---	---	1.36	---	1.36
1991	1280	21	1301	16.3	---	18.2	1.27	0.91	1.27
1992	1592	48	1640	24.4	128.6	26.1	0.92	2.61	0.97
1993	645	37	682	-59.5	-22.9	-58.4	1.50	1.47	1.49
1994	1094	12	1106	69.5	-67.6	62.2	1.44	11.00	1.67
1995	402	20	422	-63.2	66.7	-61.8	1.46	2.33	1.50
1996	28	2	30	-93.0	-90.0	-92.9	1.33	1.00	1.31

Table 2. Plant size (length of main shoot, cm, mean ± SD) at four points within the fenced area at Lougher Ridge (n = 25 for mean, n = 10 for maximum) and for all plants outside the fence, at peak of flowering, except for 1996 (see text). Overall mean values for 1990 include all treatment means (Table 18, Pavlik 1990). na = data not available.

	plant size (cm)					
	upper E	upper W	lower E	lower W	outside fence	overall mean
mean						
1990	na	na	na	na	na	21.2
1991	25.3 ± 5.9	23.8 ± 7.8	29.2 ± 3.6	26.5 ± 5.4	26.7 ± 7.3	26.3
1992	28.5 ± 6.0	30.2 ± 9.7	28.8 ± 7.3	26.9 ± 8.3	25.7 ± 8.3	28.0
1993	35.9 ± 9.1	39.8 ±12.4	33.5 ± 9.1	33.1 ± 9.8	39.0 ±10.9	36.5
1994	21.9 ± 7.8	22.2 ± 8.7	22.9 ± 7.8	20.2 ± 6.7	25.7 ± 8.3	22.2
1995	41.2 ± 14.3	37.4 ± 10.1	45.8 ± 12.6	45.4 ± 10.1	43.4 ± 9.7	42.6
1996	32.8 ± 6.8	32.9 ± 8.9	24.0 ± 11.1	29.3 ± 12.1	42.5 ± 6.5	31.5
maximum						
1990	na	na	na	na	na	30.8
1991	31.0 ± 2.8	31.6 ± 3.6	29.2 ± 2.0	31.5 ± 1.5	32.5 ± 4.5	31.2
1992	33.8 ± 4.8	40.1 ± 4.1	36.0 ± 5.0	34.8 ± 6.3	38.0 ± 5.8	36.5
1993	44.5 ± 6.6	52.5 ± 6.3	42.2 ± 7.1	42.7 ± 6.6	53.6 ± 5.7	59.1
1994	29.6 ± 4.2	30.9 ± 5.5	30.4 ± 4.4	26.4 ± 3.9	28.0 ± 6.7	36.3
1995	55.3 ± 6.9	46.0 ± 6.6	58.1 ± 9.2	55.5 ± 4.8	55.7 ± 4.8	64.9
1996	40.0 ± 2.9	41.3 ± 5.6	36.5*	43.5*	49.0*	40.8

* too few plants to calculate a mean and SD

Table 3. Estimates of nutlet production by the population at Lougher Ridge. The values for 1990 and 1996 were derived from every individual in the population, while those for 1991-1995 were based on a random sample of 100 plants from within the fenced area.

year	# of repro plants	total # nutlets produced	nutlet production growth rate (%/ yr)
1990	1101	35,800	--
1991	1301	51,400	43.6
1992	1640	66,980	30.3
1993	682	46,380	-31.0
1994	1106	16,590	-64.2
1995	422	39,871	140.3
1996	30	1,558	-96.1

An estimated 1,558 nutlets were produced in 1996, a 96% decrease compared to total nutlet production in 1995 (Table 3). Nutlet production per plant was high (mean of 52 nutlets per plant), so that the reduction was due to small population size.

Status of the Natural Populations at Site 300

The Droptower population consisted of 1949 reproductive individuals in April of 1996, the largest population ever censused at this site and the largest since annual grass management began in 1991 (Figure 3). Most *Amsinckia* individuals (about 600) were found in a patch, approximately five meters long, that dominated the northeastern corner of the old fenced enclosure. The five, discrete patches along the eastern edge of the fenced area close to the two oak trees were more apparent this year than last. The two large western patches tended to recede towards the top and bottom of the fenced area,

with relatively few plants filling in between. Another 55 plants were found 50 m west of the enclosure. In 1993 this group consisted of 31 plants and only seven plants in 1992. Furthermore, a total of 181 plants could be found downslope (north) of the original fenced area where 73 were found in 1995 and only a handful could be found before. Despite the large number of plants in the population, the overall pin/thrum ratio at the Droptower was 2.00 as it was in 1995.

Compared to 1995, plant size decreased at the Droptower significantly (Table 4). Only 5% of all reproductive plants exceeded 40 cm in height (62% in 1995, 6% in 1994, 36% in 1993) and none were greater than 50 cm (23% in 1995, 0% in 1994, 14% in 1993). Annual grass cover across the site was sparse to moderate, with the height of *Avena* in the range of 30-40 cm (50-60 cm in 1995, 10-25 cm in 1994). Plants in 1996 tended to have few branches (typically 1-2 per plant), with a maximum of 6 flowering branches each, compared to a maximum of 13 each (3-5 per plant) in 1995 and 32 each (3-6 per plant) in 1993. The large number of large reproductive plants this year produced a very showy display that lasted into May. Consequently, nutlet output per plant was high in 1996, but half that estimated for 1995.

This was the third year since the beginning of the recovery effort in 1987 that the Droptower population of *Amsinckia grandiflora* , once the only known extant population of this species, had exceeded the lower management threshold of 1000 individuals and the second year that it surpassed the minimum viable size threshold of 1500 individuals. Although the population can be expected to both decrease and increase in size over the next decade, the management objective is to confine those oscillations to a high, demographically-significant range (1000-2000 individuals) rather than the low, deleterious range (23-355 individuals) of recent years. Ongoing manipulation of the annual grass cover, both with dilute herbicide and controlled burns, is necessary.

The population in Draney Canyon population decreased in size relative to 1995, with only 9 plants found only on the east-facing side of the canyon (Figure 4). Other plants may have been present but were senescent and, therefore, difficult to see at the time of census. Plants were smaller (10-15 cm) than had been observed in previous years, but no measurements were taken. The pin/thrum ratio (3.5) was very skewed towards pins. Although the Draney Canyon population is valuable for comparative purposes in its unmanipulated, natural state, its small, fluctuating size and confinement to one wall of the canyon (apparently by severe erosion) requires some active management to improve growth and reproductive output.

Table 4. Comparison of 1991-1996 performances of the Droptower population. See Pavlik (1991, 1992, 1993, 1994, 1995b) for descriptions of the management regimes.

		plant size		nutlet production	
	P/T ratio	mean maximum (cm)	mean (cm)	mean #/repro plant)	total (# in all patches)
1991 unsprayed	1.70	34.6 ± 2.9	27.1 ± 6.6	31	1,126
sprayed	2.36	35.5 ± 4.7	22.1 ± 8.9	25	927
1992 unsprayed	0.81	34.5 ± 6.6	28.0 ± 6.7	30	4,590
sprayed	2.00	41.9 ± 7.8	36.1 ± 8.2	58	22,330
1993 unsprayed	0.99	51.4 ± 4.4	33.4 ± 12.5	49	16,270
1994 sprayed	1.22	40.4 ± 2.5	25.4 ± 8.6	21	33,726
1995 unsprayed	2.00	67.7 ± 5.3	44.1 ± 12.2	85	94,690
1996 sprayed	2.00	40.0 ± 3.0	26.9 ± 7.2	27	52,623

Status of the Reintroduced Populations at Black Diamond II, Los Vaqueros I, Connolly Ranch, and Corral Hollow

The Black Diamond II population was in its third year since extirpation, with no reproductive plants emerging from the seed bank in 1995-1996 (Table 5). Only six plants were found during the April 1993 census and those tended to be smaller than in previous years. Mean maximum size had decreased and the size-class distribution had contracted by 1993, severely limiting nutlet production. The pin/thrum ratio had been 0.50, the largest deviation from unity yet recorded in a population. These demographic characteristics were used to accurately predict the imminent failure of the population (Pavlik 1993), although

some live nutlets could still persist in the soil seed bank (Pavlik 1995b). Disturbance by gophers in 1996 was nil, affecting none of the 12 plots within the fenced area (11 out of 12 were so affected in 1993-1994). Pervasive rodent activity, combined with poor demographic performance have significantly decreased the probability of nutlets germinating and surviving in favorable habitat patches. Black Diamond II is not, therefore, a site that will contribute to the recovery of the species.

Complete extirpation appears to have occurred at Los Vaqueros I, with no reproductive plants emerging from the seed bank. In 1993-1994 the Los Vaqueros I population produced one small plant which had flowered but produced no nutlets. The steep decline over a four year period was predicted by the 1991 demographic data (Pavlik 1991a, 1992). The data clearly show that vegetative growth leading to the production of flowers was inhibited, resulting in small, unbranched plants with few inflorescences and little potential for nutlet output. Los Vaqueros I is not, therefore, a site that will contribute to the recovery of the species.

The Connolly Ranch population continued to decline in 1995-1996 as no reproductive plants were found during the April 1996 census. Only 8 flowering plants had been observed during the previous year bearing an average of 10 nutlets each. Although grasses were not as dense or tall as at other sites (45-70% absolute cover), there was no evidence that previous management had reduced competition and provided benefits to *A. grandiflora*. In two of the twelve plots there was a low degree of disturbance by rodents, with much less

Table 5. Characteristics of the Black Diamond II, Los Vaqueros, Connolly Ranch, and Corral Hollow populations, 1996.

	repro pop size (# pl)	P/T ratio	plant size: mean maximum[1] (cm)	plant size: mean[2] (cm)	nutlet production: mean (#/repro plant)	nutlet production: total (# in all plots)
Black Diamond II	0	0	0	0	0	0
Los Vaqueros I	0	0	0	0	0	0
Connolly Ranch	0	0	0	0	0	0
Corral Hollow	18	2.6	39.4 ± 4.9	32.9 ± 9.0	47	846

[1] n = 10 [2] n = repro pop size

mounding of soil and clearing of plant cover than in previous years. Nevertheless, seed predation by rodents and birds may have been a primary factor in the rapid decline of this population. Petri dishes containing *A. grandiflora* nutlets are frequently visited during many times of the year (data collection still in progress), and there is ample evidence of seed collection by kangaroo rats within the fenced area. Furthermore, four trap lines, consisting of a total of 87 Sherman-type live traps, captured five seed-eating rodents on a single night (18 November 1995) in the immediate vicinity of the population. Two of the rodents were large kangaroo rats (*Dipodomys heermanii*), two were deer mice (*Peromyscus maniculatus*) and one was a pocket mouse (*Perognathus californicus*). One of the kangaroo rats was large (75 g) and captured within 5 m of the fenced exclosure (which could easily be traversed by small mammals). Therefore, intense seed predation may have had a large impact on the Connolly Ranch population of *A. grandiflora* .

The total population at Corral Hollow on 24 April 1996 was only 18 plants with a pin/thrum ratio of 2.60 (Table 5). This represents a precipitous decline since the 173 recorded last year. The greatest number of plants (14) were found in the 1991-1992 scatter-sown plots. As observed at most other sites, the plants were slightly larger than average, with mean maximum and mean size significantly larger than reported in most other years (with the exception of 1994-1995). Nutlet production, however, was much lower than in previous years due to the small total population. Annual grasses were tall and cover was moderate (60-80%). Common fiddlenecks were not abundant either, unlike in previous years. There was little sign of kangaroo rat foraging or gopher mounding even though such activities were intense in 1993-1994.

Newly Discovered Natural Population

The new population of *Amsinckia grandiflora* discovered on private property east of Connolly Ranch occurs in a large, west-draining canyon on the steep north-facing slope at approximately 1000' elevation (see Pavlik 1993 for a full description). The population is contained in an area of approximately 50 X 52 meters, the upper edge coming within 25 meters of the ridgecrest and the lower edge within 10 m of the canyon bottom. The distribution of plants is not homogeneous - there are about eight high density patches (some as large as 20 m X 10 m, others only 2 m X 2 m) and at least six to eight low density patches (also variable in size).

Census of the Carnegie Canyon population took place on 16 May 1996, very near the peak of the floral display. The population had contracted significantly relative to all other years, and the largest of patches was perhaps 3 m X 3 m. Unlike before, the eastern and

western edges of the population were difficult to define, as isolated plants were scattered across the hill side. There was no showy, continuous floral display as there was in the spring of 1993. Furthermore, the density of plants within patches was 30-40 % lower than previously observed. A conservative estimate of the total population size would still lie in the range of 1500 - 2500 large plants, the lowest yet observed. Using the circular random sampling technique in four patches (n = 25 plants each) across the population, the pin/thrum ratio was 1.28 (n = 105). Most plants were large with 2-6 branches (maximum of 21). Mean plant size decreased slightly (45.6 ± 13.7 cm vs. 46.1± 13.4 cm in 1995 vs. 36.9 ± 11.2 cm in 1994 vs. 49.7 ± 15.4 cm in 1993), but mean maximum plant size remained high (71.8 ± 8.3 cm vs. 71.7 ± 5.7 cm in 1995 vs. 55.5 ± 2.4 cm in 1994 vs. 73.6 ± 6.6 cm in 1993). Estimated mean nutlet output per plant would easily exceed 80 nutlets. There were no obvious signs of disturbance by rodents at this site.

Common Garden Experiment at Lougher Ridge and Corral Hollow

In most years at both sites no significant differences in demographic performance could be detected between the Davis and Carnegie nutlet sources (Table 6). Survivorship to reproduction ranged between 39 and 75%, slightly but consistently higher in plants derived from the Carnegie source. Pin-to-thrum ratio and reproductive plant size showed no pattern with respect to source, but tended toward "normal" or mean values during 1995-1996. Year-to-year and site differences appear to be more important than source differences, but all values fall within the range observed at Lougher Ridge in 1989-1990 (Pavlik et al. 1993).

Total germination ranged between 18 and 38 %, with the highest values found at Lougher Ridge during the 1993-1994 year. These values were well below the 40-74 % range observed at Lougher Ridge during the 1989-1990 year (Pavlik et al. 1993). However, a significant difference in total germination was detected at both sites during 1995-1996. Germination was very low overall, but germination of Carnegie nutlets was at least twice that of Davis nutlets ($P<0.05$ at Corral Hollow, $P<0.005$ at Lougher Ridge). Even though few plants were thus produced, Carnegie plots were relatively showy at flowering time and attracted more pollinators (mostly anthophorid bees) than Davis plots.

It is important to note that this difference could only be detected when most nutlets remained dormant. The conditions during 1995-1996 which constrained germination are difficult to identify. Rainfall was near normal and higher germination has been documented in many low rainfall years (e.g. 1993-1994, 1990-91 and 1989-1990) as well as in high rainfall years (e.g. 1994-1995, 1992-1993). It began in early December (neither

early or late in the season) and was not associated with extreme winter temperatures (hot or cold). However, temperatures recorded at Black Diamond Mines Regional Preserve (Kathleen Young, pers. comm.) did show that average minimum temperature in December 1995 (10.0 C) was much higher than in all Decembers since 1991 (averages between 0.6 and 2.2 C). Although sensitivity of *A. grandiflora* germination to low soil temperatures has been previously noted (Pavlik 1993) and recently linked to variations in climate and litter cover (Carlsen and Pavlik, in prep.), there may still be a requirement for low temperature exposure (e.g. stratification) in order to promote germination. Alternatively, some other factor, unknown at present, may play a role in cueing nutlets at the soil surface.

The low germination observed in these experimental plots provides evidence that the small population sizes observed at Lougher Ridge, Corral Hollow, Connolly Ranch and Carnegie Canyon were not due to extirpation of their seed banks. Unfavorable conditions for germination, perhaps the aforementioned warm-wet December, did not break nutlet dormancy. This was especially true of Davis nutlets, which constituted the largest fraction in the founding population at Lougher Ridge (Pavlik et al. 1993). Interestingly, the Droptower population grew substantially this year, indicating that its nutlets were less sensitive to the unfavorable conditions or that the unfavorable conditions did not occur at this site. In general, this is the first year since 1990 that the natural and reintroduced populations of *Amsinckia grandiflora* did not exhibit similar patterns of germination and growth (Pavlik 1995b).

Source-specific differences in population performance, whether they be statistically significant (germination) or simply consistent across multiple years (survivorship, plant size), suggest the importance of genetic factors in determining the chance of persistence (Guerrant and Pavlik 1997). Genetic factors are generally considered secondary to the effects of environmental stochasticity (Menges 1992), but data from rare plant populations were not available until now. The present study would indicate that genetic variants, such as the Carnegie Canyon plants that germinated and reproduced during 1995-1996, show themselves during a year with environmental conditions that otherwise would have completely inhibited the species. Presumably, these variant genotypes were lost from the cultivated Davis source of nutlets and must be present to insure the persistence of natural and reintroduced populations. A program of genetic management, involving the infusion of Carnegie genotypes into the Lougher Ridge population, is warranted.

Table 6. Demographic characteristics of experimental populations of *Amsinckia grandiflora* derived from two nutlet sources (Davis and Carnegie Canyon) and reciprocally sown at two sites (Lougher Ridge and Corral Hollow) over several growing seasons. The only significant difference (ANOVA) detected between sources was in 1995-1996 at both sites (different superscript letters).

	# of plots - # of nutlets per plot	germination (% of sown)	survival to repro (% of germ)	P/T ratio	repro plant size (cm)	repro plants (n)
Lougher Ridge						
1993-1994						
Davis 89	6-70	32.2 ± 11.9	41.6 ± 24.6	0.83	13.4 ± 3.5	61
Carnegie 93	6-30	37.8 ± 13.1	47.4 ± 28.0	4.00	14.4 ± 2.6	32
1995-1996						
Davis 89	4-100	2.0 ± 1.2[a]	62.5 ± 41.5	2.0	17.0 ± 2.4	3
Carnegie 94	4-100	8.8 ± 1.9[b]	74.9 ± 11.4	1.5	25.2 ± 7.6	27
Corral Hollow						
1993-1994						
Davis 89	6-70	23.3 ± 5.1	38.5 ± 25.4	1.33	21.6 ± 5.4	39
Carnegie 93	6-30	31.7 ± 11.0	39.7 ± 27.6	1.50	22.7 ± 6.1	21
1994-1995						
Davis 89	4-50	29.5 ± 11.5	47.4 ± 33.8	2.62	40.9 ± 10.3	29
Carnegie 94	4-50	18.0 ± 6.2	54.2 ± 8.8	1.50	43.7 ± 7.0	20
1995-1996						
Davis 89	4-100	4.0 ± 1.6[a]	61.6 ± 12.6	2.33	27.4 ± 5.6	10
Carnegie 94	4-100	8.0 ± 1.9[b]	67.0 ± 12.5	2.14	26.6 ± 7.8	22

Conclusions and Management Recommendations

1) The reintroduced population of *Amsinckia grandiflora* at Lougher Ridge was comprised of only 30 flowering plants in April 1996, a 93% decrease since 1995 (Table 1). Small population size was the result of conditions which differentially inhibited germination of nutlets in the seed bank derived from the Davis source (Table 6). Those conditions have not been identified, but may include that lack of low temperatures at the time of initial rainfall to provide a stratification-type stimulus. Mean plant size remained high compared to most other years (Table 2), but small population size lowered total nutlet production to 1,560. In the past the Lougher Ridge population has demonstrated resilience (the ability to recover from low population size), which is a critical demographic characteristic with respect to the success of reintroduced populations of *Amsinckia grandiflora* (Pavlik 1996). The potential for continued growth and self-maintenance of the population has been significantly reduced. The recommendation for the eighth year of this population is to increase the abundance and quality of low-competition neighborhoods at Lougher Ridge by mid-winter treatment of patches with a grass-specific herbicide. This patchiness may also be achieved by light, seasonal livestock grazing. Attempts to use livestock to control annual grass cover need to follow an *Amsinckia*-sensitive protocol, developed in cooperation with Black Diamond Mines Regional Preserve. Efforts to restore a portion of the grassland by transplanting plugs of *Stipa pulchra , Poa scabrella, and Elymus* from local individuals into the fenced area also needs to be resumed. More *A. grandiflora* nutlets should be released on the site in a controlled, careful manner so that monitoring of the original Lougher Ridge population is not compromised.

2) The natural Droptower population at Site 300 consisted of 1949 reproductive individuals in April of 1996, a large increase since the previous year (Table 4). The increase was linked to the large, fecund plants produced in 1995. Individual plants in this year were generally smaller than they had been in previous years, even with recent habitat treatment (Table 4). These data strongly suggest that the Droptower population has considerable resilience when habitat manipulations are conducted for purposes of recovery, but that variations in important environmental variables (e.g. rainfall, temperature) will still cause fluctuations in population size and reproductive output. The size of the untreated, natural population in Draney Canyon decreased to 9 plants and plant size probably decreased.

The recommendation for 1996-7 is to further enhance the Droptower population by controlling annual grasses with grass-specific herbicide during the late fall or early winter. Monitoring of grass cover and demographic characteristics are required during the spring of 1997. Greater intervention in the form of nutlet collection is required on behalf of the Draney Canyon population, but not until a season with favorable rainfall amounts and patterns stimulates germination and plant growth so that a larger size-class distribution (with greater fecundity) develops *in situ* . This could be promoted by treating the population during the late winter with dilute, grass-specific herbicide, but access is always problematic.

3) The reintroduced Black Diamond II population remained extirpated during 1995-1996 and produced no reproductive plants. Previous disturbance by gophers probably increased mortality of established plants and further reduced nutlet production. As a result, this population probably has no potential for self-maintenance and is not going to contribute to the recovery of the species. All recovery activities should be terminated at the site five years after the last individuals are recorded.

4) The reintroduced Los Vaqueros I population remained extirpated during 1995-1996 and produced no reproductive plants. As a result, this population probably has no potential for self-maintenance and is not going to contribute to the recovery of the species. All recovery activities should be terminated at the site five years after the last individuals are recorded.

5) The reintroduced population at Connolly Ranch declined significantly and no reproductive plants were found. Although it is only speculation at this time, stem clipping and seed collection by kangaroo rats may have had a large impact on the Connolly Ranch population of *A. grandiflora* . All recovery activities should be terminated at the site five years after the last individuals are recorded.

A study of nutlet mortality with respect to nocturnal rodents and diurnal foraging by birds might help explain the unexpected decline of *A. grandiflora* at Connolly Ranch, and provide data for demographic simulation models (e.g. RAMAS/stage). Live trapping, intensive observation, and fecal analysis are also recommended, perhaps comparing rodent densities and diets at this site to those at the new, natural population, the Droptower, Lougher Ridge (where rodent activity has had minor impacts) and Black Diamond II. These studies have already begun but need to be expanded significantly.

6) The original population reintroduced to Corral Hollow Ecological Reserve decreased, but the surviving plants were large with high nutlet output per plant. Although the CH population remains small, it has a potential for growth and may contribute to the recovery of the species.

The recommendation for the CH population in its sixth year is to conduct a fall burn in order to begin restoration activities on a larger scale. Additional nutlets from the new population should be precision-sown in order to significantly enhance population size and initiate high rates of nutlet production *in situ* . Demographic monitoring and habitat enhancements should occur concurrently.

7) The newly-discovered population east of Connolly Ranch decreased in size and extent in 1995-1996, although plants still number in the thousands. Mean size and mean maximum size were above average, and at least 80 nutlets were produced per plant.

An ongoing dialogue with the leasee of the property is essential for maintaining access and developing a basis for additional conservation action. A census in spring 1997, including the collection of nutlets, is also recommended.

8) In most years at both sites no significant differences in demographic performance could be detected between the Davis and Carnegie nutlet sources (Table 6). Year-to-year and site differences appeared to be more important than source differences. However, a significant difference in total germination was detected at both sites during 1995-1996. Germination was very low overall, but germination of Carnegie nutlets was at least twice that of Davis nutlets. Even though few plants were thus produced, Carnegie plots were relatively showy at flowering time and attracted more pollinators (mostly anthophorid bees) than Davis plots. This difference could only be detected when most nutlets remained dormant.

Source-specific differences in population performance, whether they be statistically significant (germination) or simply consistent across multiple years (survivorship, plant size), suggest the importance of genetic factors in determining the chance of persistence. The present study would indicate that genetic variants, such as the Carnegie Canyon plants that germinated and reproduced during 1995-1996, show themselves during a year with environmental conditions that otherwise would have completely inhibited the species. Presumably, these variant genotypes were lost from the cultivated Davis source of nutlets and must be present to insure the persistence of natural and reintroduced populations. A program of genetic management, involving the infusion of Carnegie genotypes into the Lougher Ridge population, is warranted.

Table 7. A summary of the characteristics and status of created populations of *Amsinckia grandiflora* during the 1990-1996 recovery effort.

year	management regime	repro population (# of plants)	nutlet production (# of nutlets)	pin/thrum ratio	status
Lougher Ridge					
1990	experimental	1,101	35,800	1.36	growing
1991	enhancement	1,301	51,400	1.27	growing
1992	natural	1,640	66,980	0.97	growing
1993	natural	682	46,380	1.49	declining
1994	enhancement	1,106	16,590	1.67	growing
1995	enhancement	442	39,870	1.50	declining
1996	enhancement	30	1,558	1.33	declining
Black Diamond II					
1991	experimental	288	11,280	1.68	growing
1992	enhancement	70	2,163	1.50	declining
1993	natural	6	162	0.50	declining
1994	enhancement	0	0	0	extirpated?
1995	natural	0	0	0	extirpated
1996	natural	0	0	0	extirpated
Los Vaqueros I					
1991	experimental	374	3,200	1.32	declining
1992	enhancement	9	177	0.80	declining
1993	natural	0	0	0	extirpated?
1994	enhancement	1	0	0	declining
1995	natural	0	0	0	extirpated
1996	natural	0	0	0	extirpated

Table 7. (cont.)

year	management regime	repro population (# of plants)	nutlet production (# of nutlets)	pin/thrum ratio	status
Connolly Ranch					
1991	experimental	580	17,030	1.43	growing
1992	enhancement	707	12,019	1.26	growing
1993	natural	133	2,530	1.16	declining
1994	enhancement	23	161	1.58	declining
1995	natural	8	80	3.00	declining
1996	enhancement	0	0	0	extirpated?
Corral Hollow					
1992	experimental	64	1,827	1.39	growing
1993	enhancement	81	6,410	1.38	growing
1994	enhancement	157	1,744	1.58	growing
1995	enhancement	173	16, 090	1.48	growing
1996	natural	18	846	2.60	declining

Table 8. A summary of the characteristics and status of natural populations of *Amsinckia grandiflora* during the 1990-1996 recovery effort. na = data not available

year	management regime	reproductive population (# of plants)	mean plant size (cm)	pin/thrum ratio	status
Site 300 - Droptower					
1990	natural	104	na	1.04	declining
1991	natural	92	24.3 ± 8.3	2.04	declining
1992	enhancement	546	31.4 ± 8.5	1.17	growing
1993	natural	332	33.4 ± 12.5	0.99	declining
1994	enhancement	1606	25.4 ± 8.6	1.22	growing
1995	natural	1104	44.1 ± 12.2	2.00	stable
1996	enhancement	1949	26.9 ± 7.2	2.00	growing
Site 300 - Draney Canyon					
1990	natural	16	na	4.33	?
1991	natural	29	na	1.42	growing
1992	natural	28	28.5 ± 7.7	1.54	stable
1993	natural	28	33.7 ± 15.2	1.54	stable
1994	natural	13	26.7 ± 6.5	4.00	declining
1995	natural	27	31.0 ± 10.8	1.60	stable
1996	natural	9	na	3.50	declining
New Population - Carnegie Canyon					
1993	natural	3000-4000	49.7 ± 15.4	1.13	?
1994	natural	2500-3000	36.9 ± 11.2	1.41	declining
1995	natural	2000-3000	46.1 ± 13.4	1.23	stable
1996	natural	1500-2500	45.6 ± 13.7	1.28	declining

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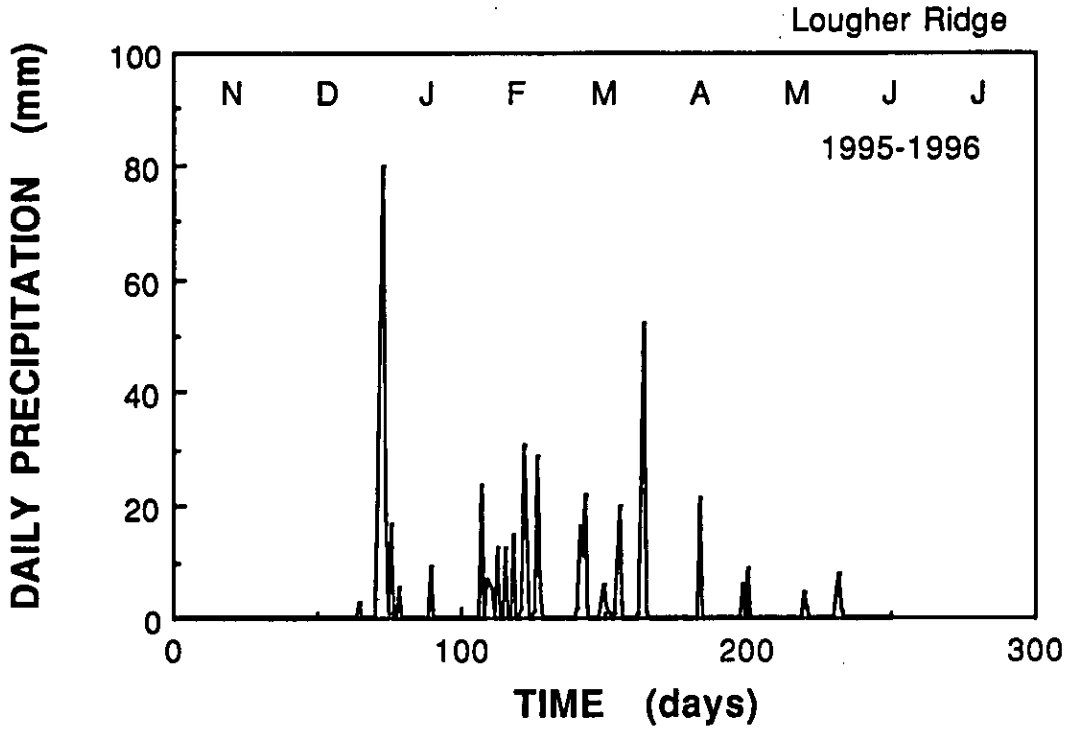

Figure 1. Seasonal pattern of daily precipitation at Lougher Ridge. Day 0 = October 1. Compare to Figure 1 of Pavlik (1995).

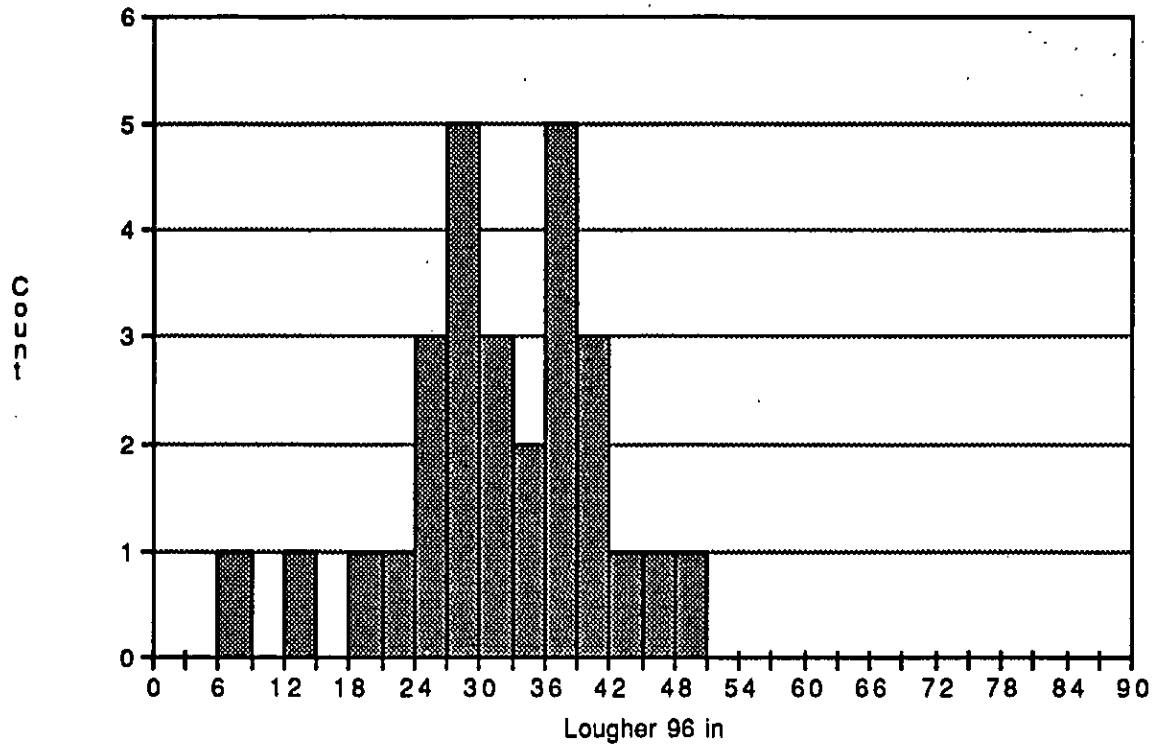

Figure 2. Plant size-class distribution for individuals growing inside the original fenced area at Lougher Ridge, 1995. Size-class dimensions on X axis are in cm of shoot length. Compare with Figure 2 of Pavlik (1994)/

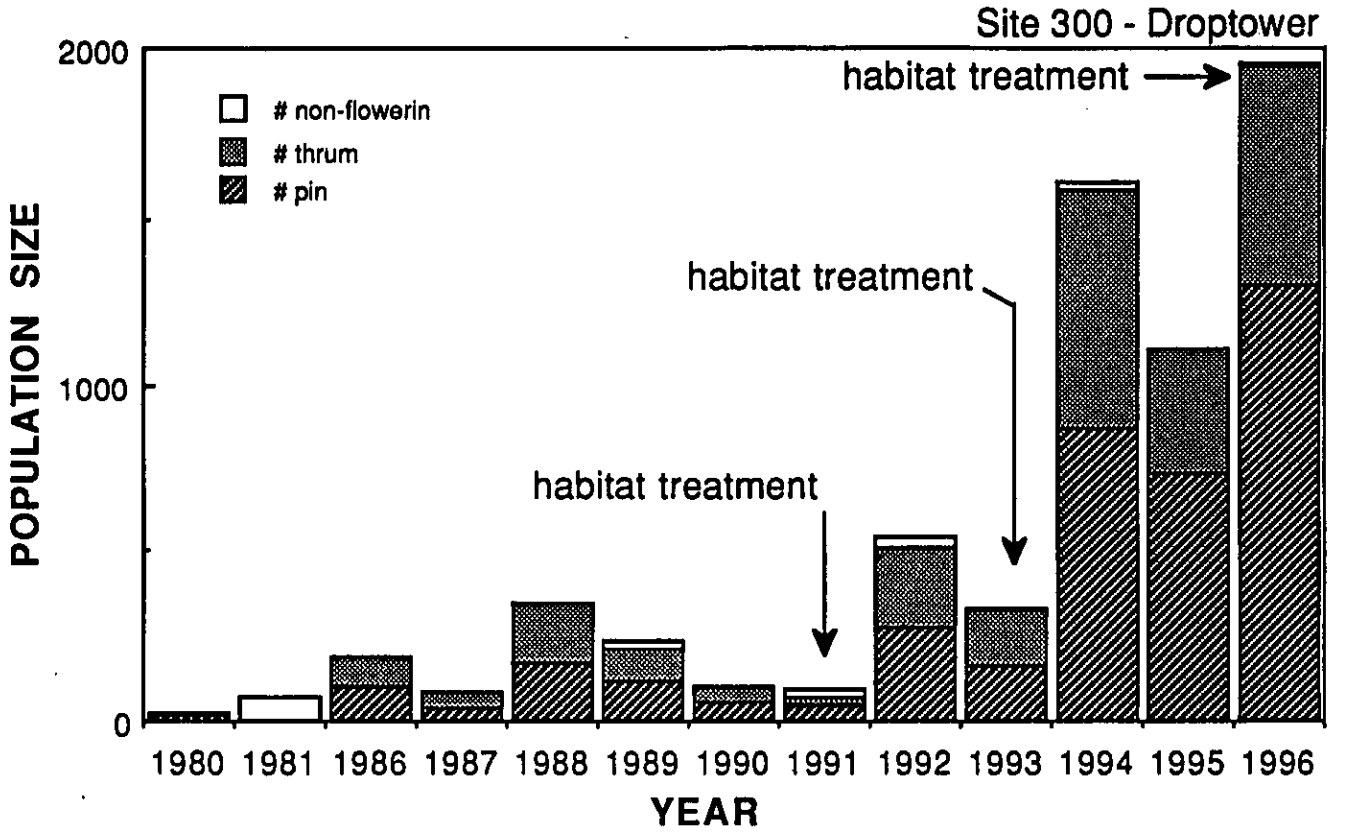

Figure 3. Spring census of the Droptower population of Amsinckia grandiflora at Site 300. Total population size and the proportion of pin and thrum individuals are shown. Approximate timing of treatments to reduce annual grass competition is shown.

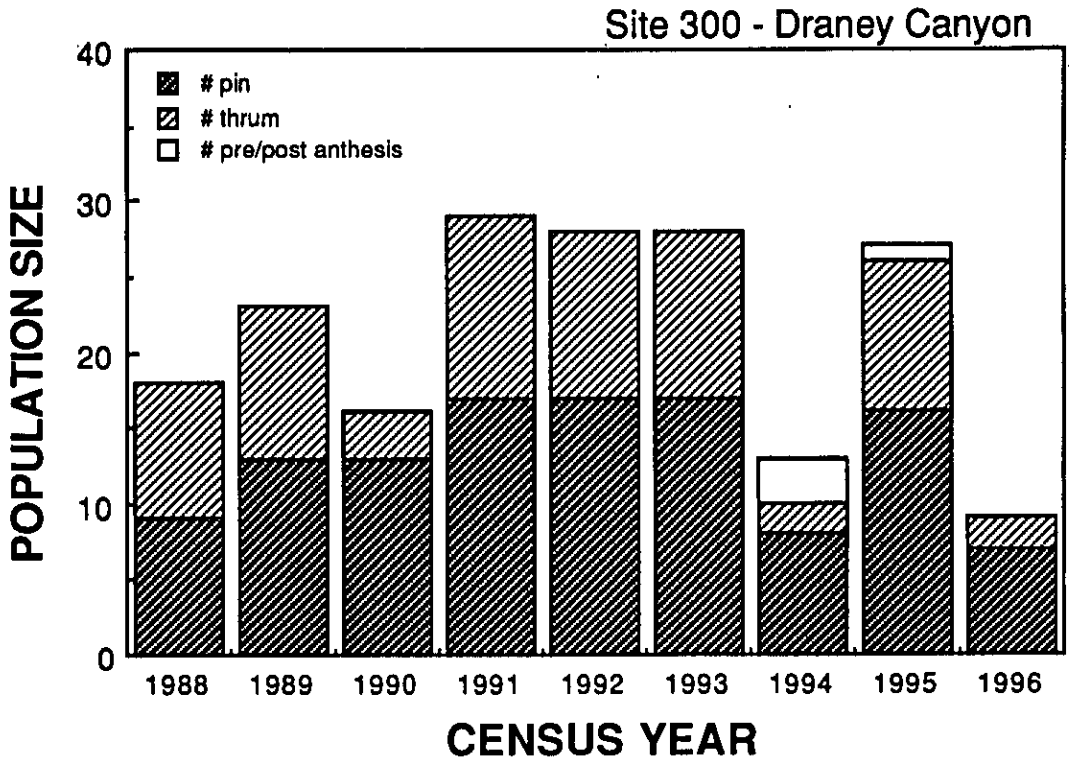

Figure 4. Spring census of the Drany Canyon population of Amsinckia grandiflora at Site 300. This population remains under a natural management regime.