Creating New Populations of *Acanthomintha duttonii*. IV. Demographic Performance at Pulgas Ridge and Edgewood Park.

Bruce M. Pavlik and Erin K. Espeland
Department of Biology
Mills College
Oakland, CA 94613

Prepared for

Endangered Plant Program
California Department of Fish and Game
1416 Ninth Street, Room 1225
Sacramento, CA 95814

Funded by

U.S. Fish and Wildlife Service Section 6 Grant-in-aid
California Drought Relief Funds
Contract Nos. CA HER 012993 and FG 2240R3

December 1994

Creating New Populations of *Acanthomintha duttonii*. IV. Demographic Performance at Pulgas Ridge and Edgewood Park.

Bruce M. Pavlik and Erin K. Espeland
Department of Biology
Mills College
Oakland, CA 94613

Prepared for

Endangered Plant Program
California Department of Fish and Game
1416 Ninth Street, Room 1225
Sacramento, CA 95814

Funded by

U.S. Fish and Wildlife Service Section 6 Grant-in-aid
California Drought Relief Funds
Contract Nos. CA HER 012993 and FG 2240R3

December 1994

Pavlik, B.M. and E.K. Espeland. 1994. Creating new populations of *Acanthomintha duttonii*. IV. Demographic Performance at Pulgas Ridge and Edgewood Park. State of California Department of Fish and Game, Endangered Plant Program, Sacramento, CA. 25 p.

Abstract

The San Mateo thornmint, *Acanthomintha duttonii* (= *A. obovata* ssp. *duttonii*), is state and federally -listed as an endangered plant. Of the four known historical occurrences of this distinctive species in San Mateo County, California, three have been extirpated. The only remaining natural population occurs in Edgewood County Park, north of Woodside, where there is still a great potential for extinction. In order for the species to recover, populations must now be created in appropriate habitat within historic range. The current project represents the fourth phase of an effort to create new populations and to determine the demographic, ecologic, and genetic factors that limit their growth and long-term stability. The objectives of this study included; 1) comparing the demographic performance (size, density, survivorship, reproductive output) of the only extant natural population at Edgewood Park to the reintroduced population at Pulgas Ridge, 2) attempting to stimulate germination from the seed bank of quiescent portions of the Edgewood Park population, and 3) releasing a large number of propagules into streak-sown plots for supplementing the reintroduced population at Pulgas Ridge.

The total population size of *Acanthomintha duttonii* (AD) at Edgewood Park increased during 1994 to an estimated 53,136 plants and covered an area that was approximately the same size as in 1993. Survivorship was slightly lower than in 1993, but exceeded 50% overall despite very low rainfall. Plants were smaller than in previous years with correspondingly lower nutlet output per individual, evidence of the onset of density-dependent regulation of population size. Nevertheless, the large number of small but fecund plants produced a very large number of nutlets. High survivorship and high fecundity indicate that the potential for continued population growth remains high.

Although artificial disturbance did not stimulate germination from the seed bank of quiescent portions of Edgewood subpopulation 2B in 1994, the plots should be monitored again in 1995. This is because 90% of the germination had already taken place by the time of plot installation, according to observations of nearby seedlings. Perhaps an additional rainy winter will expose buried nutlets to germination in these same disturbance plots.

A total of 158 reproductive plants were found in all reintroduction plots at Pulgas Ridge in 1994. This was down from the 181 plants observed in 1993 despite the input of 2000

nutlets in the 1994 streak plots. However, all plots did produce plants regardless of whether they were sown this year or left to rely upon the seed bank from previous years. In the case of the 1992 NF and SF plots, 17 plants represented the third generation of *Acanthomintha duttonii* at Pulgas Ridge with no additional nutlet inputs since reintroduction. Therefore, completion of the life cycle has occurred in several successive years at the site despite large fluctuations in the seasonal patterns of precipitation and temperature. There were also more large individuals (> 8 cm total stem length) with multiple branches and glomerules in the 1994 population, indicating that some nutlets germinated in more favorable microsites or that overall conditions had improved this season. The increased frequency of larger, branched plants at Pulgas Ridge is a very positive indication that this site is physiologically suitable for the species. A total of 5,688 nutlets were produced by all the plants at Pulgas Ridge in 1994. There were larger amplications of founder nutlets than observed in 1993, suggesting a potential for self-maintenance and perhaps population growth. However, the total nutlet production at Pulgas declined 36% relative to 1993.

A number of management recommendations were made, including 1) an ongoing program of demographic monitoring for the natural and reintroduced populations, including germination potential, estimates of population size, survivorship, and nutlet output 2), ongoing harvest of several thousand to ten thousand nutlets per year from the Edgewood population for conservation purposes, 3) continued monitoring of disturbance plots in areas at Edgewood Park that once supported subpopulations and probably have a quiescent seed bank, and 4) additional monitoring and supplementation of the Pulgas population with nutlets from Edgewood, sown into the best available microhabitats.

Acknowledgements

We gratefully acknowledge the assistance and field experience of Susan Sommers (California Native Plant Society), and Joe Naras (San Francisco Water Department). Ann Howald and Diane Steeck of the Department of Fish and Game made the research possible and contributed many helpful suggestions.

Creating new populations of *Acanthomintha duttonii*. IV. Demographic Performance at Edgewood Park and Pulgas Ridge.

Bruce M. Pavlik and Erin K. Espeland

Introduction

The San Mateo thornmint, *Acanthomintha duttonii* (Abrams) Jokerst & B.D. Tanowitz (= *A. obovata* Jepson ssp. *duttonii* Abrams), is state and federally -listed as an endangered species. Of the four known historical occurrences of this distinctive plant in San Mateo County, California, three have been extirpated by development (York 1987, Jokerst 1991). The only remaining natural population occurs in Edgewood Park, which is administered by the San Mateo County Department of Environmental Management (Parks and Recreation Department). Although the site (see Sommers 1984 for a description) is now protected by the County, there is still a great potential for extinction. Significant changes in upslope drainage patterns have already taken place due to house and road construction. In addition, fire, vandalism (including off-road vehicles), and accidental disturbance will probably occur with increasing frequency as the adjacent human population grows.

To recover the San Mateo thornmint, the risk of extinction needs to be spread among several populations instead of being concentrated on a single population. Populations must, therefore, be created in appropriate habitat within historic range and afforded adequate protection and management (Pavlik 1994, Pavlik *et al.* 1993). The current project represents the fourth phase of an effort (see Pavlik and Espeland 1991, Pavlik et al. 1992, Pavlik and Espeland 1993) to create the new populations and to determine the demographic, ecologic, and genetic factors that limit their growth and long-term stability. The objectives of this study included; 1) comparing the demographic performance (size, density, survivorship, reproductive output) of the only extant natural population at Edgewood Park to the reintroduced population at Pulgas Ridge, 2) attempting to stimulate germination from the seed bank of quiescent portions of the Edgewood Park population, and 3) releasing a large number of propagules into streak-sown plots for supplementing the reintroduced population at Pulgas Ridge.

Methods and Materials

CHARACTERISTICS OF THE NATURAL POPULATION AT EDGEWOOD PARK

Seedling Density and Survivorship to Reproduction

Estimates of the densities of reproductive *Acanthomintha duttonii* (AD) plants at Edgewood Park (EP) were made in May 1990 and June 1991 using 0.125 m^2 circular quadrats. Five permanent quadrats were randomly positioned within the population using measuring tapes as axes and a random numbers table. These five were used to determine the mean density ($\#/m^2$) and to estimate the total size of the population when multiplied by its area. Eight more non-random, transient quadrats were also used to map the pattern of variation in plant density across the population.

In 1992, however, downslope expansion of the population required that two additional permanent quadrats be added. Also, the variation in plant density across the population was found to be much greater than in previous years. Areal expansion and a greater range of plant densities required that a new method be used for calculating total population size at Edgewood Park. Data from the seven permanent quadrats and from six transient quadrats were combined into a total of four mean density estimates for four different sectors of the population. Those four estimates were for the southern third, the middle third, and the northern third of the 1990-91 distribution and also for the new downslope area. The delineation attempted to group adjacent permanent and transient plots having similar densities to obtain more homogenous estimates for each sector. These sectors were used again in 1992-1993, but shifts in the population required new mapping and areal estimates.

The randomly-located permanent quadrats were also used to estimate survivorship to reproduction during the 1993-1994 growing season. On 3 March 50 seedlings of AD were marked within each of the seven quadrats (5 old + 2 new) . These were revisited on 4 June at the onset of senescence to tally the number of fruiting plants that survived to reproduce.

Plant Size and Nutlet Production

During the peak period of nutlet set in June 1994, 25 whole plants of AD were collected at EP. Each plant was cut at the soil surface and placed in its own zip-lock bag. These were returned to the lab, allowed to air dry at room temperature, and then dissected to determine 1) the total number of nutlets produced, 2) the number of glomerules, 3) the total number of flowers and ovules, and 4) the sum of the stem lengths for each plant. Stem length was measured from the clipped point (at soil surface) to the base of the lowest glomerule. Nutlets were removed by shaking the whole plant or crushing the dry calyxes and placed in paper envelopes. The envelopes were stored in an air-tight plastic container and refrigerated at 5^{o} C. Regressions were made between nutlet output and the sum of the stem lengths per plant or the number of glomerules per plant, as in previous years (Pavlik and Espeland 1991).

All plants that survived to reproduce within the permanent quadrats were measured for stem length and number of glomerules on 4 June 1994. These were used to estimate mean plant size and nutlet output for the Edgewood Park population and to generate frequency distributions of plant size for comparison with similar data collected at Edgewood Park and Pulgas Ridge in previous years.

STIMULATING THE QUIESCENT SEED BANK OF PORTIONS OF THE EDGEWOOD PARK POPULATION

Observations made by Susan Sommers over the many years of her studies at Edgewood Park indicated that although some subpopulations had apparently been extirpated, a few individual plants have been found in former habitat. This indicates that such subpopulations could can be manipulated, and possibly restored, because of the presence of a long-quiescent seed bank. For example, downslope from the current population (called 2B by Sommers) is another small area that supported a subpopulation (called 1 by Sommers) during the 1977-1984 period. No plants were observed after the end of the 1982-1984 El Nino event until the spring of 1993 when about 75 reproductive individuals were found. Perhaps the rainfall of 1992-1993 eroded this hillside and exposed nutlets that had fallen into soil fissures. Alternatively, gophers may have churned the soil by digging tunnels and casting materials around the entrances to their burrows, thus bringing dormant nutlets closer to the surface. These observations demonstrated that AD nutlets were present in the seed bank and remained viable for at least eight years. Could germination and seedling emergence be stimulated in apparently extirpated portions of the population by bringing shallow layers in the soil profile to the surface with trowels?

Selection of the Subpopulation

In late May 1993 approximately 50 flowering AD plants were observed some 50 m upslope from the main population at Edgewood Park. These plants marked the site of a once large subpopulation (2000 - 3000 plants called 2A by Sommers) that had produced no reproductive plants since 1984 (S. Sommers pers. communication). The reasons for the decline of 2A are not clear, but may involve direct impact from off-road vehicles and indirect impact from upslope construction and runoff diversion (Sommers 1984, 1986). Due to the isolation of the site from the main population by tall grasses, it is extremely unlikely that the 1993 plants were produced by recent recolonization of this poorly-dispersing species. The reappearance of reproductive plants in 1993, therefore, indicated the persistence of a quiescent seed bank.

We delinated a 3.8 m X 4.1 m rectangle in the center of the 2A site that included the patch of 1993 plants. On 10 January 1994 (during the typical period of germination) four rows of five disturbance plots were situated within the rectangle, taking care to exclude areas with recent plants. Each plot was initially delineated with a 20 cm X 20 cm metal frame. A trowel was used to cut the plot edges to a depth of 8 cm (fissures in this clay soil are commonly 6-10 cm deep by late sping when nutlets begin dispersing), which could then be slid beneath the pad of soil. The pad was then flipped over like a pancake, placed back into its hole and then broken into small clods and pellets. Grass thatch from the former surface was pushed under or removed. In some cases the pad may already have been disturbed by gophers, so our disturbance was additional. Each plot was marked at its eastern edge with two blue flags and checked for plants during the late winter and spring.

CENSUS OF THE REINTRODUCED POPULATION AT PULGAS RIDGE

The status of the population reintroduced to Pulgas Ridge was determined from observations made on 4 June 1994. Plants in the vicinity of the original 24 plots (12 north-facing (NF) and 12 south-facing (SF) from 1992), the six enhancement plots (from 1993) and five streak plots (from 1993) were noted if they had open flowers and measured for size and number of glomerules. These were used to estimate mean plant size and nutlet output for the Pulgas Ridge population and to generate frequency distributions of plant size for comparison with similar data previously collected at Edgewood Park and Pulgas Ridge.

ENHANCING THE REINTRODUCED POPULATION AT PULGAS RIDGE

Microhabitat Selection

The microhabitat characteristics and exact location of the enhancement were determined from previous field and laboratory studies (Pavlik and Espeland 1991, Pavlik et al. 1992, Pavlik and Espeland 1993). The recommendation of the 1993 study was to streak-sow as many as 20 plots (200 seeds each) on the SF (south-facing) slope within 1 m of the channel bottom or on the NF (north-facing) slope approximately 3 m from the channel bottom because these microhabitats produced the highest plant survivorship (germination, plant size, and nutlet production were not affected by slope or topographic position). Consequently, two such areas were selected: one on the SF slope about 2 m west of the precision-sown plots of 1993 and one on the NF slope 2 m west of the 1992 plots. In both cases the lowest plots with respect to the stream channel were 0.6 m away from the wet edge of the channel bottom, extending 1.5 m upslope.

Characteristics of the Founder Nutlets

All of the propagules (= nutlets) of *Acanthomintha duttonii* used in this reintroduction were collected from Edgewood Park in June of 1991 or June of 1993. Nutlets were taken from at least 25 individuals that represented the complete size range and microenvironmental amplitude of the natural population. The collection would be likely, therefore, to contain a representative sample of the existing genetic variation (Falk and Holsinger 1991). Nutlets were stored at 4° C in paper pouches within sealed plastic bags until they were sown in the field.

Installation of the Enhancements

A total of 2000 nutlets of *Acanthomintha duttonii* from the 1991 and 1993 crops were sown on 16 November 1993 into 20 streak plots, 10 plots on each side of the channel. Five NF streaks and 5 SF streaks received exactly 100 1991 nutlets, while the other five streaks on each slope received 1993 nutlets. A large, blunt nail was used to carve a 1 cm deep furrow into the soil surface that was 25 cm long and was oriented north-south. The nutlets were poured into the complete length of the furrow and covered with a small amount of fine sand (that had been rinsed 11 times in water and dried in a hot oven for 45 min). The northern end of each furrow was marked with a numbered flag. No supplements of water or nutrients were subsequently applied. This rapid method (each streak took only 3-4 minutes, compared to 30 minutes for each precision-sown plot) had been previously used to sow AD nutlets into the field with some success (Pavlik and Espeland 1993).

Monitoring and Evaluation

It was not possible to demographically monitor the streak plots because the fates of individual nutlets could not be followed. Rough estimates of germination and survivorship were made, but unmarked seedlings could die and be replaced by a new germinule between census dates.

To estimate nutlet production of the new Pulgas Ridge population, the relationship between plant size and nutlet output developed for the 1993 Edgewood Park population was used (see above). Combined with plant size measurements from Pulgas Ridge, the equation would estimate nutlet output for each plant in the new population. This allowed a non-destructive assessment of reproductive performance *in situ* and comparisons with plants from the natural population.

Results and Discussion

CHARACTERISTICS OF THE NATURAL POPULATION AT EDGEWOOD PARK

Seedling Density and Survivorship to Reproduction

Despite increasing plant densities and decreasing fecundity for the last three years of the study (Pavlik and Espeland 1993), population size continued to increase in 1994, with an estimated 53,136 reproductive plants found in the main population (called 2B by Sommers) by early June of 1994 (Table 1). The increase resulted from the coincidence of several favorable events. First, the large 1993 population produced large amounts of nutlets despite an abundance of small, unbranched, one-glomeruled plants (Pavlik and Espeland 1993). More than 36,000 nutlets were produced per square meter of habitat , adding to the already existing seed bank from past reproduction. Secondly, open, high-quality habitat was downslope and adjacent to the main population for ongoing dispersal and colonization (Figure 1). The distance between the new habitat and the northern end of the population was less than 1 m, with no intervening area of tall grass to inhibit dispersal. Density in this new area was low in previous years. Consequently, density-dependent mortality remained at moderate levels in 1993-94 and overall survivorship was relatively high across the northern and new sectors of the population area (Figure 2). Finally, reproductive densities continued to increase across all sectors of the population, even though rainfall was low and the growing season short compared to 1992-1993. Population area in 1994 was similar to that in 1992 and 1993 ($\Sigma = 59$ m^2).

Table 1. Density and survivorship of *Acanthomintha duttonii* at Edgewood Park, 1994 to 1990. n = 5 permanent quadrats for 1990 and 1991, n = 7 for 1992 to 1994 overall. Density and survivorship in 1992 to 1994 also shown by sector. na = data not available

year	mean density (# plants/m^2)	range of density (# plants/m^2)	mean survivorship (%)	estimated total repro population size
1994 - overall	1106 ± 589	232 - 2280	52.0 ± 18.0	53,136
south	396 ± 164	232 - 560	na	6,692
middle	626 ± 120	464 - 736	22.0	10,079
north	1207 ± 598	368 - 2224	52.0 ± 9.0	18,105
new	1660 ± 620	1040-2280	66.0 ± 14.0	18,260
1993 - overall	794 ± 756	16 -2376	62.9 ± 21.2	36,279
south	74 ± 58	16 - 132	30.0	1,251
middle	613 ± 481	16 - 1256	64.0	9,869
north	1249 ± 646	452 - 2376	66.0 ± 23.6	18,735
new	584 ± 560	24 -1144	74.0 ± 8.0	6,424
1992 - overall	689 ± 704	8 -1736	59.4 ± 29.4	18,772
south	44 ± 4	40 - 48	6.0	616
middle	324 ± 44	268 - 376	42.0	4,536
north	934 ± 595	108 -1736	59.3 ± 10.0	13,076
new	32 ± 24	8 - 56	95.0 ± 5.0	544
1991	230 ± 78	80 - 432	54.8 ± 14.9	9,660
1990	302 ± 294	64 - 960	na	12,864

Plant Size and Nutlet Production *in situ*

The output of nutlets by *Acanthomintha duttonii* plants at Edgewood Park in 1994 was linearly related to the sum of the stem lengths per plant (Figure 3). The slope of the relationship was similar to those recorded in previous years (Table 2), and there was little yearly variation despite large differences in annual rainfall. The number of glomerules per

Table 2. Linear correlations between various measures of plant size and nutlet output per *Acanthomintha duttonii* individual at Edgewood Park and Pulgas Ridge, 1990 - 1994.

n	X	Y	slope	intercept	r	P
Edgewood Park 1994						
25	# glomerules/plant	# nutlets	11.97	11.01	.63	<0.01
25	Σ of stem lengths (cm)	# nutlets	2.25	27.27	.51	<0.05
Pulgas Ridge 1994						
10	# glomerules/plant	# nutlets	12.38	2.82	.94	<0.01
10	Σ of stem lengths (cm)	# nutlets	2.53	22.40	.74	<0.05
Edgewood Park 1993						
25	# glomerules/plant	# nutlets	19.48	4.43	.78	<0.01
25	Σ of stem lengths (cm)	# nutlets	2.86	36.07	.45	<0.05
Edgewood Park 1992						
25	# glomerules/plant	# nutlets	13.16	-2.84	.91	<0.01
25	Σ of stem lengths (cm)	# nutlets	1.88	3.09	.85	<0.01
Edgewood Park 1990						
40	#glomerules/plant	#nutlets	12.68	11.72	.80	<0.01
40	Σ of stem lengths (cm)	# nutlets	2.83	21.11	.71	<0.01

plant was also positively correlated with nutlet output (Figure 4), but with a slope that was most similar to 1990 and 1992. There were also no site-specific differences in the size/nutlet output relations during 1994 when plants from the EP and Pulgas Ridge sites are compared.

Most plants at EP fell into the one glomerule or short stem length categories and there were very few large, well-branched plants in the population (Figure 5). This suggests that habitat conditions were sub-optimal in 1994, perhaps because of high survivorship, high seedling density, and the resultant intraspecific competition. More large plants (> 18 cm stem length and > 5 glomerules) were produced in 1992 as the new area to the north of the population was colonized at low plant densities. Mean plant size (total stem length) in 1994 was 4.0 ± 3.2 cm Table 3), compared to 4.5 ± 2.4 cm in 1993, 6.9 ± 7.1 cm in 1992 and 4.7 ± 2.5 cm in 1990.

Using the 1994 values of mean plant density (1106 pl/m^2) and mean plant size (4.0 cm of stem length), combined with the 1994 nutlet output equation (Table 2), a rough estimate of nutlet production can be obtained. An average of 27,650 nutlets/m^2 were produced in 1994 at EP, compared to 36,767 in 1993, 11,024 in 1992 and 10,363 in 1990. The decrease was mostly the result of decreases in nutlet output per plant rather than decreases in population density. Therefore, fewer nutlets were produced per unit of plant biomass in 1994, indicating that high densities and small plant sizes have begun to impair the potential for ongoing population growth at Edgewood Park.

STIMULATING THE QUIESCENT SEED BANK OF PORTIONS OF THE EDGEWOOD PARK POPULATION

Despite the presence of 90 *Acanthomintha duttonii* seedlings in the vicinity of the 20 disturbance plots in January 1994, no new seedlings were found within the plots during the next five months. An additional 10 seedlings in the 4-6 leaf stage were noted outside of the plots on 20 March, indicating that some germination had occurred since plot installation. Although it is obvious that artificial disturbance did not stimulate germination of buried nutlets in the seed bank of subpopulation 2B in 1994, these plots should be monitored again in 1995. This is because 90% of the germination had already taken place by the time of installation, according to observations of nearby seedlings. Perhaps an additional rainy winter will expose buried nutlets to germination in these same disturbance plots. It is also possible, however, that the seed bank of subpopulation 2B is spatially patchy and that the plots simply were in the "wrong" places.

ENHANCEMENT AND CENSUS OF THE REINTRODUCED POPULATION AT PULGAS RIDGE

A total of 158 reproductive plants were found in all reintroduction plots at Pulgas Ridge in 1994 (Table 3). This was down from the 181 plants observed in 1993 despite the input of 2000 nutlets in the 1994 streak plots. However, all plots did produce plants regardless of whether they were sown this year or left to rely upon the seed bank from previous years. In the case of the 1992 NF and SF plots, 17 plants represented the third generation of *Acanthomintha duttonii* at Pulgas Ridge with no additional nutlet inputs since reintroduction. Therefore, completion of the life cycle has occurred in several successive years at the site despite large fluctuations in the seasonal patterns of precipitation and temperature.

Most of the germination in the 20 enhancement plots of 1993-1994 occurred by 16 January 1994. On the NF (north-facing) microsite, maximum absolute germination (compared to the number of sown nutlets) was 6.7 ± 5.9% (n = 10 plots) while on the SF (south-facing) microsite it was 15.1 ± 8.5% (n=10) at the same time. These levels of germination were much lower than in previous years, ranging between 25 and 28% in the moderately dry year of 1991-1992 and between 34 and 45% in the very wet year of 1992-1993 (Pavlik et al. 1992, Pavlik and Espeland 1993). Low field germination during the extremely dry 1993-1994 year apparently accentuated the effects of microsite on the nutlets because the difference in germination between NF and SF slopes was sigificant at the $P<0.05$ level (ANOVA). Survivorship to reproduction (between the January and June sample dates) was statistically identical for the NF and SF slopes (52.6 ± 35.9% vs. 46.7 ± 29.3%, respectively). Consequently, the overall pattern of more plants on the SF slope (85) than on the NF slope (27), first observed in the reintroduction experiment of 1991-1992, was repeated again in 1993-1994.

Reproductive plant size in the NF and SF plots of 1993-1994 was skewed toward larger plants than in previous years (Table 3 and Figure 6). There were more larger individuals (> 8 cm total stem length) with multiple branches and glomerules in the 1994 population, indicating that some nutlets germinated in more favorable microsites or that overall conditions had improved this season (compare with Figure 7 in Pavlik and Espeland 1993 and Figure 12 in Pavlik et al. 1992). With respect to size distribution, plants in the NF plots at Pulgas exceeded those in the SF plots, as well as plants in the natural population at Edgewood Park. When all Pulgas plants are included in the distribution (Figure 7) the

Table 3. Reproductive plant size, nutlet output, and nutlet production at Edgewood Park population size (= n at Pulgas, = 53,136 at Edgewood).

	mean Σ stem length (cm)	n	estimated mean nutlet output (#/plant)	estimated nutlet production (#/site)
1994 Edgewood Park Population	4.0 ± 3.2	155	25	1.3×10^6
1993 Edgewood Park Population	4.5 ± 2.4	220	49	1.8×10^6
1994 Pulgas Population				
all plots	5.2 ± 4.8	158	36	5,688
1994 Enhancements at Pulgas Ridge				
NF streak plots	8.7 ± 8.6	27	44	1,188
SF streak plots	4.0 ± 2.4	85	32	2,720
1994 Cohort of the 1993 Enhancements at Pulgas Ridge				
precision-sown plots	8.9 ± 2.0	7	45	315
streak plots	2.5 ± 1.4	22	29	638
1994 Cohort of the 1992 Pulgas population				
NF plots	6.7 ± 5.4	12	40	480
SF plots	9.1 ± 3.4	5	45	225
1993 Pulgas Population				
all plots	4.4 ± 2.5	181	49	8,869

skewing towards larger sizes becomes pronounced. Mean plant size and nutlet output per plant at Pulgas were higher than at Edgewood, indicating favorable site conditions overall for the reintroduced population as noted in previous years with higher rainfall. The increased frequency of larger, branched plants at Pulgas Ridge is a very positive indication that this site is physiologically suitable for the species.

A total of 5,688 nutlets were produced by all the plants at Pulgas Ridge in 1994 (Table 3). Most were found in the SF plots because of the larger number of plants surviving to reproduce. The 27 NF plants produced a total of 1,188 nutlets, 188 more than were sown.

The 85 SF plants produced a total of 2,720 nutlets, 1,720 more than were sown. These positive amplications of founder nutlets were greater than observed for the NF and SF plots of 1993 Therefore, both and NF and SF subpopulations appear to have potential for self-maintenance and perhaps growth as they become localized in more favorable microhabitats along their respective topographic-moisture gradients. However, the total nutlet production at Pulgas declined 36% relative to 1993. Nutlet mortality is expected to be high in the vicinity of the plots because of the high probability of burial by flooding in the stream channel and subsequent fungal attack. The large soil fissures observed in these heavy clay soils may also "swallow" many nutlets. The yield of new plants in 1995, therefore, will depend heavily on the impact of post-dispersal mortality factors in these microhabitats.

Conclusions and Management Recommendations

1) The total population size of *Acanthomintha duttonii* (AD) at Edgewood Park increased during 1994 to an estimated 53,136 plants and covered an area that was approximately the same size as in 1993. Survivorship was slightly lower than in 1993, but exceeded 50% overall despite very low rainfall. Plants were smaller than in previous years with correspondingly lower nutlet output per individual, evidence of density-dependent regulation of population size. Nevertheless, the large number of small but fecund plants produced a very large number of nutlets. High survivorship and high fecundity indicate that the potential for continued population growth remains high.

The Edgewood Park population should be monitored in the future but not manipulated. Its fundamental demographic characteristics (survivorship, density, size distribution, nutlet output, and nutlet production) appear positive and resilient in the face of large fluctuations in yearly precipitation. It is possible to harvest several thousand to ten thousand nutlets per year for conservation purposes (including cold storage and reintroduction) without significant impairment. Exogenous threats (aseasonal fire, vehicle and foot traffic, vandalism) remain, but there is little evidence for endogenous constraints on the ability of the population to maintain itself if appropriate habitat is available.

2) Although it is obvious that artificial disturbance did not stimulate germination of buried nutlets in the seed bank of subpopulation 2B in 1994, these plots should be monitored again in 1995. This is because 90% of the germination had already taken place by the time of installation, according to observations of nearby seedlings. Perhaps an additional rainy winter will expose buried nutlets to germination in these same disturbance plots. Otherwise,

further attempts to stimulate quiescent seed banks should begin in late fall, just prior to the first heavy rains of the season.

3) A total of 158 reproductive plants were found in all reintroduction plots at Pulgas Ridge in 1994. This was down from the 181 plants observed in 1993 despite the input of 2000 nutlets in the 1994 streak plots. However, all plots did produce plants regardless of whether they were sown this year or left to rely upon the seed bank from previous years. In the case of the 1992 NF and SF plots, 17 plants represented the third generation of *Acanthomintha duttonii* at Pulgas Ridge with no additional nutlet inputs since reintroduction. Therefore, completion of the life cycle has occurred in several successive years at the site despite large fluctuations in the seasonal patterns of precipitation and temperature. There were also more larger individuals (> 8 cm total stem length) with multiple branches and glomerules in the 1994 population, indicating that some nutlets germinated in more favorable microsites or that overall conditions had improved this season. With respect to size distribution, plants in the NF plots at Pulgas exceeded those in the SF plots, as well as plants in the natural population at Edgewood Park. The increased frequency of larger, branched plants at Pulgas Ridge is a very positive indication that this site is physiologically suitable for the species. A total of 5,688 nutlets were produced by all the plants at Pulgas Ridge in 1994. There were positive amplications of founder nutlets than observed in 1993, suggesting a potential for self-maintenance and perhaps population growth. However, the total nutlet production at Pulgas declined 36% relative to 1993.

Increases in plant size despite very low rainfall in 1993-1994 indicate that the Pulgas Ridge site may prove valuable for conserving *A. duttonii* . The site may function as an effective back-up reserve if the reintroduced population can grow or be enhanced to a size of several thousand individuals. This requires additional monitoring and supplementation with nutlets from the Edgewood population that are sown into the best available microhabitats.

4) Addition efforts should be made to protect the populations at Edgewood Park and Pulgas Ridge. This will require coordination between the County of San Mateo, the San Francisco Water Department, the Department of Fish and Game, the U.S. Fish and Wildlife Service, and perhaps most importantly, the property owners who live adjacent to both sites. A meeting to discuss and formulate these efforts should be held with representatives from all parties.

Literature Cited

Falk, D.A. and K.E. Holsinger (eds.) 1991. Genetics and Conservation of Rare Plants. Oxford University Press, New York. 272 p.

Harper, J.L. 1977. The Population Biology of Plants. Academic Press, London

Jokerst, J.D. 1991. A revision of *Acanthomintha obovata* (Lamiaceae) and a key to the taxa of *Acanthomintha*. Madrono 38, 278-286.

Menges, E.S. 1991. Seed germination percentage increases with population size in a fragmented prairie species. Conservation Biology 5, 158-164.

McCarten, N. F. 1986. A study of the ecological aspects related to the reintroduction of *Acanthomintha obovata* ssp. *duttonii*. State of California, Department Fish and Game, Endangered Plant Program, Sacramento, CA 36 pp.

Pavlik, B. M. 1990. Reintroduction of *Amsinckia grandiflora* to Stewartville. State of California, Department of Fish and Game, Endangered Plant Program, Sacramento, Ca. 59 pp.

Pavlik, B. M. 1991. Reintroduction of *Amsinckia grandiflora* to three sites across historic range. State of California, Department of Fish and Game, Endangered Plant Program, Sacramento, Ca. 45 pp.

Pavlik, B. M. 1994. Demographic monitoring and the recovery of endangered plants. In: Bowles, M. and C. Whelan (eds.) Recovery and Restoration of Endangered Species. Blackwell Scientific. pp. 322-350.

Pavlik, B.M. and E.K. Espeland. 1991. Creating new populations of *Acanthomintha duttonii*. I. Preliminary laboratory and field studies. State of California, Department of Fish and Game, Endangered Plant Program, Sacramento, Ca. 26 pp.

Pavlik, B.M., E.K. Espeland and F. Wittman. 1992. Creating new populations of *Acanthomintha duttonii*. II. Reintroduction at Pulgas Ridge. State of California Department of Fish and Game, Endangered Plant Program, Sacramento, CA. 35 p.

Pavlik, B.M. and E.K. Espeland. 1993. Creating new populations of *Acanthomintha duttonii*. III. Enhancement at Pulgas Ridge. State of California Department of Fish and Game, Endangered Plant Program, Sacramento, CA. 30 p.

Pavlik, B. M., and E. Manning. 1993. Assessing limitations on the growth of endangered plant populations. I. Experimental demography of *Erysimum capitatum* ssp. *angustatum* and *Oenothera deltoides* ssp. *howellii*. Biological Conservation 65, 257-265.

Pavlik, B. M., Ferguson, N. and M. Nelson. 1993a. Assessing limitations on the growth of endangered plant populations. II. Seed production and seed bank dynamics of *Erysimum capitatum* ssp. *angustatum* and *Oenothera deltoides* ssp. *howellii*. Biological Conservation 65, 267-278.

Pavlik, B.M., D.L. Nickrent and A.M. Howald. 1993. The recovery of an endangered plant. I. Creating a new population of *Amsinckia grandiflora*. Conservation Biology 7, 510-526.

Sommers, Susan. 1984. Edgewood Park. Fremontia 11:5, 19-20.

Sommers, Susan. 1986. Survey Report on *Acanthomintha obovata* ssp. *duttonii*. File Report, California Natural Diversity Data Base, Sacramento, CA.

York, Richard P. 1987. California's Most Endangered Plants. In: T. Elias (ed.) *Conservation and Management of Rare and Endangered Plants*. California Native Plant Society, Sacramento. pp. 109 -120.

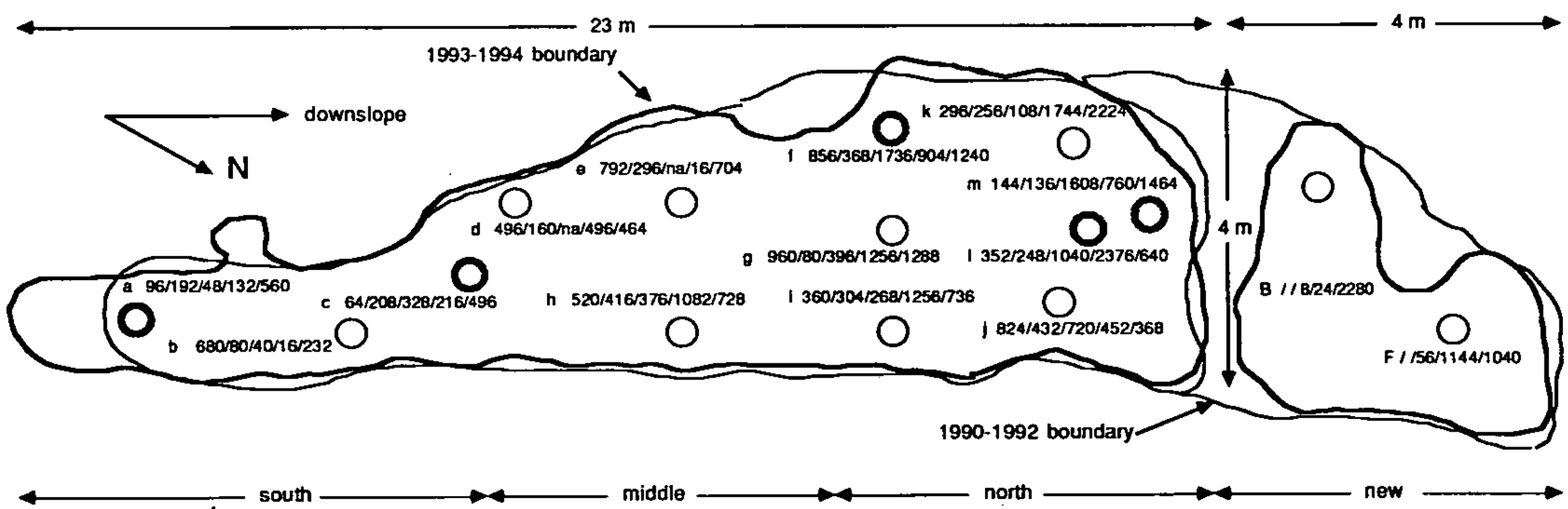


Figure 1. Density (# plants/m^2) of A. duttonii for 1990/1991/1992/1993/1994 at Edgewood Park. Previous population boundary (thin line) and current boundary (thick line) are shown.

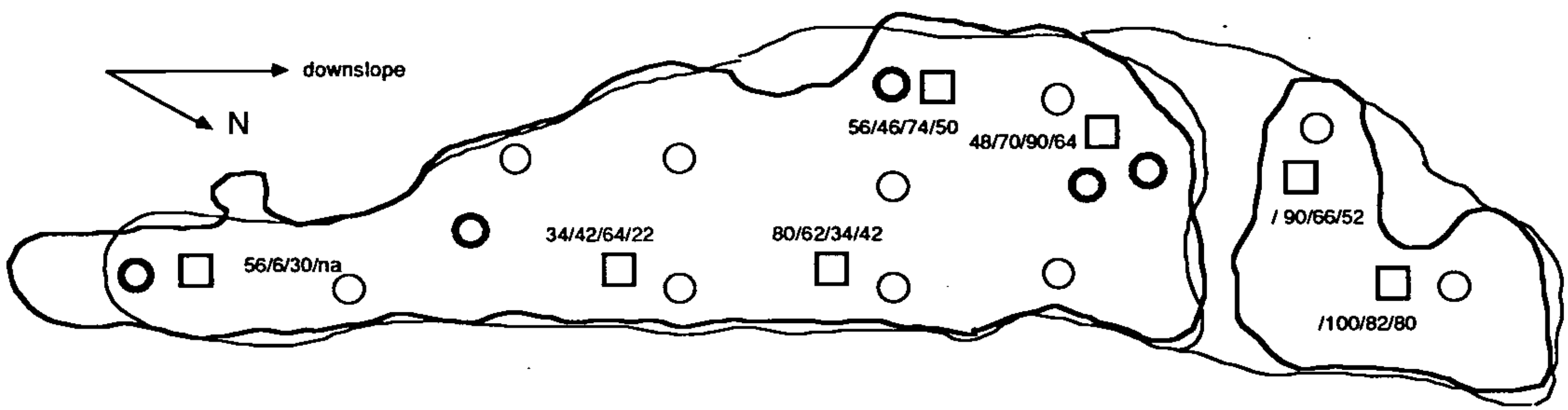


Figure 2. Survivorship to reproduction (%) of _A_. _duttonii_ within 1991/1992/1993/1994 plots at Edgewood Park. na = data not available (plot missing).

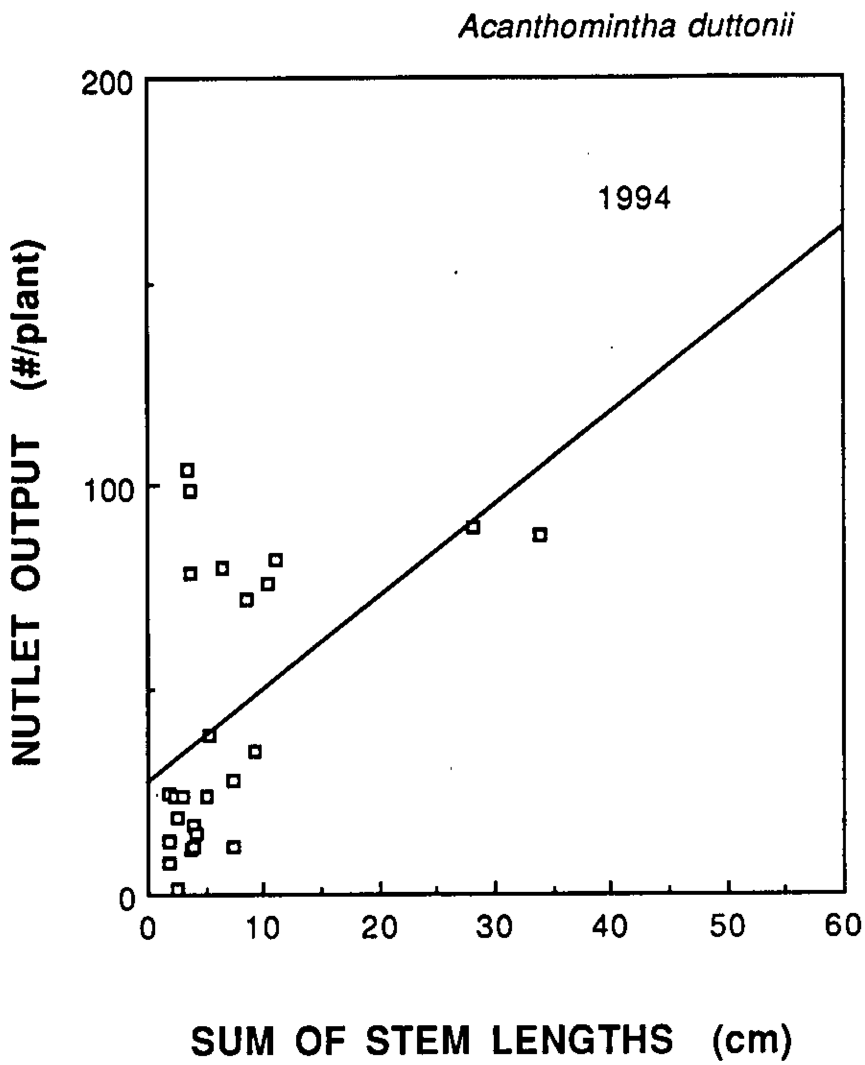


Figure 3. Nutlet output as a function of stem length of plants at Edgewood Park, 1994. See Table 2 for line equations. Compare to Figure 3 in Pavlik and Espeland (1993).

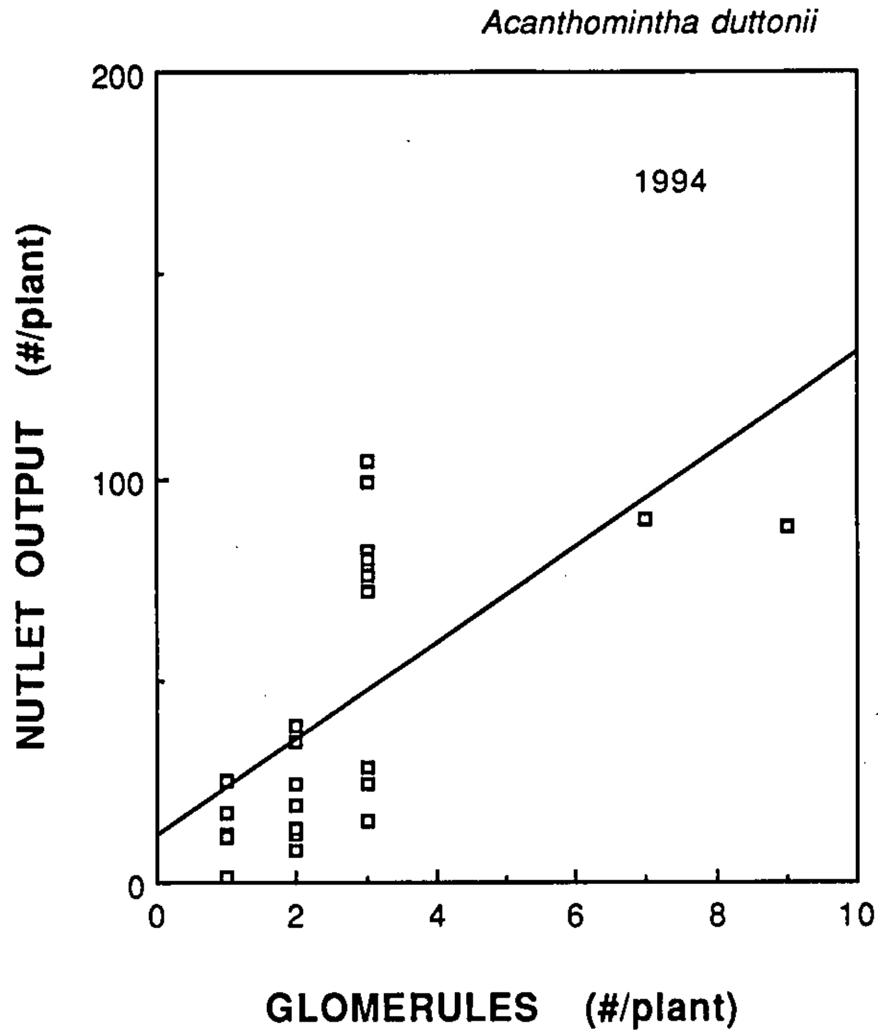
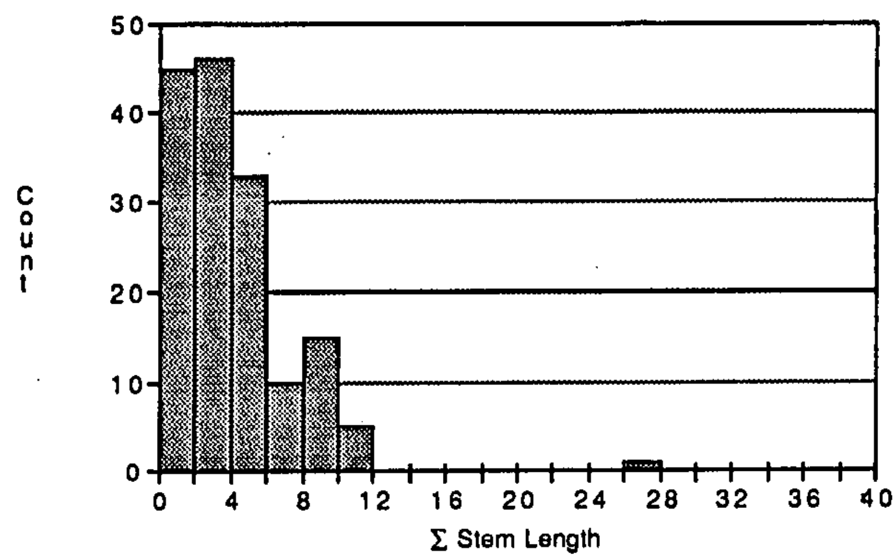


Figure 4. Nutlet output as a function of the number of glomerules of plants at Edgewood Park, 1994. See Table 2 for line equations. Compare to Figure 4 in Pavlik and Espeland (1993).



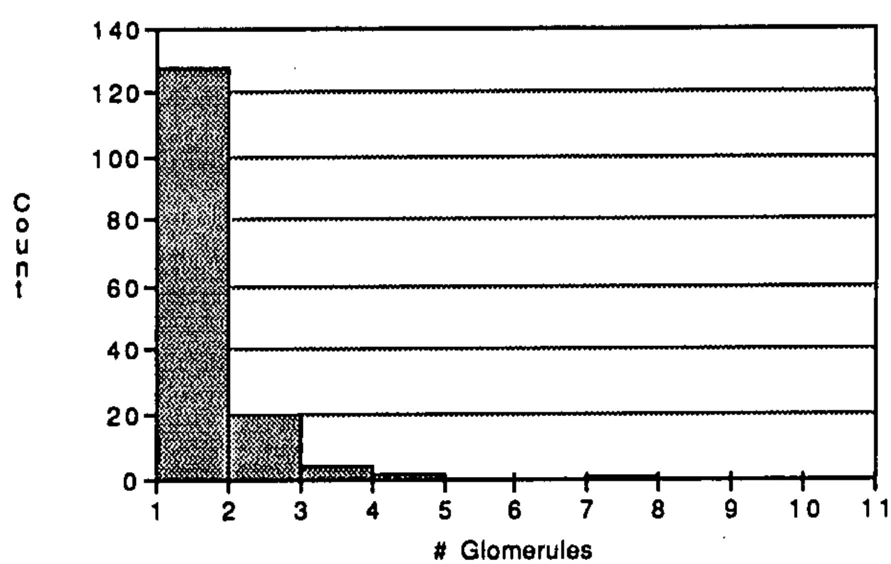


Figure 5. Plant size distributions (sum of stem length in cm and number of glomerules per plant) at Edgewood Park, 1994. n = 155. Compare to Figure 6 in Pavlik and Espeland (1993).

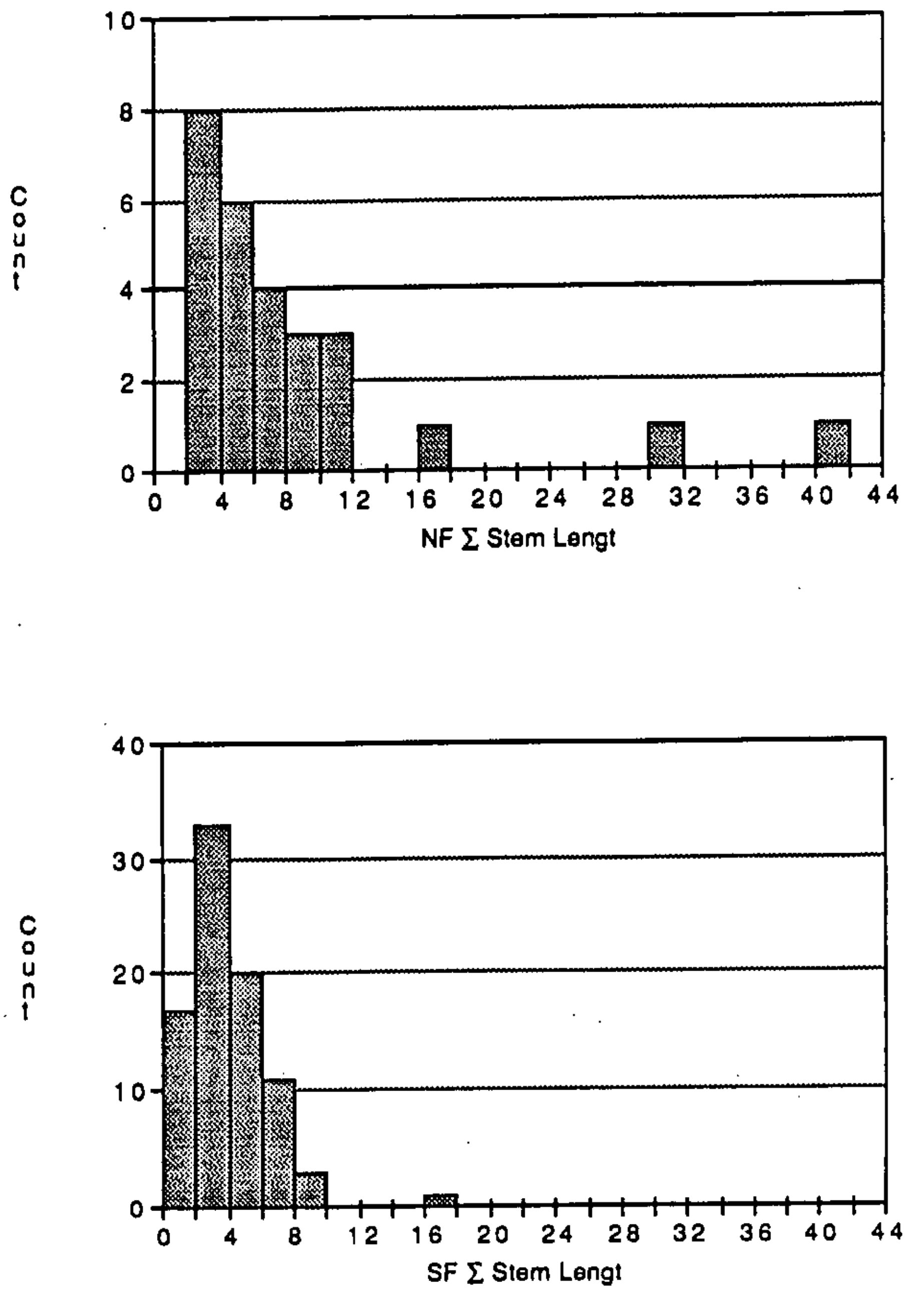


Figure 6. Plant size distributions (sum of stem length in cm) for plants in the north-facing (NF) and south-facing (SF) plots at Pulgas Ridge, 1994. n = 27 (NF) and n = 85 (SF).

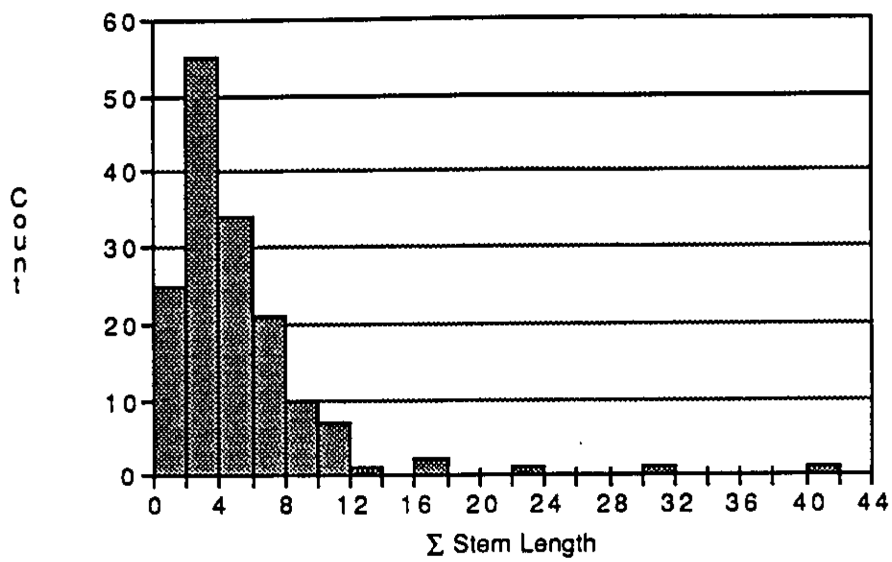


Figure 7. Plant size distribution (sum of stem length in cm) at Pulgas Ridge, 1994. All plants in all plots (NF, SF, precision-sown, streak-sown) are shown. n = 158. Compare to Figure 9 in Pavlik and Espeland (1993).