Creating new populations of *Acanthomintha duttonii*.
III. Enhancement at Pulgas Ridge.

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Prepared for

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

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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 third 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) describing the demographic characteristics (size, density, survivorship, reproductive output) of the only extant natural population of *Acanthomintha duttonii* at Edgewood Park, 2) census of the second year population reintroduced to Pulgas Ridge in 1991-1992, and 3) enhancing the Pulgas Ridge population by sowing additional nutlets into favorable microhabitats.

The total population size of *Acanthomintha duttonii* (AD) at Edgewood Park increased to an estimated 36,280 plants and covered an area that was approximately the same size as in 1992. Survivorship was higher than in previous years and densities increased in eight of the fifteen plots. Plants were smaller than in previous years, but nutlet output per unit of stem length increased. 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.

A total of 102 nutlets germinated in the 24 plots at Pulgas Ridge, or about 9% of the 1157 nutlets produced by the reintroducted population in the spring of 1992 (Pavlik et al. 1992). Approximately 64% of the germination occurred by 14 December and the remainder by 3 March. On the NF (north-facing) microsite, 77 % of the germination occurred in the drier upslope plots while on the SF (south-facing) microsite 89% occurred in the wetter downslope plots near the channel bottom. By late May a total of 64 plants flowered and set fruit in all NF and SF plots so that overall survivorship to reproduction was 63%, up from 38% the year before. Survivorship was highest on the SF (69%) rather than NF (58%)

microsite. Among the SF plots survivorship was much higher in the wetter downslope plots near the channel bottom compared to the drier upslope plots (75 vs. 20%, respectively). This slope-dependent topographic differential in survivorship was also noted during 1991-1992, thus confirming the very narrow habitat requirements of this endangered plant.

Reproductive plant size in the NF and SF plots increased in 1992-1993 relative to 1991-1992. There were more larger individuals (> 8 cm total stem length) with multiple glomerules in the 1993 population, indicating that some nutlets had dispersed into more favorable microsites or that overall conditions had improved this season. With respect to size distribution, performance in the NF + SF plots compared favorably to performance at Edgewood Park. Overall, estimated nutlet production in 1993 was three times greater than that estimated for the 1992 population. 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.

Total *in situ* germination in the enhancement plots during the December to May period was low compared to concurrent laboratory germination on the same 1992 seed lot. Among all 6 precision-sown plots it averaged 34.0 ± 7.4 %, statistically identical to the 25 % total germination found among all plots in the previous year regardless of microhabitat differences (north-facing, south-facing, channel top, channel bottom). There was no difference in germination between the three low and three high plots, indicating that small differences in distance from the channel were inconsequential. Streak plots in the nearby shallow depression had an estimated minimum germination of 39.0 ± 3.5 %. Microhabitat characteristics, therefore, had no effect on germination at Pulgas Ridge.

During the December to June growing season a total of 100 live seedlings and established plants could be found among the 6 precision-sown plots at Pulgas Ridge, representing 34 % of the total nutlets sown (294). In addition, the five streak plots produced 82 seedlings during the same period. Potential enhancement, therefore, was 182 plants from both sowing methods. More than half of the seedlings producing in the precision-sown plots survived to reproduce in early June. Overall survivorship to reproduction was 63% in 1993, significantly higher than the 38% observed in 1992. There was no significant difference between high and low plots. Estimated survivorship in the streak plots was 51 %. After taking survivorship into account, actual enhancement at Pulgas Ridge was 117 reproductive plants in all plots, or 23 % of the total nutlets sown

(514). The total number of reproductive plants at Pulgas Ridge in 1993, therefore, was 181 (117 + 64 from the 1992 plots).

Mean plant size in the precision-sown and streak plots was less than in the NF and SF plots. Very few large plants were present and nutlet output was relatively low. Nevertheless, when considered together with the NF and SF cohort these plants did enhance the overall size distribution at Pulgas Ridge and contributed several thousand new nutlets to the site.

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 for conservation purposes, 3) manipulation of 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

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Creating new populations of *Acanthomintha duttonii*. III. Enhancement at Pulgas Ridge

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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 1993, Pavlik *et al.* 1993). The current project represents the third phase of an effort (see Pavlik and Espeland 1991, Pavlik et al. 1992) 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) describing the demographic characteristics (size, density, survivorship, reproductive output) of the only extant natural population of *Acanthomintha duttonii* at Edgewood Park, 2) census of the second year population reintroduced to Pulgas Ridge in 1991-1992, and 3) enhancing the Pulgas Ridge population by sowing additional nutlets into favorable microhabitats.

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 growing season. On 8 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 1993, 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 then placed in paper envelopes. The envelopes were stored in an air-tight plastic container and refrigerated at a constant 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 1993. 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.

CENSUS OF THE REINTRODUCED POPULATION AT PULGAS RIDGE

The status of the population reintroduced to Pulgas Ridge in 1991-1992 was determined from observations made on 14 December 1992, 9 March 1993, and 20 May 1993. Plants in the vicinity of the 24 plots (12 north-facing (NF) and 12 south-facing (SF)) were marked with wooden potstickers as they first appeared as seedlings. Mortality of marked plants and additional germination were also noted. Measurements of plant size and number of glomerules were made on 20 May at the peak of flower production. 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.

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). The recommendation of the 1992 study was to sow nutlets on south-facing slopes between 0.6 and 1.0 m away from the edge of the wet channel bottom because this microhabitat produced the highest plant survivorship (germination, plant size, and nutlet production were not affected by slope or topographic position). Consequently, a new area was selected approximately 10 m west of 1992's south-facing (SF) plots for placing six additional precision-sown plots.

An additional microhabitat was selected for the enhancement effort. A shallow depression, approximately 30 m south of 1992's north-facing plots, resembled some portions of AD habitat at Edgewood Park; deeply fissured, moist clay with little perennial plant cover. The circular area was about 2 m in diameter, drained to the west, and surrounded on three sides by gently-undulating serpentine grassland. A total of five streak plots would be located in this shallow depression.

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 1992. 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^{o} C in paper pouches within sealed plastic bags until they were sown in the field.

Laboratory germination trials were conducted in January 1993 using three replicates of 25 nutlets each. A replicate consisted of a plastic petri dish (5.5 cm diameter) containing a filter paper disk that was kept moist with distilled water. Nutlets were spread across the paper disks and kept in a dark room in which the temperature averaged 25^{o} C. Replicates were checked every day for 12 days, noting germination (protrusion of the radicle through the pericarp) and removing germinules with a soft paintbrush.

Installation of the Enhancements

The channel enhancement was installed by placing six precision-sown plots in a line parallel to the edge of the channel bottom. Three plots were located 0.6 m away from the edge of the wet channel and would likely be inundated by water for short periods during the winter. These were designated the "low" plots. Three "high" plots were 0.9 m away from the channel edge and would probably not be inundated. Differences in germination, survivorship, plant size, and nutlet production between low and high plots could be used to better resolve optimal habitat for this endemic plant. The locations of the plots were permanently marked with two, 20 cm long stainless steel rods driven into the soil so that 5 cm protruded above the surface. The rods positioned a removable wooden frame, 18 x 18 cm, into which a grid of 49 holes (7 holes x 7 holes, each 2.5 cm diameter) had been drilled. The holes allowed exact placement of nutlets within the plot and subsequent monitoring of germinules and juvenile plants.

A total of 294 nutlets of *Acanthomintha duttonii* from the 1992 crop were sown on 16 October 1992 into the six plots within the channel. After a frame was in place, a blunt nail was used to drill 1 cm deep depressions into the mineral soil beneath each sowing hole. One nutlet was pressed into each depression (49 per plot) and covered with about 20 cc of loose, native soil. No supplements of water or nutrients were applied during the study and the site received 105 % of its average precipitation during the 1 October to 1 May season.

A total of 220 nutlets of *Acanthomintha duttonii* from the 1992 crop were sown on 16 October 1992 into the five streak plots within the shallow depression. Each streak plot was made by carving a 25 cm long, north-south furrow, 1 cm deep, into the soil surface using a large spike. Exactly 50 nutlets were sown along the entire length of four such streaks, with 20 sown into the fifth streak. Native soil was used to close the furrows and the northern end was permanently marked with a painted spike. This rapid method (each streak took only 3-4 minutes, compared to 30 minutes for each precision-sown plot) had not been previously used to sow AD nutlets into the field and needed to be evaluated.

Monitoring and Evaluation

The fate of each nutlet in each precision-sown plot was followed during the December to June growing season by repositioning the wooden frames and searching for seedlings.

The condition of each seedling was recorded on plot-specific data sheets to allow calculation of critical demographic parameters (Pavlik 1993). Those parameters included field germination, stress factors (desiccation, etiolation, grazing by microherbivores), mortality, phenology, reproductive survivorship, and plant size (number of glomerules and stem length). All plots were censused on 14 December, 27 January, 9 March, 19 April, 20 May, and 4 June 1993.

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 (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

The population of *A. duttonii* at Edgewood Park covered an area of about 42 m^2 in 1990 and 1991, with densities ranging from 64 plants/m^2 to 960 plants/m^2 during the reproductive months of May and June. Relatively large amounts of variation were found in 1990 compared to 1991, which had ranges of 896 plants/m^2 and 352 plants/m^2 across the population (Table 1). During 1992, the population expanded downslope and towards the north by approximately 4.4 m and covered a total of 59 m^2 of serpentine clay habitat. Across the old and new areas, AD densities had a much greater variation in 1992 than in previous years, from 8 plants/m^2 to 1736 plants/m^2 (range of 1726 plants/m^2). Using the values of mean density from four geographic sectors of the population, the total reproductive population was estimated to be 18,772 individuals in June 1992.

Population size increased dramatically in 1993, with an estimated 36,280 reproductive plants found in mid-June (Table 1). The increase resulted from the coincidence of several favorable events. First, the large 1992 population produced large amounts of nutlets despite an abundance of small, unbranched, one-glomeruled plants (Pavlik et al. 1992). Secondly, open, high-quality habitat was available downslope for colonization (Figure 1), so that density-dependent mortality remained at a low level in 1992-1993 and overall survivorship increased across the population area (Figure 2). Finally, reproductive densities had increased across all sectors of the population, perhaps sustained by the high rainfall and protracted growing season. Although there was a contraction of population

Table 1. Density and survivorship of *Acanthomintha duttonii* at Edgewood Park, 1990 to 1993. n = 5 permanent quadrats for 1990 and 1991, n = 7 for 1992 and 1993 overall. Density and survivorship in 1992 and 1993 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
1990	302 ± 294	64 - 960	na	12,864
1991	230 ± 78	80 - 432	54.8 ± 14.9	9,660
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
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

area in the new sector (17 to 11 m^2), some expansion also occurred in the southern (14 to 16.9 m^2) and middle (14 to 16.1 m^2) sectors that compensated. Despite the observed dynamism, population area in 1993 was the same as in 1992 ($\Sigma = 59$ m^2).

Plant Size and Nutlet Production *in situ*

The output of nutlets by *Acanthomintha duttonii* plants at Edgewood Park in 1993 was linearly related to the sum of the stem lengths per plant (Figure 3). The slope of the relationship was most similar to that recorded in 1990 (Table 2), but there was little yearly variation despite large differences in annual rainfall. The number of glomerules per plant was also positively correlated with nutlet output (Figure 4). As in 1990, the smallest plants (<10 cm total stem length or 1 glomerule) tended to have the highest reproductive efficiency as measured by the nutlet/ovule ratio (Figure 5).

Most plants at EP fell into the one glomerule or short stem length categories and there were no large, well-branched plants in the population (Figure 6). This suggests that habitat conditions were sub-optimal in 1993, 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 than in 1993 or 1990 as the new area to the north of the population was colonized at low plant densities. Mean plant size (total stem length) in 1993 was 4.5 ± 2.4 cm Table 3), compared to 6.9 ± 7.1 cm in 1992 and 4.7 ± 2.5 cm in 1990.

Using the 1993 values of mean plant density (794 pl/m^2) and mean plant size (4.5 cm of stem length), combined with the 1993 nutlet output equation (Table 2), a rough estimate of nutlet production can be obtained. An average of 36,767 nutlets/m^2 were produced in 1993 at EP, compared to 11,024 in 1992 and 10,363 in 1990 (using the appropriate 1992 and 1990 data and equations). The three-fold increase was mostly the result of increased nutlet output per plant, rather than increases in population density or plant size (Figure 6). Therefore, more nutlets were produced per unit of plant biomass in 1993 (and 1990) than in 1992, indicating that high densities and small plant sizes did not impair the potential for population growth at Edgewood Park.

Table 2. Linear correlations between various measures of plant size and nutlet output per *Acanthomintha duttonii* individual, 1990 - 1993.

n	X	Y	slope	intercept	r	P
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

CENSUS OF THE REINTRODUCED POPULATION AT PULGAS RIDGE

A total of 102 nutlets germinated in the 24 plots at Pulgas Ridge, or about 9% of the 1157 nutlets produced by the reintroducted population in the spring of 1992 (Pavlik et al. 1992). Approximately 64% of the germination occurred by 14 December and the remainder by 3 March. On the NF (north-facing) microsite, 77 % of the germination occurred in the drier upslope plots while on the SF (south-facing) microsite 89% occurred in the wetter downslope plots near the channel bottom. This slope-dependent topographic preference in germination was not noted during 1991-1992, in part because all plots were evenly sown with nutlets. In 1992-1993, however, it is likely that germination depended heavily on the survival and nutlet production by last year's plants. Survivorship to reproduction was higher in the upslope NF plots and in the downslope SF plots in 1992 (Pavlik et al. 1992), thus producing an uneven distribution of nutlets along the topographic/moisture gradient.

By late May a total of 64 plants flowered and set fruit in all NF and SF plots so that overall survivorship to reproduction was 63%, up from 38% the year before. This agrees very well with estimates of survivorship made at Edgewood Park (Table 1) and in the enhancement plots (see below) during the same time period. Seedling mortality was not confined to any one time period during the season, nor was there any readily apparent cause. As observed in 1991-1992, survivorship was highest on the SF (69%) rather than NF (58%) microsite, although the difference was not pronounced. Among the NF plots survivorship was slightly higher in the drier upslope plots compared to the wetter downslope plots (59 vs. 54%, respectively). Among the SF plots survivorship was much higher in the wetter downslope plots near the channel bottom compared to the drier upslope plots (75 vs. 20%, respectively). This slope-dependent topographic differential in survivorship was also noted during 1991-1992, thus confirming the very narrow habitat requirements of this endangered plant.

Reproductive plant size in the NF and SF plots increased slightly in 1992-1993 relative to 1991-1992 (6.2 vs. 3.5 cm, respectively). There were more larger individuals (> 8 cm total stem length) with multiple glomerules in the 1993 population, indicating that some nutlets had dispersed into more favorable microsites or that overall conditions had improved this season (compare Figure 7 with Figure 12 in Pavlik et al. 1992). With respect to size distribution, performance in the NF + SF plots compared favorably to performance at Edgewood Park (Figure 7 and Figure 6). There was no difference in the sizes (and, therefore, the nutlet output) of plants that grew on the NF or SF sites (Table 3). Because the reproductive population sizes were also similar, there was no difference in subpopulation nutlet production with slope aspect. Overall, estimated nutlet production in 1993 (3,456 nutlets, Table 3) was three times greater than that estimated for the 1992 population. 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.

Table 3. Reproductive plant size, nutlet output, and nutlet production at Edgewood Park and Pulgas Ridge, 1993. Nutlet output estimated using the size-output equation from Edgewood Park, 1993 (Table 2). Nutlet production is the product of nutlet output and population size (= n at Pulgas, = 36,279 at Edgewood).

	mean Σ stem length (cm)	n	estimated mean nutlet output (#/plant)	estimated nutlet production (#/site)
1993 Edgewood Park	4.5 ± 2.4	220	49	1.8×10^6
1993 Cohort of the 1992 Pulgas population				
NF + SF plots	6.2 ± 2.8	64	54	3,456
NF plots	6.2 ± 2.7	33	54	1,782
SF plots	6.1 ± 3.0	31	53	1,643
1993 Enhancements at Pulgas Ridge				
precision-sown plots	4.0 ± 1.8	63	47	2,961
streak plots	3.0 ± 1.5	54	45	2,430
1993 Total Pulgas Population				
all plots	4.4 ± 2.5	181	49	8,869

ENHANCING THE REINTRODUCED POPULATION AT PULGAS RIDGE

Laboratory Germination of the Nutlets

When tested in January 1993, nutlets from the 1992 crop had moderate rates of germination in the laboratory. Germination averaged 71 % for 1992 nutlets, compared to 63% for 1991 nutlets and 87% for 1990 nutlets, even though all crops were approximately one year old at the time the tests were conducted. This variation in germination potential could be due to deleterious genetic and environment factors that operate in small populations (Menges 1991). As a result, the 1992 nutlets used at Pulgas Ridge would probably have low germination and produce a small population with less than robust demographic characteristics.

Field Germination

Germinules in precision-sown plots were first observed on 14 December 1992, even though the first storm of the season occurred in late October (35 mm). Winter germination appears to be characteristic of this species, owing to a rigid endogenous control mechanism that stratification, pericarp scarification, fire, wet-dry cycling and red light cannot override (Pavlik and Espeland 1991). Perhaps such a mechanism prevents germination before a thorough saturation of the clay substrate takes place, thus avoiding the possibility of seedling desiccation during warm days in fall and early winter. Percolation is slower within clay substrates and so a higher proportion of the falling rain is likely to run off. Furthermore, clay particles require much more water than sands and gravels to bring soil water potentials into the tolerable range of -0.1 to -1.5 MPa for most seedlings.

Total *in situ* germination (% of nutlets sown) during the December to May period was low compared to concurrent laboratory germination on the same 1992 seed lot. Among all 6 precision-sown plots, it averaged 34.0 ± 7.4 %, with a high of 44.9 % in plot 1. The mean value was statistically identical to the 25 % total germination found among all plots in the previous year regardless of microhabitat differences (north-facing, south-facing, channel top, channel bottom). There was no difference in germination between the three low and three high plots, indicating that small differences in distance from from the channel were inconsequential. Streak plots in the nearby shallow depression had an estimated minimum germination of 39.0 ± 3.5 %. Microhabitat characteristics, therefore, had no effect on germination at Pulgas Ridge.

Seedling Establishment and Mortality

During the December to June growing season a total of 100 live seedlings and established plants could be found among the 6 precision-sown plots at Pulgas Ridge, representing 34 % of the total nutlets sown (294). In a larger population this would correspond to an average density of 228 plants/m^2, which falls within the range observed in the natural population at Edgewood Park (Table 1). In addition, the five streak plots produced 82 seedlings during the same period. Potential enhancement, therefore, was 182 plants from both sowing methods.

More than half of the seedlings produced in the precision-sown plots survived to reproduce in early June. Overall survivorship to reproduction was 63% in 1993, significantly higher (P< 0.025) than the 38% observed in 1992. There was no significant difference between high and low plots (68 vs. 58 %, respectively). Estimated survivorship in the streak plots was 51 %, although this was lowered by poor performance in one streak plot alone. There was no apparent difference between precision- and streak-sown plots in terms of their ability to produce reproductive plants from relatively small quantities of nutlets. After taking survivorship into account, actual enhancement at Pulgas Ridge was 117 reproductive plants in all plots, or 23 % of the total nutlets sown (514). The total number of reproductive plants at Pulgas Ridge in 1993, therefore, was 181 (117 + 64 from the 1992 plots).

Mortality was low during the winter and peaked during the March to April period just before flower production. The principle cause was difficult to identify from observations of grazing, desiccation, and etiolation stresses. Grazing by microherbivores (insects, snails, etc.) was the most commonly observed stress, but the loss of whole shoots, leaves and cotyledons was rarely noted and the amount of tissue missing from any one plant was usually small. Wilting of plants occurred in May and June, but on the whole it affected very few live plants. Likewise, etiolation was rarely observed. Other stresses, including pathogens, may also be important during the early phases of population growth, but these were not assessed during this study.

Plant Size and Nutlet Production

Mean plant size in the precision-sown and streak plots was less than in the NF and SF plots (Table 3). Very few large plants were present (Figure 8) and nutlet output was relatively low (Table 3). Nevertheless, when considered together with the NF and SF cohort these plants did enhance the overall size distribution at Pulgas Ridge (Figure 9) and contributed several thousand new nutlets to the site. Nutlet mortality is expected to be high in the vicinity of the precision-sown plots because of the high probability of burial by flooding in the stream channel and subsequent fungal attack. The large soil fissures observed in the shallow depression may also swallow many nutlets produced in the streak plots. The yield of new plants in 1994, 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 to an estimated 36,280 plants and covered an area that was approximately the same size as in 1992. Survivorship was higher than in previous years and densities increased in eight of the fifteen plots. Plants were smaller than in previous years, but nutlet output per unit of stem length increased. 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. 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) Observations made by Susan Sommers over the many years of her studies at Edgewood indicate that areas which once supported subpopulations could be easily manipulated and possibly restored because of the presence of a 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 until 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. Regardless, these observations indicate that nutlets were present and viable for at least eight years. Other such subpopulations are known at Edgewood (e.g. 2A) and could be artificially exposed with rakes or hand trowels. Attempts to do so are highly recommended.

3) A total of 102 nutlets germinated in the 24 plots at Pulgas Ridge, or about 9% of the 1157 nutlets produced by the reintroducted population in the spring of 1992. By late May a total of 64 plants flowered and set fruit in all NF and SF plots so that overall survivorship to reproduction was 63%, up from 38% the year before. Reproductive plant size in the NF and

SF plots increased in 1992-1993 relative to 1991-1992. There were more larger individuals with multiple glomerules in the 1993 population, indicating that some nutlets had dispersed into more favorable microsites or that overall conditions had improved this season. With respect to size distribution, performance in the NF + SF plots compared favorably to performance at Edgewood Park. Overall, estimated nutlet production in 1993 was three times greater than that estimated for the 1992 population. 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.

Improvements in germination, survivorship, and plant size indicate that the Pulgas Ridge site may prove valuable for conserving *A. duttonii* . Although there are still many comparisons with Edgewood that indicate Pulgas is sub-optimal, 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 (see below).

4) Among all 6 precision-sown enchancement plots germination averaged 34.0 ± 7.4 %, statistically identical to the 25 % total germination found among all plots in the previous year regardless of microhabitat differences. There was no difference in germination between the three low and three high plots, or between precision-sown and streak plots found in a nearby shallow depression. Microhabitat characteristics, therefore, had no effect on germination at Pulgas Ridge. A total of 100 live seedlings and established plants were produced in the 6 precision-sown plots, representing 34 % of the total nutlets sown . In addition, the five streak plots produced 82 seedlings so that potential enhancement was 182 plants. Overall survivorship to reproduction was 63% in precision-sown plots and 51% in streak plots. Actual enhancement at Pulgas Ridge was 117 reproductive plants in all plots. The total number of reproductive plants at Pulgas Ridge in 1993, therefore, was 181 (117 + 64 from the 1992 plots). Mean plant size in the precision-sown and streak plots was less than in the NF and SF plots. Very few large plants were present and nutlet output was relatively low. Nevertheless, when considered together with the NF and SF cohort these plants did enhance the overall size distribution at Pulgas Ridge and contributed several thousand new nutlets to the site.

This attempt to identify more favorable patches of microhabitat was partially successful. All plots within 1 m of the channel bottom on the south-facing slope demonstrated high survivorship to reproduction but only modest growth and low nutlet output. This was also true of the streak-sown plots in the shallow depression. Nevertheless, growth and nutlet output in the enhancement plots were not statistically different from that measured at Edgewood Park in the same year. Additional enhancements are recommended and should be located on the SF slope within 1 m of the channel bottom or on the NF slope approximately 3 m from the channel bottom. Streak-sowing as many as 20 plots (200 seeds each) could begin the process of increasing population size at Pulgas Ridge as a hedge against extinction.

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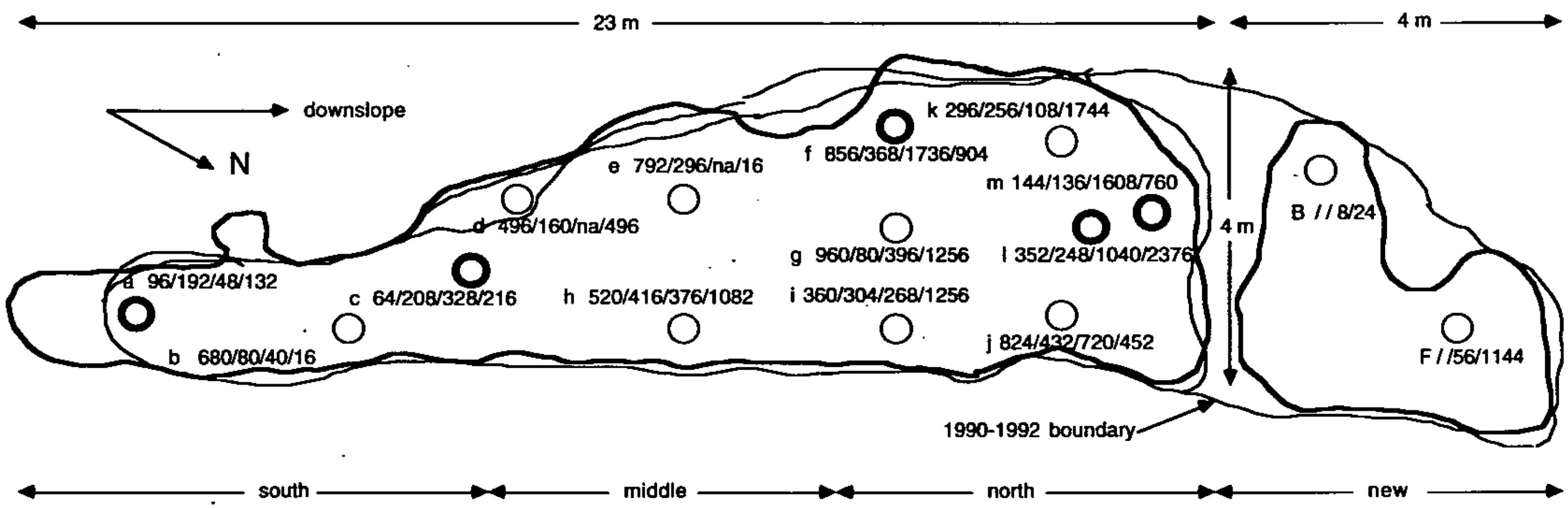


Figure 1. Density (# plants/m^2) of A. duttonii for 1990/1991/1992/1993 at Edgewood Park. Previous population boundaries (thin lines) and current boundary (thick line) shown.

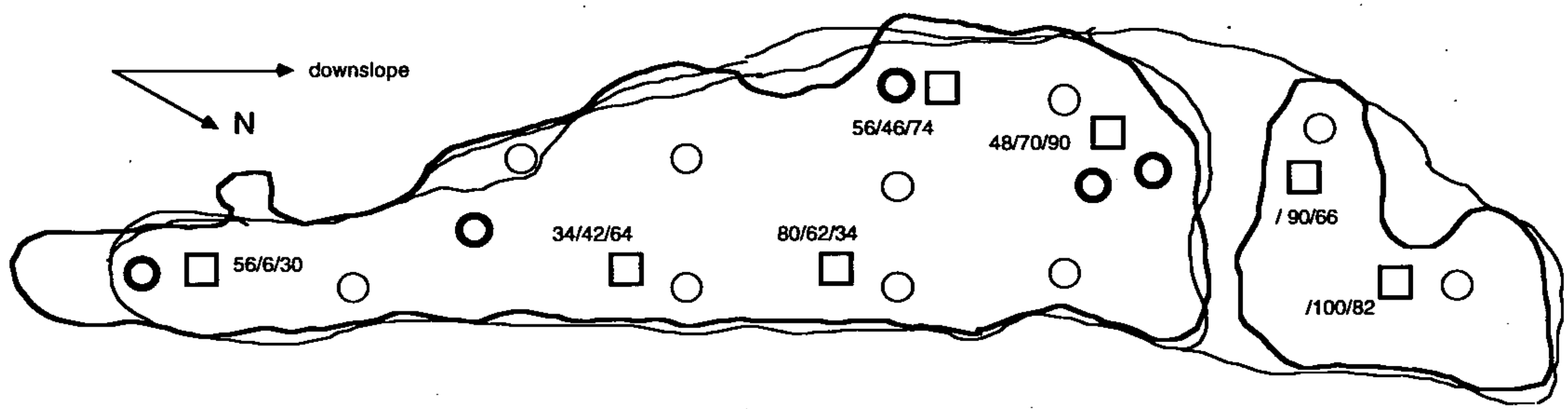


Figure 2. Survivorship to reproduction (%) of _A. duttonii_ within 1991/1992/1993 plots at Edgewood Park.

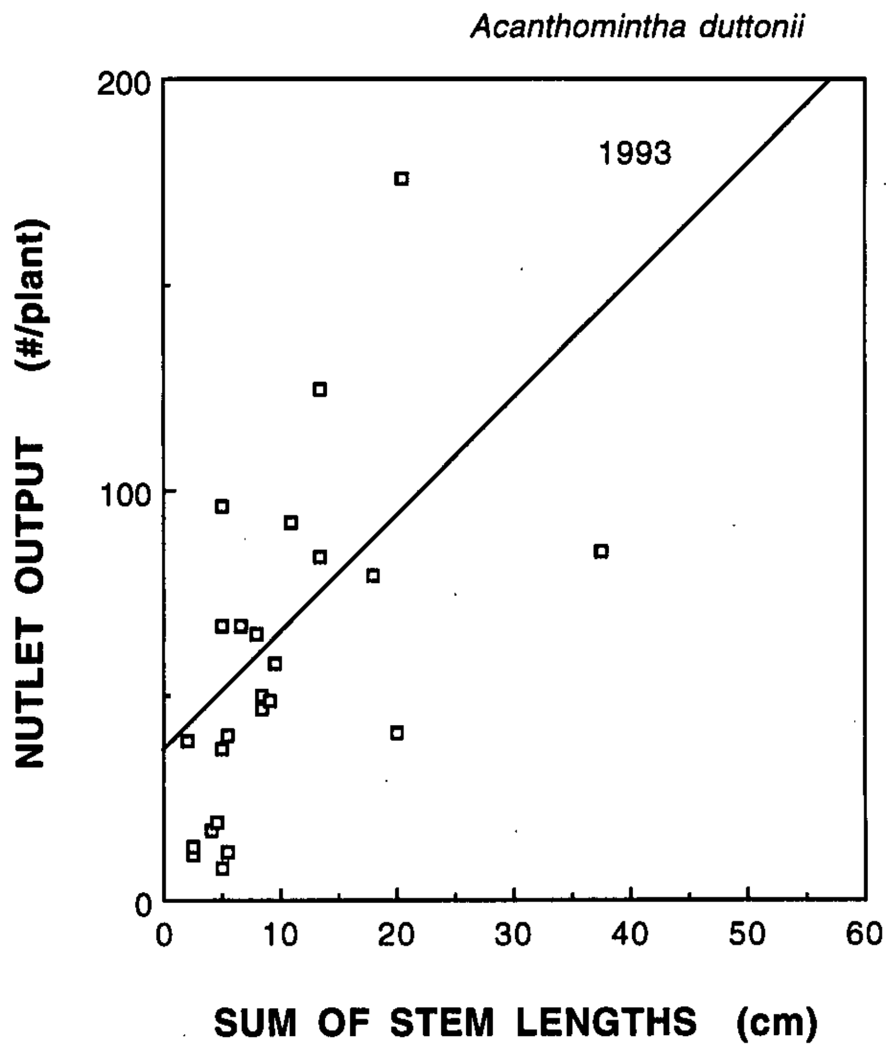


Figure 3. Nutlet output as a function of stem length of plants at Edgewood Park, 1993. See Table 2 for line equations. Compare to Figure 5 in Pavlik et al. (1992).

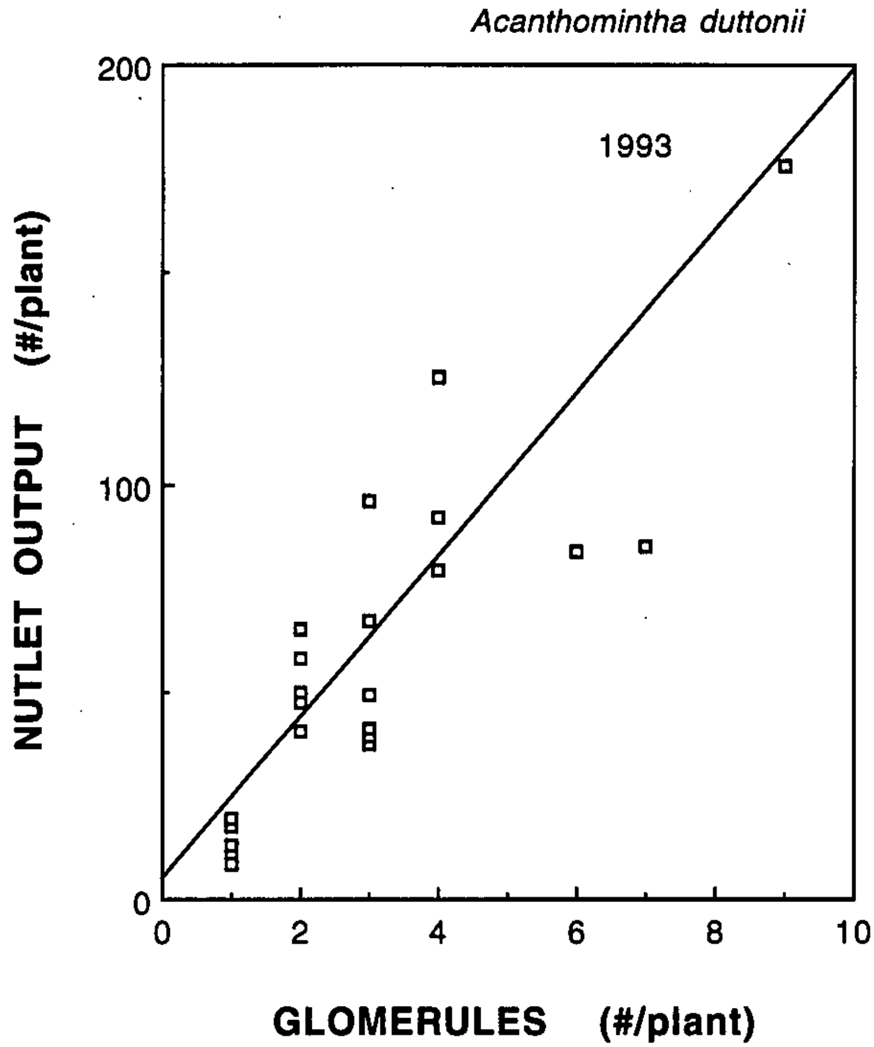


Figure 4. Nutlet output as a function of the number of glomerules of plants at Edgewood Park, 1993. See Table 2 for line equation. Compare to Figure 6 in Pavlik et al. (1992).

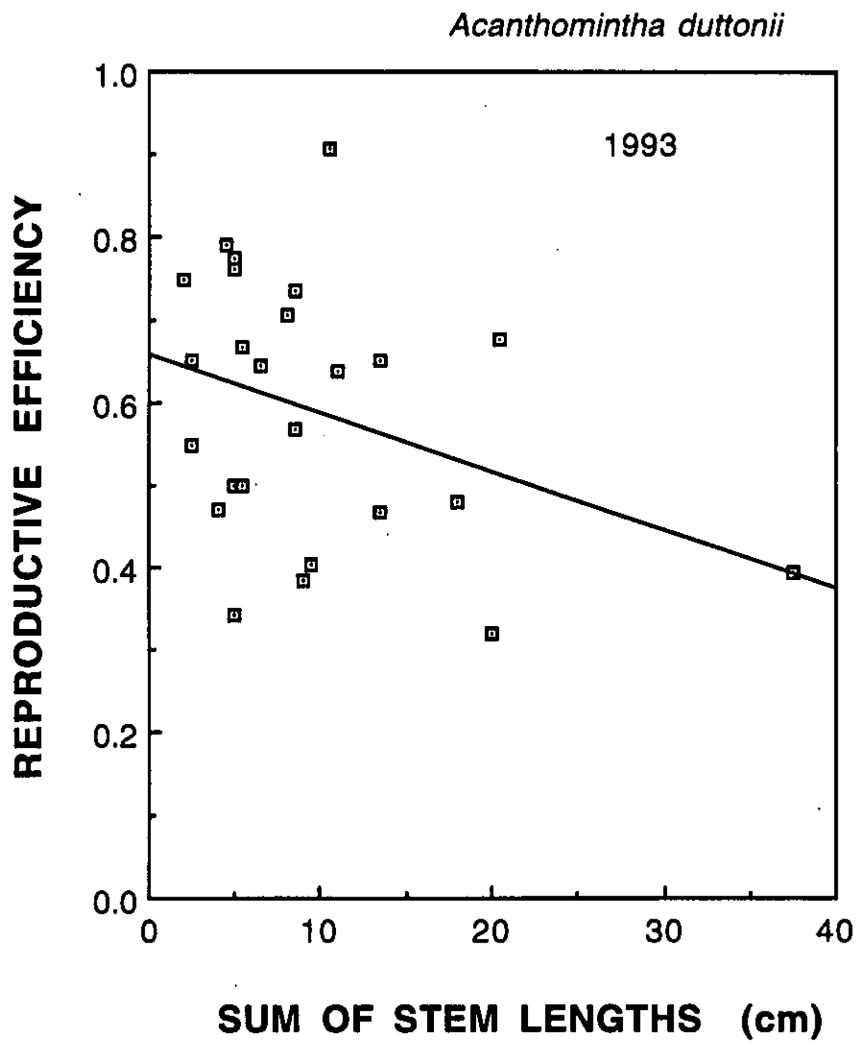
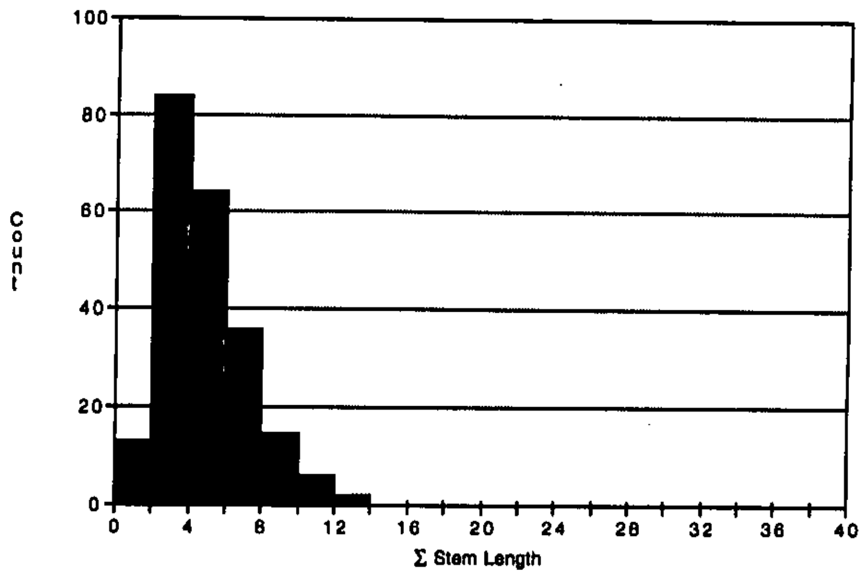


Figure 5. Reproductive efficiency (nutlet/ovule ratio) as a function of stem length of plants at Edgewood Park, 1993.



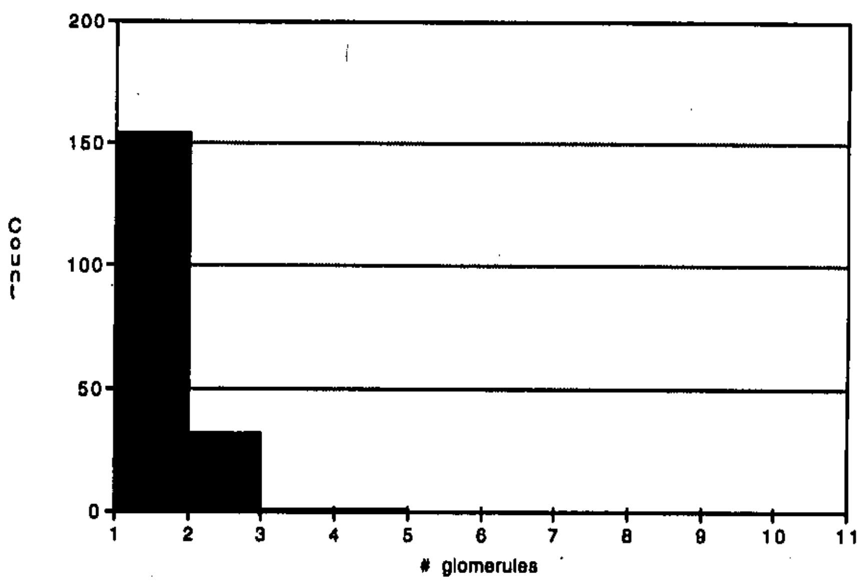


Figure 6. Plant size distributions (sum of stem length in cm and number of glomerules per plant) at Edgewood Park, 1993. n = 220. Compare to Figure 7 in Pavlik et al. (1992).

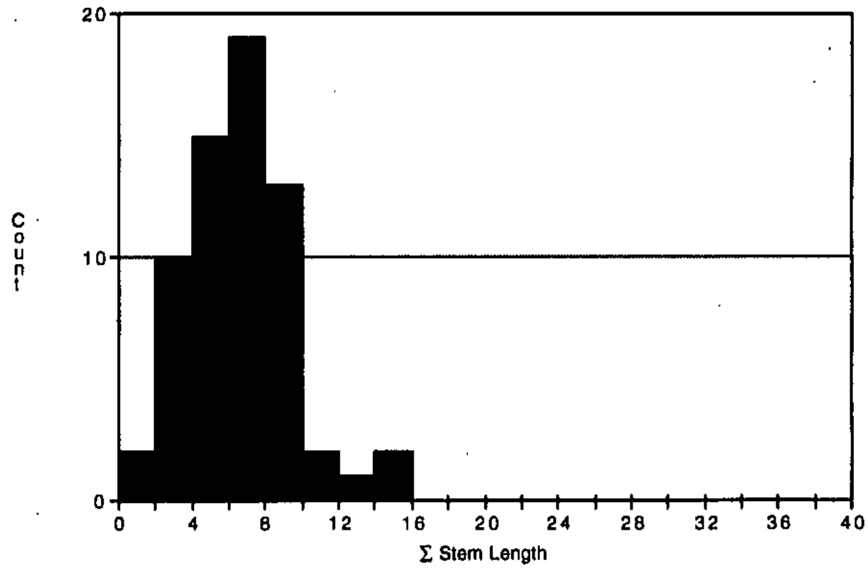
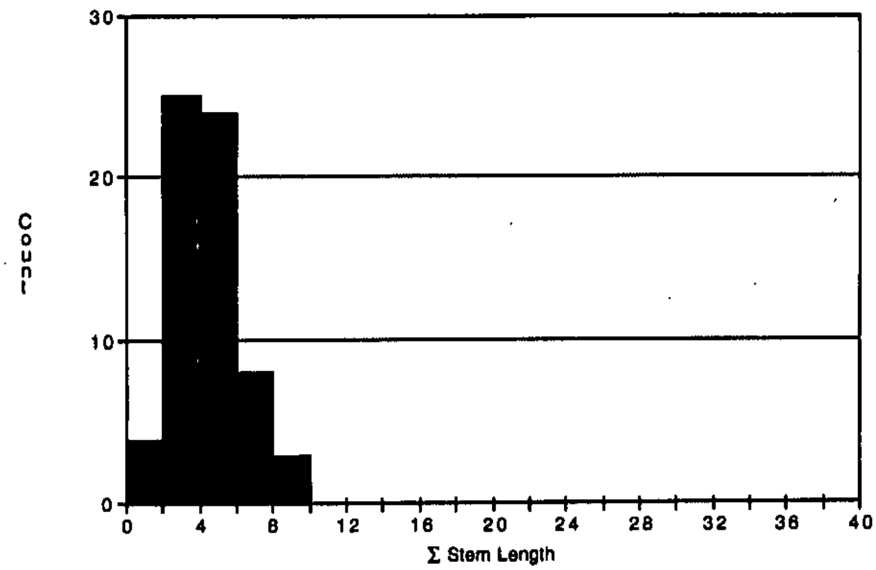


Figure 7. Plant size distribution (sum of stem length in cm) at Pulgas Ridge, 1993. The NF + SF reintroduction plots (from 1992) are shown. n = 64. Compare to Figure 12 in Pavlik et al. (1992).



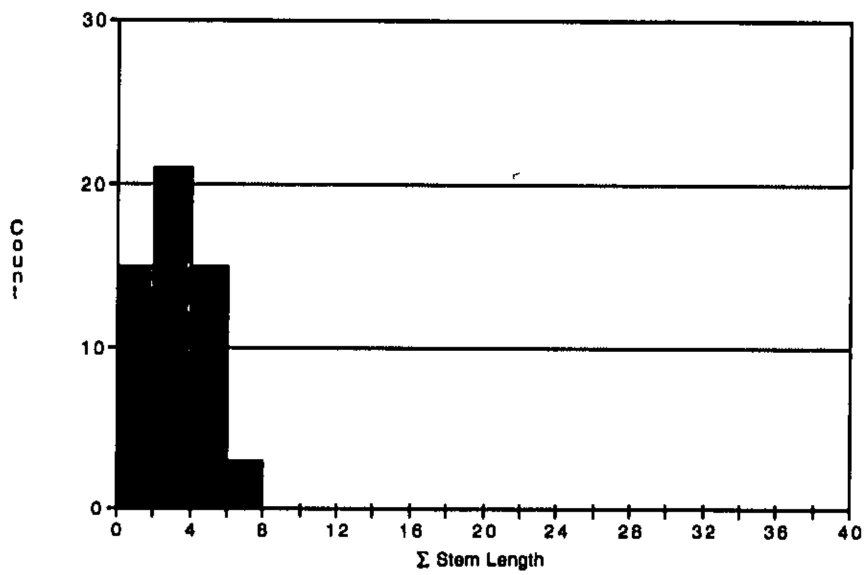


Figure 8. Plant size distributions (sum of stem length in cm) at Pulgas Ridge, 1993. Upper figure shows plants in precision-sown enhancement plots (n = 64), lower figure shows plants in streak-sown enhancement plots (n = 54).

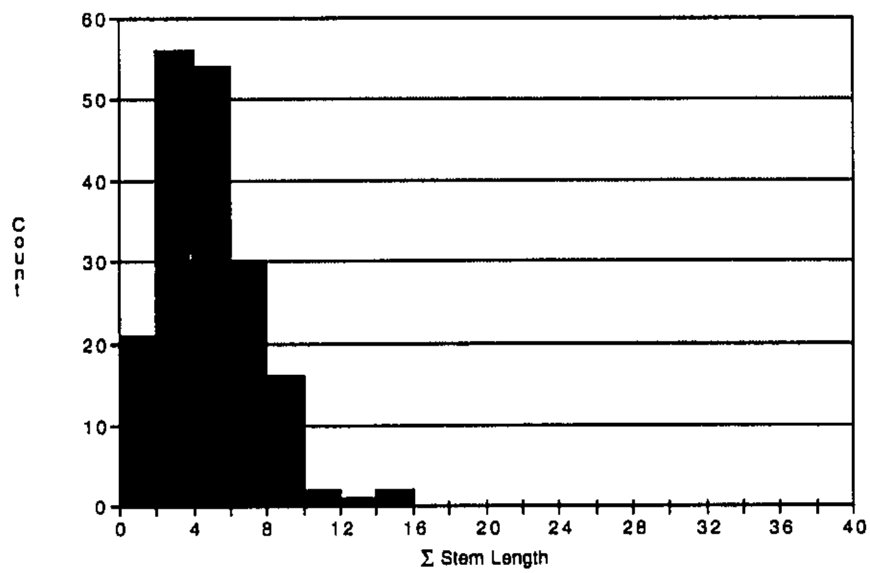


Figure 9. Plant size distribution (sum of stem length in cm) at Pulgas Ridge, 1993. All plants in all plots (NF,SF,precision-sown, streak-sown) are shown. n = 181.