Inching Towards Recovery: Evaluating the Performance of *Amsinckia grandiflora* Populations Under Different Management Regimes

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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 reintroduced population at Lougher Ridge under a "natural" (unmanipulated) management regime, 2) ongoing enhancement of the natural population at the Droptower on Site 300, and 3) second year management of the reintroduced populations at Black Diamond II, Los Vaqueros I and Connolly Ranch, and 4) installation of two new populations at Los Vaqueros II and Corral Hollow.

The reintroduced population of *Amsinckia grandiflora* at Lougher Ridge was comprised of 1640 reproductive plants in 1992, an increase of 26 % over 1991. These plants produced an estimated 66,980 nutlets, an increase of 30 % over the number produced in 1991. The gains were made under a natural, third year management regime without fire or herbicide to control competition from introduced grasses. The potential for continued growth and self-maintenance of the population appears to be high.

The natural Droptower population at Site 300 consisted of 546 reproductive individuals in March of 1992, an increase 494% since the previous year. The increase was due to treatments of habitat patches with the grass-specific herbicide Fusilade®. The size of the untreated, natural population in Draney Canyon decreased by one individual to 28 plants. These data strongly suggest that additional habitat manipulations at the Droptower are warrented for purposes of recovery.

The reintroduced Black Diamond II population declined severely in 1991-92, contrary to what was predicted from its first year demographic performance. Only 70 reproductive plants were found and these tended to be weak despite a second year management regime that controlled grass competition. Intensive disturbance by gophers directly increased mortality of established plants. However, the complete lack of new plants in untreated control plots and beyond the fence indicated that competition from annual grasses was severe in this early rainfall year. It seems unlikely that demographic performance of *Amsinckia* will improve under a natural, third year management regime.

According to predictions, the reintroduced Los Vaqueros population continued to decline. Only nine plants reaching reproductive maturity, despite a second year managment regime that controlled grass competition with Fusilade®. Plant size and nutlet output were enemic, indicating that this population will become extinct in the near future and not contribute to the recovery of the species.

The reintroduced population at Connolly Ranch conformed to predictions and grew significantly in its second year. A total of 707 reproductive plants were found, an increase of 22% over 1991. More than a third were beyond the fence in areas that did not receive second year management treatment with herbicide. Grass cover (and presumably, competitive inhibition) had increased because of the pattern of early fall rain, thus reducing mean plant size, floral display, and nutlet production in the population. Although the size of this population may fluctate significantly in coming years, It is likely that this southernmost occurrence will contribute to the overall recovery of the species.

The attempt to install a new population at Los Vaqueros II failed because of unfavorable site characteristics as well as severe disturbance by yearling cattle. It is highly unlikely that the LV II population will contribute to the recovery of the species. However, the attempt to install a new population at Corral Hollow appears to have been successful, although the scatter-sowing technique for putting out nutlets was very inefficient. Only 64 plants reached reproductive maturity out of the 10,000+ nutlets sown, but these were large and fecund in habitat patches treated with Fusilade®.

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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 1993). 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). The present study is part of an ongoing recovery effort for the species (Pavlik 1988, Pavlik and Hiesler 1988, Pavlik 1990, 1991a, 1991b, Pavlik et al. 1993) that emphasizes the creation, enhancement, and evaluation of self-sustaining populations.

The specific objectives of the present study included; 1) evaluation of the reintroduced population at Lougher Ridge under a "natural" (unmanipulated) management regime during the 1991-92 growing season, 2) ongoing enhancement and evaluation of the natural population at the Droptower on Site 300, and 3) second year management of the reintroduced populations at Black Diamond II, Los Vaqueros I and Connolly Ranch, and 4) installation of two new populations at Los Vaqueros II and Corral Hollow.

Methods and Materials

Evaluating the Reintroduced Population at Lougher Ridge

The Lougher Ridge population was not manipulated during 1991-92, allowing the evaluation of its performance under a "natural", third year management regime. The site was inspected on 20 January and 17 March 1992 to read the raingauge and repair the fence. Census of the population took place on 4 April 1992, when *Amsinckia* plants were robust (25-40 cm tall) and near 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 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 1991-92 population, 100 plants were randomly selected and measured for shoot length on 4 April. Two reference stakes were located *a priori* in each half of the area (= 4 stakes total). A random numbers table was used to generate 25 compass bearings off of each stake (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 a new correlation developed from plants growing at Lougher Ridge in 1992. On 22 April, 18 recently senescent individuals were collected from among all of the original reintroduction plots. They were chosen to represent the full plant size range, as determined by height. These plants were measured, clipped at the soil surface, sealed in separate bags and returned to the lab. Methods for determining the relationship between nutlet output and shoot length and estimating nutlet production of the population as a whole are described in Pavlik (1990, 1991a).

Managing and Evaluating the Natural Populations at Site 300

After emergence of the annual grasses at Site 300, a dilute solution of Fusilade® was applied with a hand sprayer to portions of the Droptower population. The same five patches of habitat treated in February 1991 each were given one liter of a 1/10th strength solution (6 ml Fusilade in 6 liters of water with 13 ml of non-ionic surfactant) on 25 February 1992 . Two of the patches were outside the fenceline on the north (downslope) side of the plot and contained only one or two plants the previous year. The three treated patches inside the fence had dozens of plants the year before. Each patch was different in size, but they averaged about two square meters each. Three patches inside the fence that contained a few dozen plants in prior years were left unsprayed to serve as controls.

Only the six patches within the fence (3 treatment, 3 control) were used to determine the effect of controlling annual grasses on population growth.

A census was conducted on 26 March 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, 50 plants were randomly selected and measured for shoot length on 17 April. Two reference stakes were located *a priori* near the center of the fenced area (one towards the west side, one 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. Plants were also assigned to either a treatment or control category, depending on whether they were rooted in a herbicide-sprayed patch or not. 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 also censused on 17 April 1992. Every plant was counted, measured for shoot length, and recorded as to floral morph. Never having been treated with herbicide, this population served as a control for comparisons with the Droptower population.

Managing Reintroduced Populations at Black Diamond II, Los Vaqueros I and Connolly Ranch

In the second year after reintroduction, the Black Diamond II, Los Vaqueros I and Connolly Ranch populations were managed to minimize competition from annual grasses. A dilute solution of Fusilade® was applied with a hand sprayer to the nine treatment plots within each fenced area (the three control plots were not sprayed). Each plot plus a 0.25 m buffer zone was treated in mid-January 1992 with 0.55 liter of a 1/10th strength solution (6 ml Fusilade® in 6 liters of water with 13 ml of non-ionic surfactant) after emergence and early growth of the annual grasses. Native perennial grasses (*Stipa pulchra* and *Poa scabrella*) were avoided. In addition, the two plots outside of the fence that had been exposed to mammalian grazers were also treated.

These sites were periodically visited during the late winter and spring to observe plants, check rain guages, and tighten fences. Final census of the Connolly Ranch (CR) site was conducted on 26 March 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, 50 plants were randomly selected and measured for shoot length using two reference stakes and 50 random compass-distance coordinates (see above). Shoot length was translated into nutlet output per plant using the equation developed at CR in 1991 (#nutlets/plant = 3.42 (shoot length in cm) - 65.46, $r = 0.86$, $P<0.01$, Pavlik 1991a). Final census of the Black Diamond II (BD II) site was conducted on 22 April and on 30 April at the Los Vaqueros (LV) site. The same parameters were recorded for those populations, except that every plant was measured for shoot length and this was converted to nutlet output using the appropriate 1991 equation (at BD II: #nutlets/plant = 5.61 (shoot length in cm) - 93.14, $r = 0.85$, $P<0.01$; and at LV: #nutlets/plant = 0.92 (shoot length in cm) - 3.64, $r = 0.64$, $P<0.05$, Pavlik 1991a).

New Reintroductions at Los Vaqueros II and Corral Hollow

A new population of *Amsinckia grandiflora* was installed on the edge of the Los Vaqueros watershed (Contra Costa County) in August 1991. A low saddle (680' elevation, 37° 51' N, 121° 46' W) dividing the southeast drainage into Round Valley and the northwest drainage into Canada de los Vaqueros was chosen because of its ecological and logistical characteristics (Pavlik and Hiesler 1988). A 30%, northeast facing slope on the southwest side of the saddle supports an open savanna of *Quercus douglasii* adjacent to annual grassland (including *Avena fatura, Bromus mollis, Amsinckia intermedia, Ranunculus californica* , annual *Lupinus*). The soil is mapped as Altamont-Fontana complex by the Los Vaqueros Project of the Contra Costa Water District, who agreed to host this experiment on their property. All of these chararcteristics favored the site (referred to as Los Vaqueros II or LV II) with respect to the ecology of *Amsinckia grandiflora* and the goals of the recovery project.

A total of 16 precision-sown plots were established on 8,9, and 10 August 1991 at LV II using methods already described in Pavlik (1990, 1991a). Eight of the plots were sown with 100 nutlets each of *Amsinckia grandiflora* (Davis 1989 crop), while the other eight were sown with an equal number of *Amsinckia intermedia* nutlets (also Davis 1989).

These nutlet crops had high laboratory germination rates (72% and 85%, respectively, in February 1992), and would thus allow a comparative demographic study of rare and common *Amsinckia* species at the same site. For each species, five plots were burned after sowing and three were left as controls. Burn plots were treated in winter with a dilute solution of Fusilade® to completely suppress the growth of competing grasses. The 16 plots were protected by a two strand, barbedwire fence to exclude cattle, although there was no reason to believe that animals would trample or congregate near the installation since it presented no obstruction or attraction.

In addition to the precision-sown plots, eight large "scatter-sown" plots of *Amsinckia grandiflora* were established in August at LV II just outside of the fenced area. Each scatter-sown plot was a 2.5 m X 2.5 m square marked with a wooden stake at its center. Three of these plots were left untreated as controls and five were burned prior to sowing. Sowing was done by placing a mixture of white rice and pre-weighed nutlets into a hand-held grass seed spreader and evenly distributing the mixture across the plot. The rice acted as a carrier for the nutlets and as a marker that allowed us to see and aim the "spray" coming from the spreader and to assess the final dispersion of the mixture across the plot. At LV II, each plot received 3.530-3.644 g of nutlets, which averaged 1315 nutlets per plot (10,579 scatter-sown in all 8 plots). Nutlets in the burned plots were covered by a thin layer of sandy "cactus mix" to promote germination and inhibit predation by birds. In February 1992, the burned plots were also treated with a dilute solution of Fusilade® to suppress the growth of annual grasses.

Another new population was installed in August 1991in the southern portion of *Amsinckia grandiflora's* range (San Joaquin County). The chosen site was at Corral Hollow Ecological Reserve (CH), owned by the California Department of Fish and Game. Plots were located (37° 38' N, 121° 29' W) on a 20% northwest-facing slope just below an outcropping of Neroly Blue sandstone at 600' elevation. The soil has been recently mapped as Wisflat-Arburua-San Timoteo complex, consisting of a sandy or clay loam on steep slopes (SCS, San Joaquin County, unpublished draft 7/90). The hillside vegetation is mostly annual grassland (*Bromus mollis, Avena fatua, B. diandrus* , *Amsinckia tessellata*) with scattered shrubs (*Artemisia californica* , *Eriogonum fasiculatum*) and a few small trees (*Quercus douglasii*).

A total of twelve large, scatter-sown plots were installed at CH on 6 August, 1991. Five high density plots were installed and treated the same as at LV II (1,636 nutlets per plot; 8,179 total), while the other seven plots were sown with only 0.960-0.994 g of nutlets each (approximately 360 nutlets/plot, 2,520 total). Five of the low density plots were treated with fire prior to sowing and the other two were left as controls. All 10 treated plots were covered with a thin layer of sandy cactus mix after burning and sowing and received a light application of Fusilade® in late January 1992. The arrangement of the plots, an irregular cascade from the foot of the sandstone outcrop, was meant to mimic the pattern of *Amsinckia grandiflora* patches observed in the natural population at nearby Carnegie Canyon.

Results and Discussion

Weather Patterns During 1991-1992

In northern California, the 1 November to 30 May growing season of 1991-92 had slightly below-average precipitation. Records for San Francisco, Oakland, and Sacramento indicate that rainfall was 80-111% of normal during the 1 Nov to 30 May period of 1991-1992, with an overall regional deficit of about 5-10% (compared to a 20-25% regional deficit during the previous two growing seasons). The total precipitation actually received at Lougher Ridge during the October to May period of *Amsinckia* activity was 296 mm, slightly higher than in previous years (289 mm in 1989-90 and 271 in 1990-91). Rainfall, temperature, and grass cover data for the other reintroduction sites during 1991-92 are given in Table 1 .

In terms of temporal pattern of precipitation, 1991-92 resembled 1989-90, the first year of the reintroduction project (see Pavlik 1991a for a full analysis). The first significant storm of 1991-92 dropped 44 mm of rain on 26 October (Figure 1) and was accompanied by relatively warm air temperatures (daily means above 12 C, daily minima above 0 C). Like the first storm of 1989-90, this was sufficient to simultaneously initiate the germination of *Amsinckia* and the annual grasses. Subsequent storms occurred almost at monthly intervals until mid April, with temperatures that were rarely below freezing.

Long, wet, and mild growing seasons favor the growth of introduced annual grasses in California (Murphy 1970, George et al. 1989) and accentuate the potential for strong competition for annual forbs such as *Amsinckia* (Pavlik 1991a, Pavlik et al. 1993). Such conditions occurred in 1989-90, when it was shown that the grasses significantly

Table 1. Plot-specific characteristics of the reintroduction sites, 1991-92. Precipitation and temperature measurements were recorded using a standard rain gauge and max/min thermometer mounted 1.25 m above the ground. Estimates of grass cover were made in control plots using a circular 0.125 m^2 quadrat in late April. Compare with Table 3 in Pavlik (1991a). na = data not available

	actual Nov 1-May 30 precipitation (mm) /(% of ann)	actual Nov 1-May 30		maximum grass canopy height range (cm)	total abs. grass cov. (%)	absolute cover by				
		min temp (°C)	max temp (°C)			Avena fatua (%)	Bromus diandrus (%)	B. mollis (%)	B. rubens (%)	Stipa pulchra (%)
BD II	285 / 82%	- 4.4	27.8	40-60	95.1	66.7	11.7	10.0	0	6.7
LV	503 / 110%	na	na	50-60	88.4	57.8	0	18.6	10.0	2.0
CR	272/ 85%	- 5.0	28.0	40-50	66.7	22.0	0	44.7	0	0

increased mortality rates, decreased survivorship to reproduction, and decreased plant size and reproductive output of *Amsinckia* . Relative to 1990-91, grass cover increased at all three reintroduction sites during 1991-92 (Table 1). It was predicted, therefore, that 1991-92 would be a year of strong competition from annual grasses.

<u>Status of the Reintroduced Population at Lougher Ridge</u>

A total of 1640 flowering plants of *Amsinckia grandiflora* were counted at Lougher Ridge on 4 April, 1992, a 26% increase over 1991 (Table 2). Most plants were still found in or near the 20 original reintroduction plots, but many had become established between plots and along the access paths, giving a more continuous distribution than previously observed. Overall, the floral display was not as showy as in the last two years, in part due to increased dispersion but also due to the dense, green sward of introduced annual grasses (Table 1). Sampling revealed that the pin/thrum ratio was 0.97, as close as any wild population of this species has come to equivalence of floral morphs.

Table 2. Comparison of characteristics of the Lougher Ridge population of *Amsinckia* , March or April census, 1990 - 1992. Pin/thrum ratio in 1991and 1992 based on a random sample of 100 plants in each year.

	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 (dimensionless)	Σ (dimensionless)
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

Table 3. 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. 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
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

The 1992 plants within the fenced site had the same mean and maximum sizes as in 1991, but the variability at each sample station was always greater (Table 3). This was reflected in the larger number of plant size-classes represented in the 1992 population (14 classes vs. 10 in 1991), with more individuals found in the larger (36-42 cm, 42-48 cm and 48-54 cm), reproductive categories (Figure 2). There was a similar increase of size-class representation for plants outside the fence between 1991 and 1992 (Figure 3), but with more plants in both larger, reproductive (30-36 cm and 48-52 cm) and smaller, non-reproductive (12-18 cm) categories. Increases in the array of plant size-classes may indicate that the naturally-dispersed nutlets had encountered a wider variety of competitive neighborhoods at the site. Neighborhoods with dense grasses and forbs would create highly competitive conditions and result in a greater number of small

Amsinckia plants (Pavlik et al. 1993). Conversely, more open neighborhoods with low grass and forb densities (e.g. from disturbance by fossorial mammals) would produce larger *Amsinckia* plants. This is supported by comparisons of the frequency distribution of plant sizes in control (high competition) and herbicide-treated (no grass competition) plots at Lougher Ridge in 1990 (Figure 4). Thus, the analysis of size-class distributions suggests that habitat patchiness at Lougher Ridge extends the array of plant sizes in two directions: towards smaller, non-reproductive plants that contribute few or no progeny to the population and towards larger, reproductive plants that provide a disproportionate number of progeny to the next generation. The ability of a habitat to produce such a broad hierarchy may ultimately determine how a rare plant population grows and persists among competitve, introduced grasses.

The output of nutlets by individual plants at Lougher Ridge in 1992 was linearly related to the sum of the inflorescence lengths (Figure 5) and shoot length (Figure 6). The relationship between shoot length and nutlet output was the same in 1992 as it was in 1990 at Lougher Ridge (Figure 7). The largest 1992 plants (with shoot lengths ranging from 35 to 48 cm) produced between 80 and 120 nutlets each. An estimated 66,980 nutlets were produced, a 30% increase over total nutlet production in 1991 (Table 4).

Table 4. Estimates of nutlet production by the population at Lougher Ridge. The value for 1990 was derived from every individual in the population, while those for 1991 and 1992 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

However, this also represents a 14% decrease in the rate of nutlet production and may foreshadow a slowing of population growth during 1992-1993. A slowing of population growth would be particularly evident if there were no individuals established from previous generations (meaning that the seed bank of *Amsinckia* was short-lived) or if heavy rains came during the early fall of 1992 (thus leading to strong competition with annual grasses throughout the site).

Forty-eight plants were found outside of the fence in 1992. Some were obviously progeny of plants that had dispersed in previous years, forming clusters around the same locations measured in 1991. Others were either secondary dispersers (having moved from a parental location outside the fence) or newly dispersed (from within the fence) and could be found up to 15 m away from the edge of the fenced area. More than 90%, however, were within 4 m of the fence. Nearly 70% were found uphill to the south, presumably blown by strong north winds, while 10% were found to the east (including the two longest dispersers at 15.0 m and 9.9 m).

Even though no habitat manipulation took place during the 1991-92 season, the effects of competition from annual grasses on the population as a whole were minimal. The reproductive population continued to increase in size (Table 2), mean and mean maximum shoot length were statistically equivalent in 1991 and 1992 (Table 3), and nutlet production for the population as a whole (Table 4) increased. This is not to say that individual *Amsinckia* plants did not experience strong competition from grasses whose growth was promoted by the 1991-92 pattern of rainfall. Without a treatment of fire or herbicide, however, it is not possible to determine how intense the grass competition was at Lougher Ridge in this particular year. Many small, non-reproductive plants were observed inside and outside of the fence, but so were many large, well-branched, fecund plants. The preponderance of large plants in the random sample indicates that there were either residual benefits of fire and/or herbicide treatments from previous years or that many naturally-occuring, low competition neighborhoods were being utilized by *Amsinckia* across the site. Plants outside the fence (in areas that were never treated) had a smaller mean size than plants inside the fence and those measured last year outside the fence (when there was a late winter rainfall pattern and presumably less grass competition), but the difference was not statistically significant (Table 3). Therefore, it is more likely that a large number of randomly-dispersed *Amsinckia* nutlets had come to occupy low competition neighborhoods within and beyond the fence and were thus able to establish themselves and achieve large sizes despite a disadvantageous rainfall pattern during 1991-92. The existence and exploitation of these neighborhoods at Lougher Ridge in the absence of intensive habitat management provides evidence that there is a high potential for self-maintenance in the new *Amsinckia* population.

Status of the Natural Populations at Site 300

The Droptower population consisted of 546 reproductive individuals in March of 1992, an increase of 494% since April of 1991 (Figure 8). Large numbers of plants were found in patches sprayed with Fusilade®, averaging a nine-fold increase ("growth ratio") compared to the previous year (Table 5). Unsprayed patches had only a 3-fold increase, and this was probably an overestimate because unsprayed patch B was in close proximity to sprayed patches A and F. It is likely, therefore, that the large growth ratio in patch B was due to dispersal of 1991 nutlets from A or F rather than high reproductive output in the absence of herbicide treatment. The overall pin/thrum ratio was 1.17, much less skewed towards pins than in 1991 when the the population consisted only of 92 plants. These results strongly support the conclusion that herbicide treatment during the winter of 1991 produced larger, more fecund plants by the end of spring 1991, and led directly to the 500 % increase in population size observed in 1992. Although Pavlik (1991b) could not detect enhancement of nutlet production at the time, it was clear that plants in sprayed patches were more vigorous and had a higher water potential than plants in unsprayed patches. The conclusion that such plants "would eventually produce significant numbers of nutlets in the weeks following sampling" appears to have been correct.

Significant increases in plant size were detected at the Droptower population during the spring of 1992 as the result of herbicide treatment to control annual grasses (Table 6). Plants in sprayed patches were larger and produced twice as many nutlets on the average than plants in unsprayed patches. As in 1991, many of the plants in sprayed patches were still green and vigorous and would remain active longer than plants in unsprayed patches.

In contrast, the untreated Draney Canyon population showed a slight decrease in population size compared to 1991 (Figure 9). Mean plant size was nearly the same as in unsprayed patches at the Droptower (28.5 ± 7.7 cm), while mean maximum plant size was slightly larger (37.1 ± 4.5 cm). The pin/thrum ratio of 1.54 was close to what it had been in

Table 5. Response of the Droptower population to treatment of habitat patches with herbicide during 1991 and 1992. Number of plants and pin/thrum ratios shown for each year, and the growth ratio (# plants 92/# plants 91) for sprayed and unsprayed patches.

	1991		1992		92/91
patch	# pl	P/T	# pl	P/T	growth ratio
Unsprayed patches					
B	21	1.22	128	1.02	6.1
C	3	0.50	8	1.00	2.7
E	15	3.67	17	1.29	1.1
					$\overline{X} = 3.3$
Sprayed patches					
A	35	1.88	263	1.32	7.5
D	14	3.33	56	1.30	4.0
F	4	1.00	66	0.81	16.5
					$\overline{X} = 9.3$

Table 6. Effects of herbicide treatment on the Droptower population, 1992. Plant size (length of main shoot, mean ± SD) for habitat patches that were sprayed (n = 21 for mean, n = 10 for maximum)or left unsprayed (n = 29 for mean, n = 10 for maximum) were compared with ANOVA. Values (mean ± S.D.) in a column followed by different letters are statistically different at the indicated probabilities.

		plant size		nutlet production	
	P/T ratio	mean maximum (cm)	mean (cm)	mean (#/repro plant)	total (# in all patches)
unsprayed	0.81	$34.5 \pm 6.6^{a*}$	$28.0 \pm 6.7^{a**}$	30	4,590
sprayed	2.00	41.9 ± 7.8^{b}	36.1 ± 8.2^{b}	58	22,330

* $P < 0.05$ ** $P < 0.001$

previous years.

These data and observations provide additional evidence to support an ongoing program of habitat manipulation to enhance the Droptower population so it can contribute to the recovery of the species.

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

The Black Diamond II population declined severely in 1991-92, contrary to the prediction of growth based on demographic performance during its first year (Pavlik 1991a). Only 70 reproductive plants were found during the April census, and these tended to be smaller than 1991 plants on the average (Table 7). Mean maximum size, however, increased from 29.8 cm in 1991 to 35.7 cm in 1992 and the size-class distribution remained broad (Figure 10), indicating that favorable conditions for growth did occur for a (relatively small) fraction of the population.

There were two possible explanations for the poor performance of the population overall. First, intensive subterranean activity by pocket gophers directly or indirectly contributed to high plant mortality in 1992. 10 of the 14 plots at the site were visibly disturbed by the time of the April census. Of the 10, five had between 10% and 20% of their soil surface disrupted by entrance holes, mounds, or other subterranean activity. Two others had 20-40% of their surface disturbed while the remaining three had more than 50% disturbed. It is likely that such activity during the late winter and spring decreased survivorship and reduced the size of the reproductive population. Although detailed data are lacking, eight full size, once reproductive *Amsinckia* plants were found dry, brown and dead, but standing erect in the disturbed plots. Secondly, no *Amsinckia* plants were found in the untreated control plots, even though an estimated 1893 nutlets were produced in them during the previous year (Pavlik 1991a, Table 7). This indicates that in the absence of annual grass management, the site did not have favorable, low competition habitat patches. In fact, no plants were found outside of the fenced area or outside of the two exposed (unfenced) plots as the result of disperal and establishment by last year's nutlets. Only intensive management of the grass cover will allow the reintroduced *Amsinckia* population to maintain itself at Black Diamond II. Black Diamond II does not appear to be, therefore, a site that will contribute to the recovery of the species.

Table 7. Characteristics of the Black Diamond II, Los Vaqueros, and Connolly Ranch populations, 1992.

	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	70	1.50	35.7 ± 3.0	22.1 ± 7.9	31	2,163
Los Vaqueros	9	0.80	30.4 ± 3.6	23.7 ± 8.4	19	177
Connolly Ranch	707	1.26	36.0 ± 7.9	23.9 ± 7.7	17	12,019

[1] n = 10, except at LV n = 5 [2] n = repro pop size, except at CR n = 50

The Los Vaqueros population also declined severely, as was predicted by the 1991 demographic data (Pavlik 1991a). Only nine plants reached reproductive maturity, and none were found outside of the fence or beyond the two exposed plots. Mean plant size was significantly larger than in 1991and each plant produced twice as many nutlets. The total nutlet production by the population was very low, however, being only 6% of the enemic level observed the year before. Undoubtedly, the Los Vaqueros population will continue its decline towards extinction in the immediate future.

Also as predicted, the Connolly Ranch population grew in its second year. A total of 707 reproductive plants were found during the late March census, 464 inside the fence and 243 outside. Approximately 131 plants to the north of the fenced area could either have dispersed from within the fence or from the two exposed plots. Of the remaining 112 plants outside the fence, 50 were found towards the west, 46 towards the east and 16 towards the south. The average dispersal distance was 3.6 m, with a maximum of 14 m (to the east). At least 83 of these plants were found growing in tight clusters, indicating that whole inflorescences containing nutlets were often the dispersal unit.

When compared to 1991, the 1992 population was less showy because of decreasing plant density (from dispersal) and because cover by the annual grass *Bromus mollis* was two or three times what it was in 1991 (Table 1). *Bromus* plants had even come up in plots that had been treated with Fusilade®, indicating that the herbicide residual was low and grass germination occurred in response to spring rain. Native herbs, such as *Microsteris gracilis* , that were abundant enough to form a "dense understory" in 1991 (Pavlik 1991a) were almost absent in 1992. The 1991-92 pattern of rainfall, which began in late October was followed by a relatively warm, wet winter, favored the growth of annual grasses. Such conditions are known to increase standing crop on California's annual grasslands (Murphy 1970, George et al. 1989), creating dense swards of non-native *Bromus, Avena,* and *Hordeum* . This reduced the availability of low competition habitat patches for native forbs such as *Amsinckia* and mean plant size (and mean nutlet output per plant.) declined when compared to 1991. Mean maximum plant size remained high and the size-class distribution was broad, however, indicating that some low competition patches were available at the Connolly Ranch site even in this year of intense grass competition. Overall, 1992 nutlet production declined to 12,019 from 17,032 in 1991, but the growth, spatial expansion, and broad size array of the population were favorable from the standpoint of *Amsinckia* recovery.

<u>New Reintroductions at Los Vaqueros II and Corral Hollow</u>

The reintroduction at Los Vaqueros II failed for two reasons. First (and most limiting with respect to a quantitative evaluation), a herd of yearling cattle thoroughly trampled the site sometime between 4 February and 11 March 1992. Unlike their lethargic, stupified elders, these lively and pernicious beasts ploughed into and through the barbed wire *en masse* , leaving clots of hair and blood behind, as well as an utterly churned soil surface that once harbored 16 precisely-placed, precision-sown plots. Some chose to cut deep paths across the hillside, ensuring that others would follow in their bombcrater hoofprints. Others lingered and obviously danced and dined to celebrate victory over the puny forces of exclusion and restoration. But beyond that, one cannot analyze the mindless destruction rendered by inbred, under-selected, methane- mongoring flesh factories - it is only possible to commemorate the victims. Many gentle, hopeful *Amsinckia* seedlings were crushed beyond species recognition, along with the hope of a comparative demographic study of rare and common fiddlenecks. Perhaps another strand of barbed wire would have helped, but in the final analysis......NOT.

The second reason for failure had to do with the site itself. Despite having received more than 100 mm of precipitation, germination of *Amsinckia grandiflora* averaged 17% while that of *A. intermedia* averaged only 9% by 21 January (totalling 139 and 75 plants, respectively, in precision-sown plots). Additional germination of both species was low during the winter, and vegetative growth was weak. After the trampling in mid-March, only 44 live plants of *Amsinckia grandiflora* were found in the precision-sown plots, while 153 were found among the eight scatter-sown plots (66 pin, 41 thrum, 46 pre-anthesis). Nearly all of the live plants were of the small, unbranched form observed in the 1991 Los Vaqueros population. Plant height averaged only 14.5 ± 5.9 cm and rarely exceeded 25 cm . Fecundity, therefore, was very low (0-10 nutlets/plant). Given the large number of seeds sown and the poor performance of the few resultant plants, the Los Vaqueros II population of *Amsinckia grandiflora* is expected to become extinct in the near future.

The specific deficiencies of the site remain unclear. Cold temperatures at the higher elevation (1800') Los Vaqueros site were suggested (Pavlik 1991a), but this would probably not apply to the low elevation LV II site during the relatively mild winter of 1991-92. Soil characteristics could be more important, especially high clay content. There are few consistent differences, however, between the soils associated with natural and reintroduced populations (Table 8), or even between soils associated with large, robust populations (Carnegie Canyon, Connolly Ranch) and those associated with small, poorly-performing populations (Droptower, Los Vaqueros). Soil analyses will be extended to the Los Vaqueros II, Lougher Ridge, and Corral Hollow sites to clarify the role of the substrate in determining *Amsinckia* performance in the field.

Efforts to install a population at Corral Hollow appear to have been more successful, although very inefficient from the standpoint of nutlet use. During the 13 March census 109 plants were found with newly-opened flowers, but only a fraction survived over the next month to produce nutlets. A total of 64 plants reached reproductive maturity by 14 April, with three times as many found in the high density than in the low density plots. Only one reproductive plant was found in the two control plots among the annual grasses (Table 9). Its small size indicated that nutlet production was low and that competition had been intense. Plants in the treated plots were much larger and compared favorably with vigorous plants at Carnegie Canyon, Site 300, and Lougher Ridge. They were, however, surrounded by dense populations of *A. lycopsoides* and *A. intermedia* , and would only contribute a small fraction to the total *Amsinckia* floral display in future years.

Table 8. Soil characteristics of sites with natural and reintroduced populations of *A. grandiflora*. SP = saturation percentage, EC = electrical conductivity. Bulk soil samples (-10 to -25 cm deep) analyzed by DANR Analytical Laboratory, University of California at Davis.

	SP (%)	pH	EC (mmhos-cm)	N (%)	P (ppm)	K (ppm)	Ca (meq/l)	Mg (meq/l)	Na (meq/l)
Natural populations									
Carnegie Cyn	47	6.7	0.49	0.113	24	424	3.2	0.8	0.9
Droptower	37	7.0	0.50	0.083	21	468	2.8	2.0	0.2
Draney Cyn	54	7.6	0.53	0.021	6	376	2.4	1.2	1.7
Reintroduced populations									
Black Diam II	36	5.7	0.48	0.116	16	342	1.6	2.8	0.1
Los Vaqueros	45	5.9	0.50	0.134	14	305	2.0	2.4	0.2
Connolly Ranch	42	6.3	0.45	0.106	26	324	2.0	2.0	0.5

Table 9. Characteristics of the Corral Hollow population, April 1992. All plots were scatter- sown, treated plots were burned and later sprayed with Fusilade®.

				plant size		nutlet production	
	nutlets sown (#)	repro pop size (# pl)	P/T ratio	mean maximum (cm)	mean (cm)	mean (#/repro plant)	total (# in all plots)
treated	9988	63	1.39	41.1 ± 5.0	26.6 ± 9.4	29	1814
control	711	1	---	23.0	23.0	13	13

The scatter-sown plots at CH and LV II were very inefficient with respect to producing established plants from the available nutlets (Table 10). The yield (ratio of the maximum number of established plants to the total nutlets sown) was around 1% at both reintroduction sites, compared to 17% for the precision-sown plots at LV II in the same year and 34% at Lougher Ridge in 1990 (1101plants /3260 nutlets x 100). There are several possible reasons why scatter-sowing is much less efficient than precision-sowing. First, nutlets that are scatter-sown probably end up in a greater variety of soil microhabitats than precision-sown nutlets. Some come to rest on thick accumulations of organic matter while others fall in "deep" crevices. Nutlets may land on top of stones and hard lens of clay rather than pockets of penetrable mineral soil. With microhabitat diversity, it is likely that many nutlets encounter conditions that either prevent or inhibit germination and/or establishment. Precision-sowing, on the other hand, provides more homogeneous and favorable conditions by standardizing nutlet depth, ensuring good contact with mineral soil and providing a local pocket of loose soil for penetration of roots and shoots (and, perhaps, rainfall). The second reason for inefficiency is that scatter-sown nutlets are not hand-selected for high quality as are precision-sown nutlets. As a result, many unfilled and non-viable nutlets are part of the bulk sample for

Table 10. Comparison of yield between scatter-sown and precision-sown plots at Corral Hollow (CH) and Los Vaqueros II (LV II), 1992. Only plots treated with fire and herbicide are included.

site	plot type	# of nutlets sown	max. # of established plants	yield (%)
CH	scatter-sown	10,699	109	1.0
LV II	scatter-sown	10,579	153	1.4
LV II	precision-sown	800	139	17.1

scatter-sowing, while these are usually excluded from the sample of individually-selected nutlets that are placed in the planting frames. Finally, it is possible that scatter-sowing at high densities provides more reward for seed predators (especially birds) because nutlets may be more common, clustered, or less covered by soil than in precision-sown plots. As a result, predators would spend more time gathering from the scatter-sown plots and differentially increase nutlet mortality.

It is entirely possible, however, that many of the thousands of nutlets that were scatter-sown but did not produce plants at CH and LV II are still alive in the seed bank and could germinate in the future. This will be assessed by comparing the 1992-93 populations at CH and LV II because there was seed production during 1991-92 at CH but not LV II. At CH, modest nutlet production (Table 9) will have supplemented the original cohort and both are likely to contribute to the population in 1992-93. But gross trends in population size at LV II will mostly depend on the original cohort of scatter-sown nutlets that have remained alive but dormant in the seed bank (assuming near-normal precipitation). If the population at LV II does not decline as drastically as predicted (if population size is > 300 individuals using the 3-4% yield observed at Lougher Ridge in 1991 (Pavlik 1991b)), then the overall efficiency of scatter-sowing will be much improved. If, however, the population remains small (< 150), then it will be difficult to justify the use of scatter-sowning as a technique for creating or enhancing populations of endangered plants.

Conclusions and Management Recommendations

1) The reintroduced population of *Amsinckia grandiflora* at Lougher Ridge was comprised of 1640 reproductive plants in 1992, an increase of 26 % over 1991 (Table 11). These plants produced an estimated 66,980 nutlets, an increase of 30 % over the number produced in 1991. The gains were made under a natural (unmanipulated), third year management regime which did not alter the composition of the community with fire or herbicide in order to control competition from introduced grasses. *Amsinckia* plants achieved a broader array of size classes in 1992, with more individuals found in larger, reproductive categories. The potential for continued growth and self-maintenance of the population is high, therefore, because a sufficient supply of naturally-occuring, low

competition neighborhoods exists at the site for *Amsinckia* plants to occupy. The abundance and quality of those neighborhoods could be increased, however, by habitat manipulation (large-scale burns, patch treatment with a grass-specific herbicide) or by restoration of the original bunchgrass vegetation. This population appears to be conforming to predictions based on its demographic attributes and will probably contribute to the overall recovery of the species.

The recommendation for the fourth year of this population is to increase the abundance and quality of low-competition neighborhoods at Lougher Ridge by conducting a large-scale burn (including areas beyond the fence line) and mid-winter treatment of patches with a grass-specific herbicide. An effort should also be made to restore a portion of the grassland by transplanting plugs of *Stipa pulchra* from local individuals into the fenced area after a burn has been conducted.

2) The natural Droptower population at Site 300 consisted of 546 reproductive individuals in March of 1992, an increase 494% since the previous year (Table 12). The increase was due to treatments of habitat patches with the grass-specific herbicide Fusilade® that reduced the strength of competition with introduced annual grasses. Plants in sprayed patches were significantly larger than those in unsprayed patches and consequently produced twice as many nutlets. This indicates an increased potential for population growth during the 1992-93 season. The size of the untreated, natural population in Draney Canyon decreased by one individual to 28 plants. These data strongly suggest that additional habitat manipulations at the Droptower are warrented for purposes of recovery. If the size, extent, and nutlet production of the population continue to respond favorably to the population, then additional objectives of the recovery plan will be met.

The recommendation for 1992-93 is to conduct a low-intensity burn at the Droptower during the fall using appropriate controls and precautions to safeguard the population. This should be followed by patch treatments in winter with a grass-specific herbicide.

3) The reintroduced Black Diamond II population declined severely in 1991-92, contrary to what was predicted from its first year demographic performance. Only 70 reproductive plants were found and these tended to be weak despite a second year management regime that controlled grass competition with Fusilade®. Intensive disturbance by

gophers, which directly increased mortality of established plants, was partly responsible. However, the complete lack of new plants in untreated control plots and beyond the fence (where no grass-specific herbicide was used) indicate that competition from annual grasses was severe in this early rainfall year. It seems unlikely, therefore, that demographic performance of *Amsinckia* at the site in 1992-93 will improve under the natural, third year management regime. As a result, this population probably has little potential for self-maintenance and is not going to contribute to the recovery of the species.

This population needs to be oberved and censused under a natural, third year management regime in order to document its ability to maintain itself within the existing grassland community.

4) According to predictions, the reintroduced Los Vaqueros I population continued to decline. Only nine plants reaching reproductive maturity, despite a second year managment regime that controlled grass competition with Fusilade®. Plant size and nutlet output were enemic, indicating that this population will become extinct in the near future and not contribute to the recovery of the species.

This population needs to be oberved and censused under a natural, third year management regime in order to document its ability to maintain itself within the existing grassland community.

5) The reintroduced population at Connolly Ranch conformed to predictions and grew significantly in its second year. A total of 707 reproductive plants were found, an increase of 22% over 1991. More than a third were beyond the fence in areas that did not receive second year management treatment with herbicide. Grass cover (and presumably, competitive inhibition) had increased because of the pattern of early fall rain, thus reducing mean plant size, floral display, and nutlet production in the population. Mean maximum plant size remained high and the size-class distribution was broad, however, indicating that some low competition patches were still available at the site for *Amsinckia* occupation. Although the size of this population may fluctate significantly in coming years (especially under a natural, third year management regime), It is likely that this southernmost occurrence will contribute to the overall recovery of the species.

This population needs to be oberved and censused under a natural, third year management regime in order to document its ability to maintain itself within the existing grassland community.

6) The attempt to install a new population at Los Vaqueros II failed because of unfavorable site characteristics as well as severe disturbance by yearling cattle. Soil characteristics are thought to be largely responsible, although not enough data are available to draw conclusions. It is highly unlikely that the LV II population will contribute to the recovery of the species.

Additional soil samples should be taken and analyzed and the fate of the population followed until extinction. A second year management regime should be implemented by controlling annual grass competition with Fusilade® during the winter of 1992-93.

7) The attempt to install a new population at Corral Hollow appears to have been successful, although the scatter-sowing technique for putting out nutlets was very inefficient. Only 64 plants reached reproductive maturity out of the 10,000+ nutlets sown, but these were large and fecund in habitat patches treated with Fusilade®. It is possible that many of the scatter-sown nutlets remain viable at CH as well as at LV II and could contribute to population growth in the future. Although the CH population was small in its first year, it has a potential for growth and contributing to the recovery of the species.

The recommendation for the CH population in its second year is to implement a second year management regime by controlling annual grass competition with Fusilade® during the winter of 1992-93. This will allow comparison with LV II in order to determine the relative importance of on-site nutlet production and residual nutlets in the seed bank with respect to near-term population growth.

Table 11. A summary of the characteristics and status of created populations of *Amsinckia grandiflora* during the 1990-1992 recovery effort.

year	management regime	reproductive population (# of plants)	total 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
Black Diamond II					
1991	experimental	288	11,280	1.68	growing
1992	enhancement	70	2,163	1.50	declining
Los Vaqueros I					
1991	experimental	374	3,200	1.32	declining
1992	enhancement	9	177	0.80	declining
Connolly Ranch					
1991	experimental	580	17,030	1.43	growing
1992	enhancement	707	12,019	1.26	growing
Los Vaqueros II					
1992	experimental	136	310	1.48	declining
Corral Hollow					
1992	experimental	64	1,827	1.39	growing

Table 12. A summary of the characteristics and status of natural populations of *Amsinckia grandiflora* during the 1990-1992 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	decling
1992	enhancement	546	31.4 ± 8.5	1.17	growing
Site 300 - Draney Canyon					
1990	natural	16	na	4.33	?
1991	natural	29	na	1.42	?
1992	natural	28	28.5 ± 7.7	1.54	?
Carnegie Canyon					
1991	natural	3,200+	na	1.24	?
1992	natural	4,000+	na	0.84	stable ?

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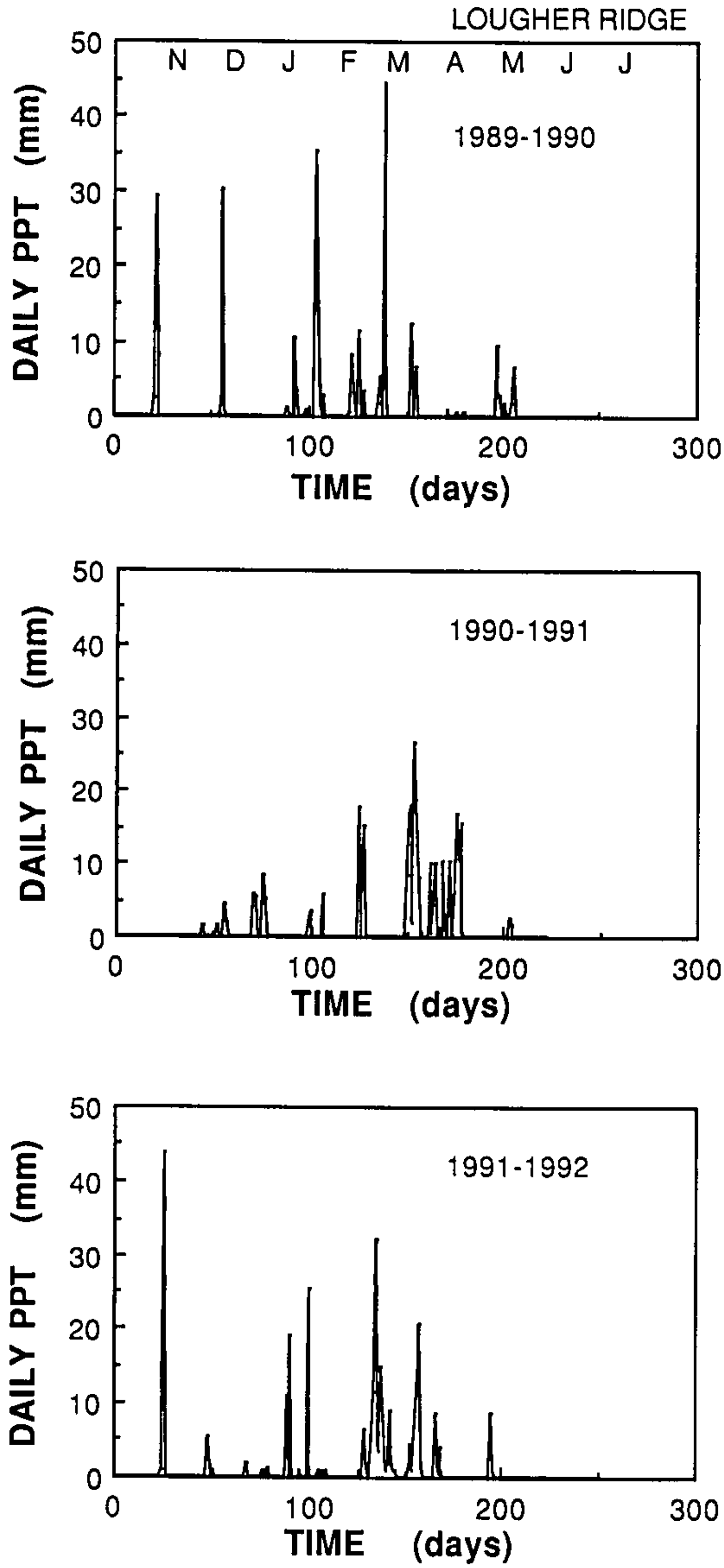
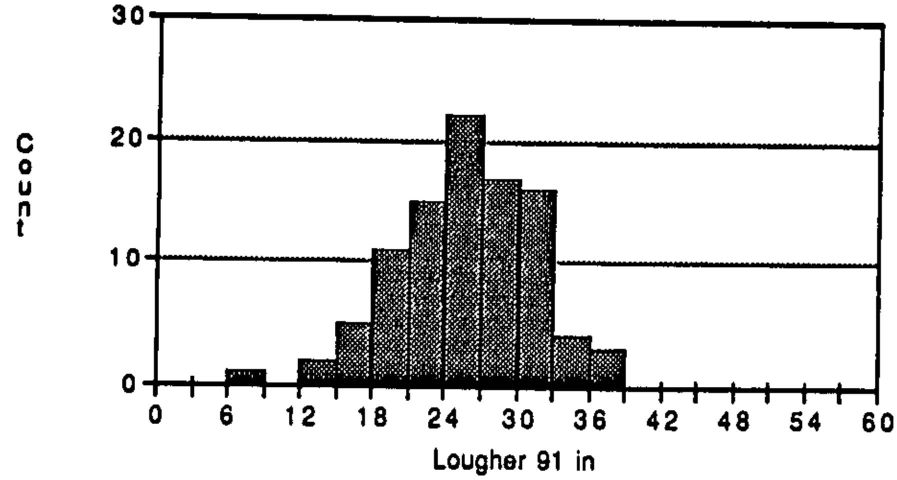


Figure 1. Seasonal patterns of daily precipitation at Lougher Ridge during three growing seasons. Day 0 = October 1.



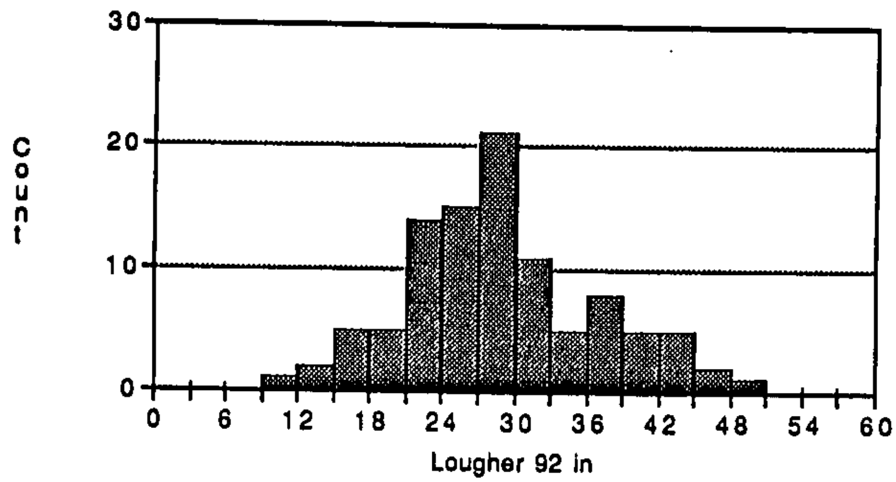
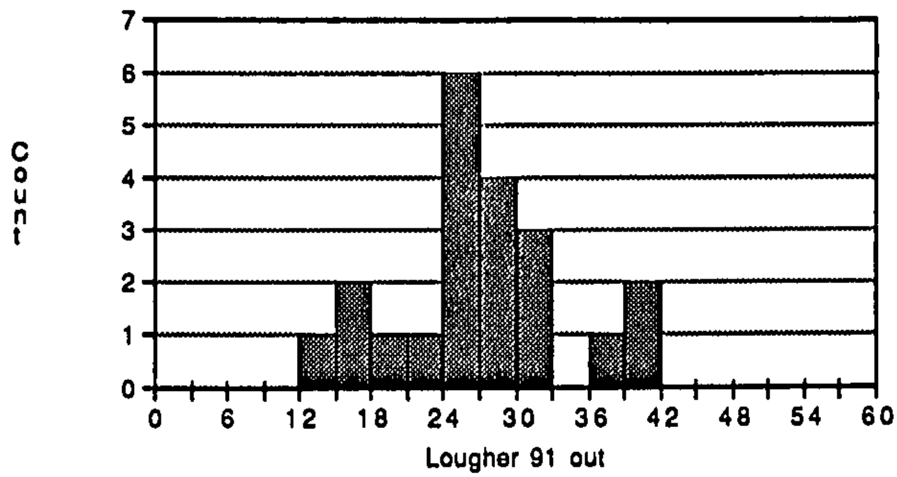


Figure 2. Plant size-class distributions for individuals growing inside the fenced area at Lougher Ridge, 1991 and 1992. Size class dimensions on X axis are in cm of shoot length.



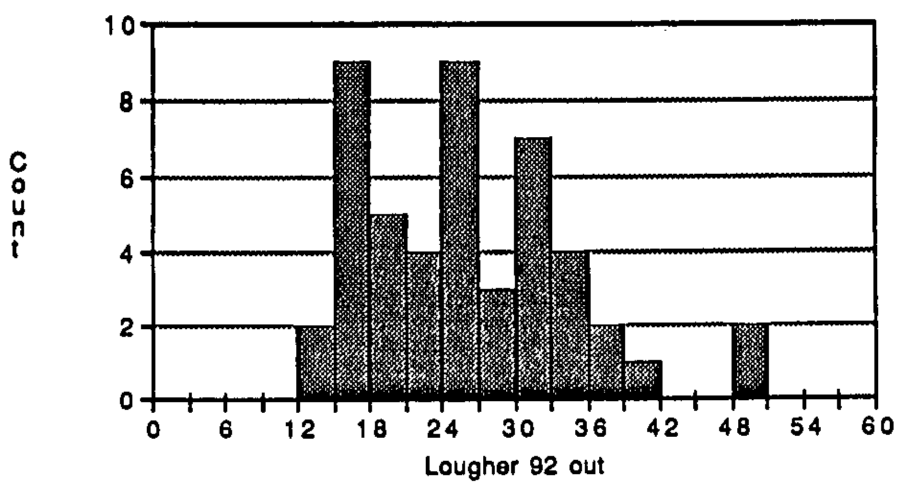


Figure 3. Plant size-class distributions for individuals growing outside the fenced area at Lougher Ridge, 1991 and 1992. Size-class dimensions on X axis are in cm of shoot length.

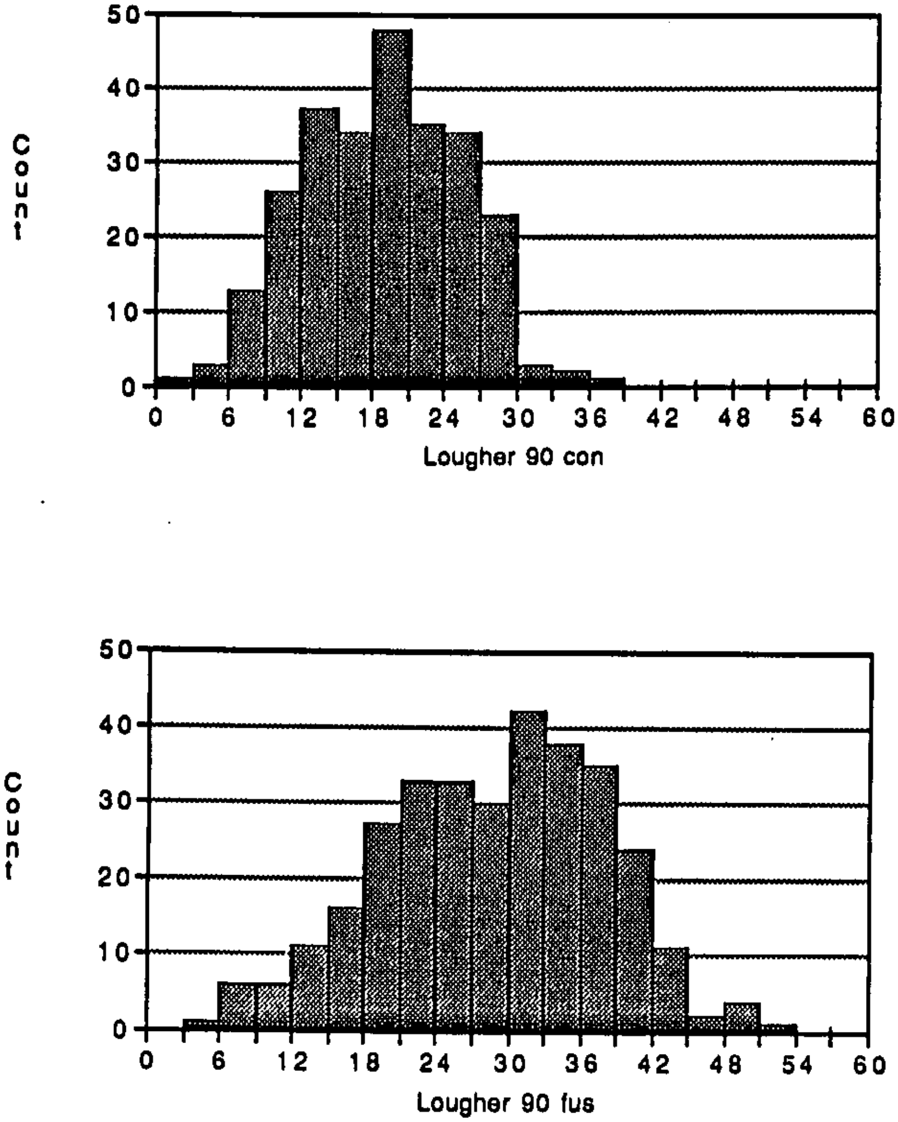


Figure 4. Plant size-class distributions for individuals growing in control plots (with dense annual grasses) and in Fusilade plots (no annual grasses) at Lougher Ridge, 1990.

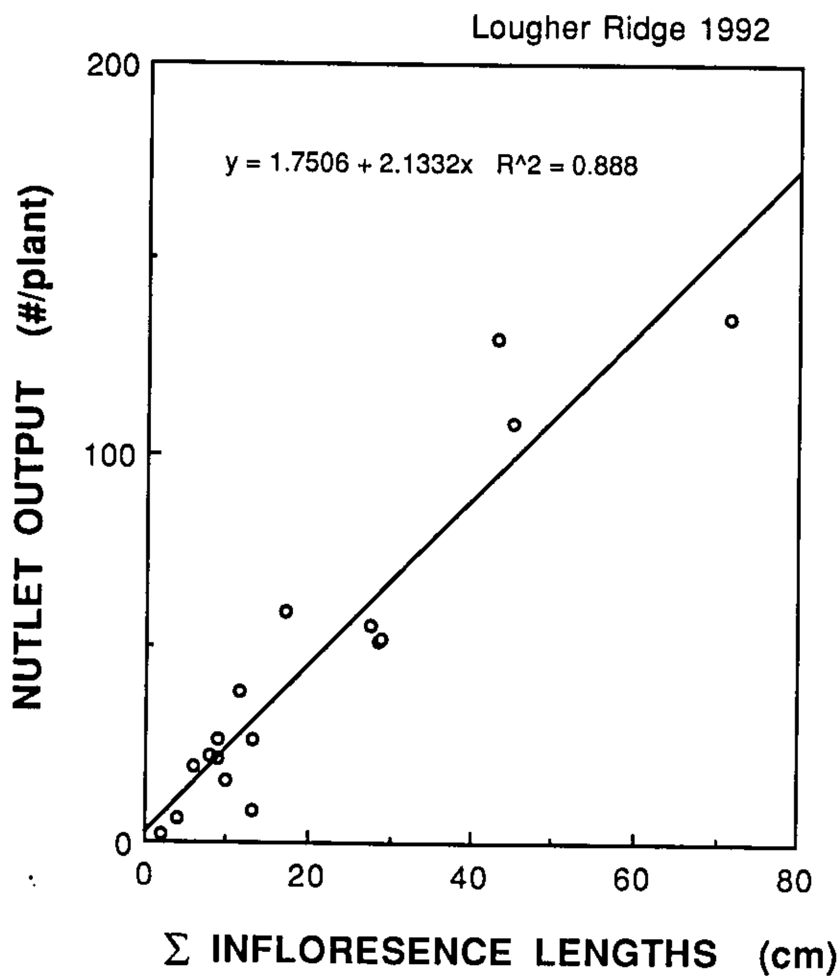


Figure 5. Nutlet output as a function of the sum of the inflorescence lengths on a single plant of Amsinckia grandiflora at Lougher Ridge, 1992.

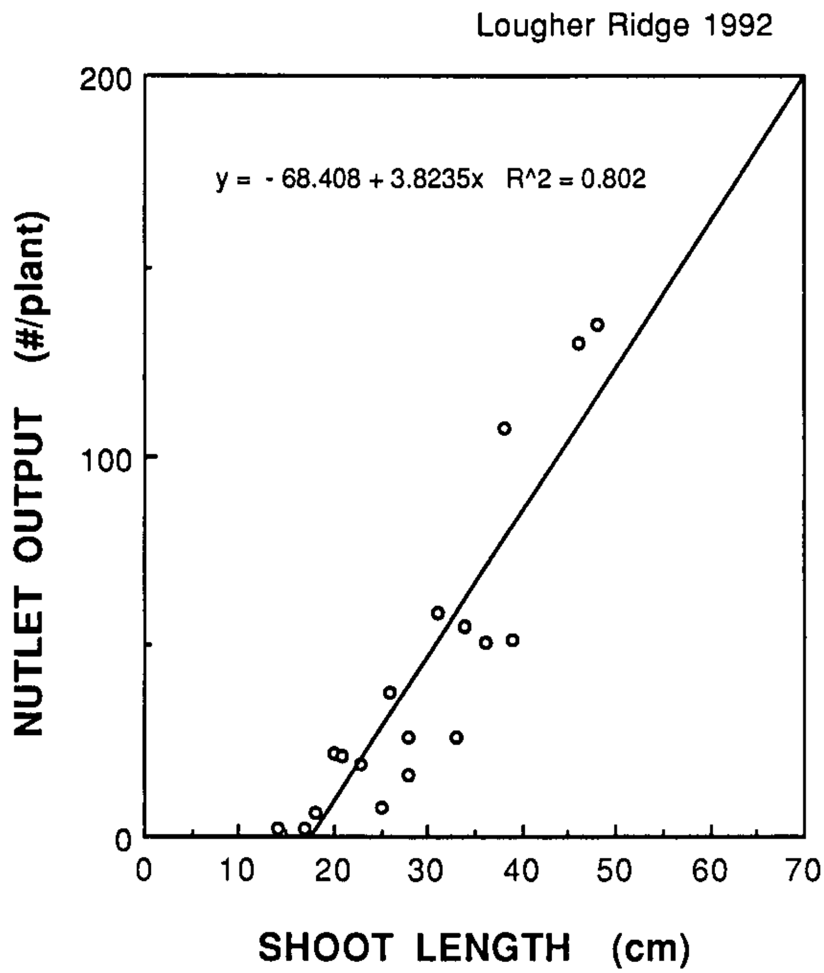


Figure 6. Nutlet output as a function of shoot length per plant of *Amsinckia grandiflora* at Lougher Ridge, 1992.

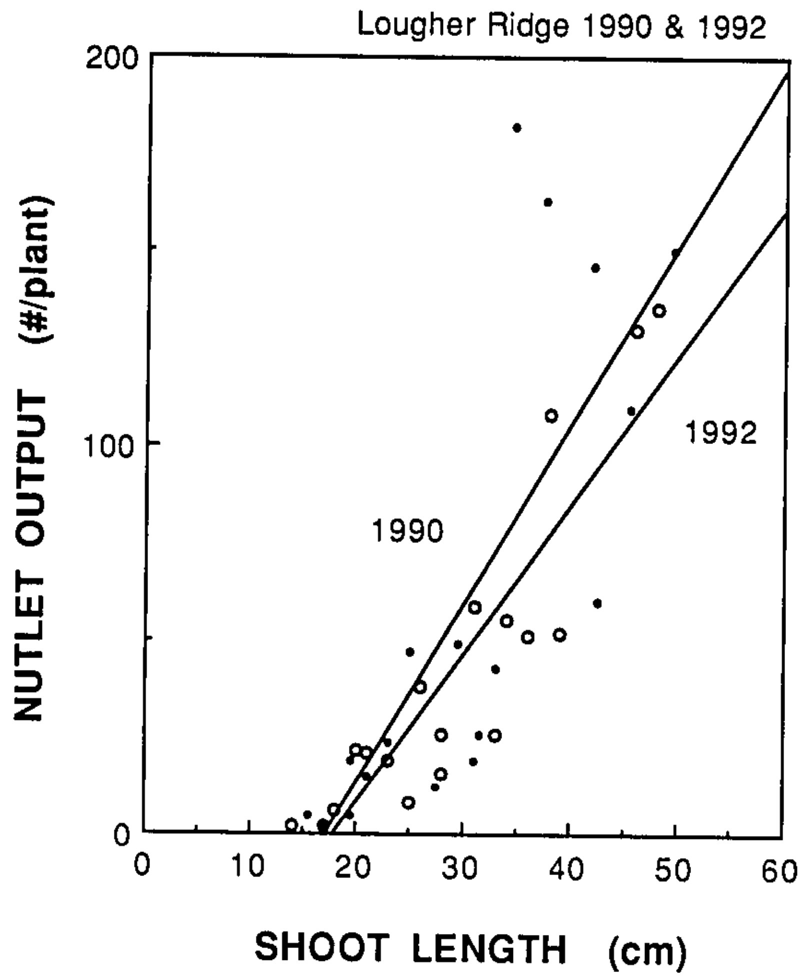


Figure 7. Comparison of nutlet output - shoot length relations for two different years at Lougher Ridge.

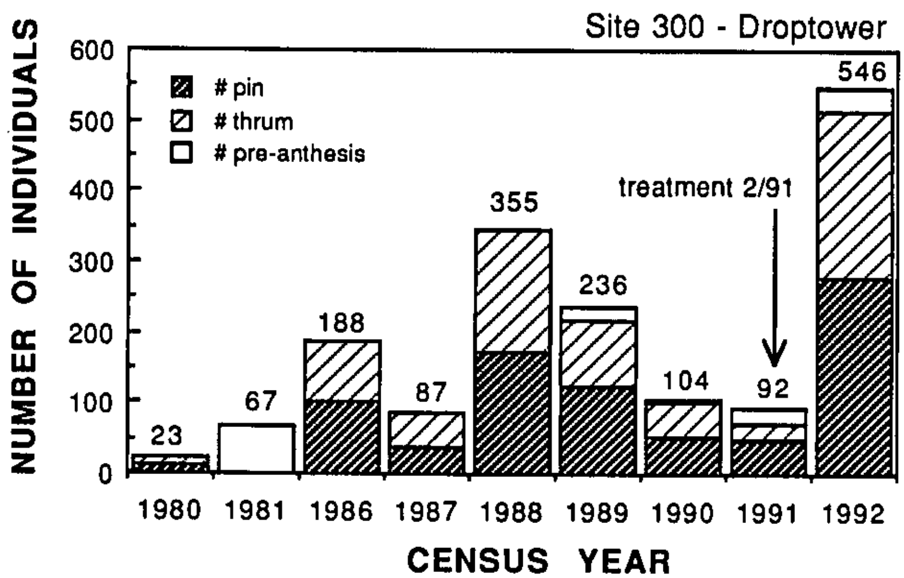


Figure 8. Spring census of the Droptower population of Amsinckia grandiflora at Site 300. Total population size and the proportions of pin and thrum individuals are shown. The February 1991 treatment of portions of the population with the grass-specific herbicide Fusilade marked a transition between natural and enhancement management regimes.

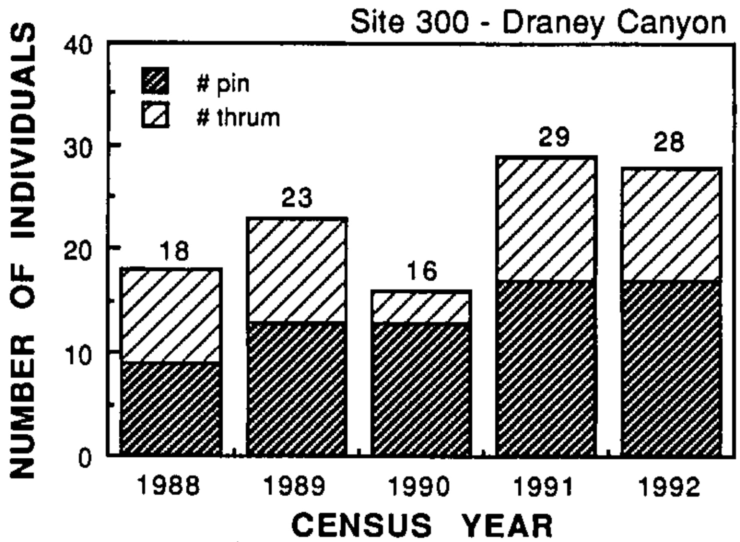


Figure 9. Spring census of the Draney Canyon population of Amsinckia grandiflora at Site 300. Total population size and proportions of pin and thrum individuals are shown. This population remains under a natural management regime.

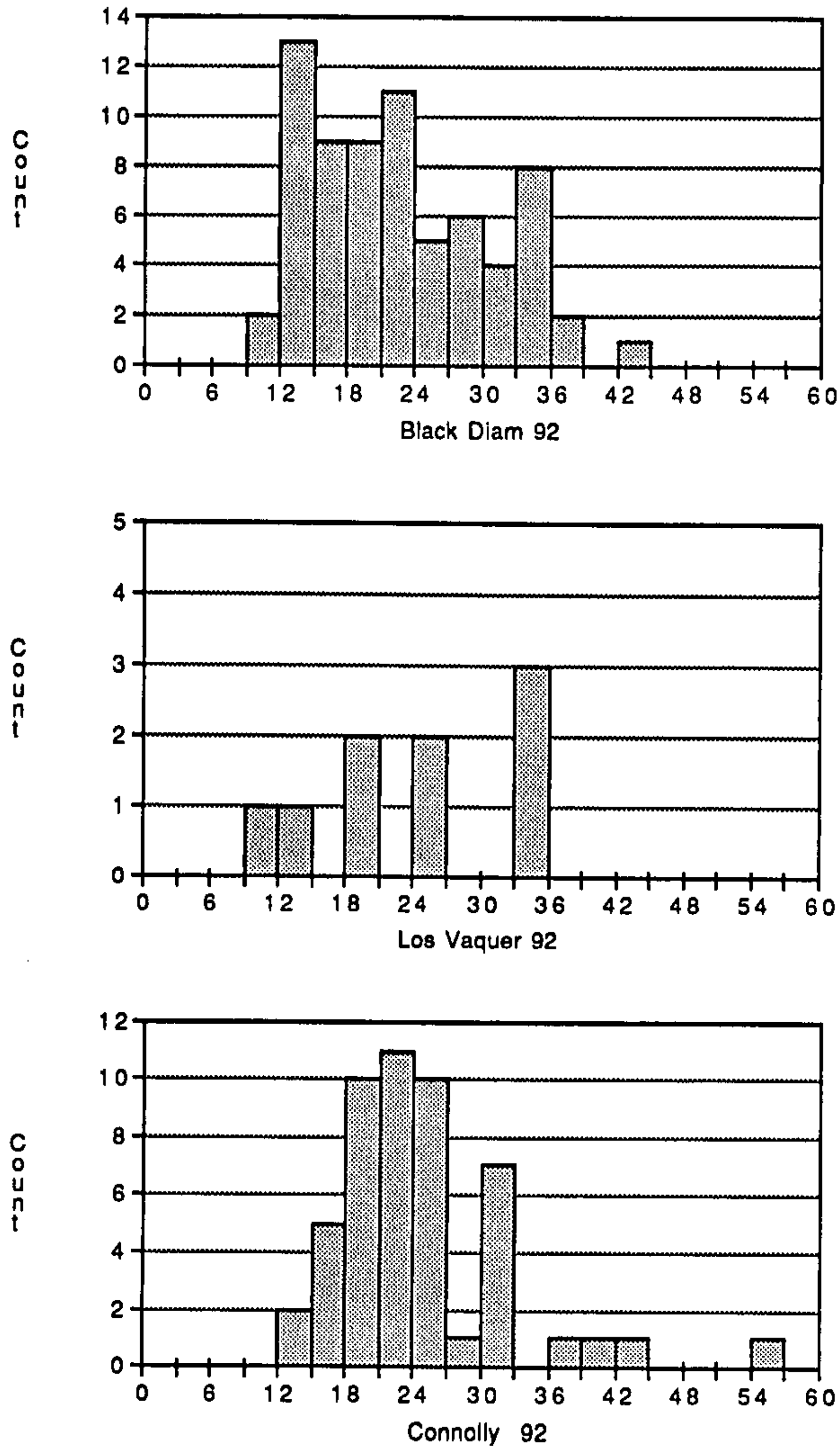


Figure 10. Plant size-class distributions for individuals growing within the fence at three reintroduction sites (Black Diamond II, Los Vaqueros I, Connolly Ranch), 1992. Size-class dimensions on X axis are in cm of shoot length.