Lawrence Livermore National Laboratory
University of California
Livermore, California 94551 **UCRL-AR-135516**

Restoration of the Large-Flowered Fiddleneck (*Amsinckia grandiflora*) at Lawrence Livermore National Laboratory Site 300

Project Progress Report Fiscal Year 1999 October 1998–September 1999

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****Associated Western Universities, Salt Lake City, UT**
*****Mills College, Oakland, CA**

Environmental Protection Department
Environmental Restoration Division

Work performed under the auspices of the U. S. Department of Energy by Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

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Table of Contents

List of Figures

List of Tables

Abstract

Amsinckia grandiflora (Gray) Kleeb. ex Greene (the large-flowered fiddleneck), is a rare annual forb native to the California winter annual grasslands. The species occurs in three natural populations on steep, well-drained north facing slopes in the Altamont Hills of the Diablo range, about 30 km southeast of San Francisco, California. Two of the natural populations (the Drop Tower and Draney Canyon populations) occur on Lawrence Livermore National Laboratory (LLNL) Site 300, a high-explosive testing facility operated by the University of California for the United States Department of Energy. The third natural population (the Carnegie Canyon population) occurs on private rangelands near the southeast border of Site 300. An experimental population was established near the Drop Tower natural population on Site 300. Management of the Site 300 *A. grandiflora* populations is ongoing, with a goal of controlling exotic annual grass competition while developing techniques to restore native perennial grasslands. Research into the role of predation as a control on population dynamics is also being conducted. This report details work conducted during the 1999 federal fiscal year (October 1998 through September 1999).

Survivorship in the experimental population was extremely poor, with only 2.5% of marked seedlings surviving to flowering. Numbers of individuals in both populations have dramatically declined in recent years, with only 42 plants observed in the experimental population and 6 plants in the native population (compared to highs of 720 and 1,949 individuals observed in 1996 in the experimental and native populations, respectively). Several years of high rainfall have resulted in large amounts of standing biomass (approx. 285 g/m^2 in 1998 and 170 g/m^2 in 1999), likely contributing to increased competition. No plants were located at the Draney Canyon population site in either 1998 or 1999. Heavy rains in 1997 resulted in a landslide in the area of the population. Only one plant was observed in 1997. Further erosion from rain occurred during 1998. It is likely this population has been extirpated.

Higher nutlet predation pressure was observed this year compared to last year, possibly predicting a continuing decline in population numbers. The average weekly rate of predation in the experimental site for 1999 was 39%, whereas it was 18% in 1998. Weekly predation rates were higher after the spring burn (45%) than before it (36%).

A controlled burn was conducted at the experimental site in July, after *A. grandiflora* had senesced. As in 1998, the half of the site containing no plants was burned in hopes of encouraging establishment of *A. grandiflora* into this area.

In addition, the experimental population was expanded in June 1998 by burning an area adjacent to the existing plots. This area was used to establish plots containing restored perennial bunch grass in which *A. grandiflora* will be transplanted in the late fall/early winter of 1999. These plots, containing thirty-three *Poa* plants each, will be burned at varying frequencies and monitored for bunch grass and *A. grandiflora* persistence and dispersal.

Introduction

The large-flowered fiddleneck, *Amsinckia grandiflora* (Gray) Kleeb. ex Greene (Boraginaceae), is a rare annual forb native to the California winter annual grasslands. *A. grandiflora* germinates with the onset of fall or early winter rain, grows vegetatively throughout the winter, flowers in the early spring, set seeds and dies prior to the summer drought, a pattern observed in most of the herbaceous species in the California winter annual grasslands (Heady 1990). Of the fifteen species in the genus recognized by Ray and Chisaki (1957a and 1957b), *A. grandiflora* is one of four heterostylous species with highly restricted distributions that are probably ancestors of the weedy, widespread, and homostylous congeners (Ray and Chisaki 1957a and 1957b, Schoen et al. 1997). As a heterostylous species, *A. grandiflora* produces pin and thrum flower forms (also known as morphs). Each individual plant has only one type of flower. Pin flowers are characterized by having an exserted stigma and anthers within the corolla tube. Thrum flowers have the opposing morphology, with exserted anthers and the stigma within the corolla tube (Figure 1). Characteristic of the genus, each flower type has four ovaries at the base of the style, each of which matures into a seed, known as a nutlet. Thus, each flower can produce a maximum of four nutlets.

A. grandiflora has been recently known from only three natural populations containing individuals numbering from fewer than 30 to several thousand. All natural populations occur on steep, well-drained north facing slopes in the Altamont Hills of the Diablo range, about 30 km southeast of San Francisco, California. The populations occur at low elevations (approx. 300 m) and border on blue oak woodland and coastal sage scrub communities. Two of the natural populations occur on LLNL Site 300, a high-explosive testing facility operated by the University of California for the United States Department of Energy. The two populations at Site 300 are known as the Drop Tower population and the Draney Canyon population. Located in the north/southwest trending Drop Tower canyon, the Drop Tower population is the larger of the two populations at Site 300 and was the only known population of *A. grandiflora* up through 1987. In 1987, the Draney Canyon population was discovered in a north/southwest trending canyon to the west of the Drop Tower canyon. This population is now believed to have been extirpated. In 1993, a large *A. grandiflora* population, known as the Carnegie Canyon population, was discovered on private rangelands near the southeast border of Site 300. Attempts at establishing two experimental populations have also occurred near Site 300. Located adjacent to the southeast border of Site 300 is an ecological reserve owned by the California Department of Fish and Game (CDFG). An attempt was made to establish an experimental population of *A. grandiflora* at this site (known in Pavlik 1994 as the Corral Hollow population), but no reproductive plants have been observed at this site in recent years, suggesting the establishment was not successful. Also near the southeast border of Site 300 is the Connolly Ranch, a privately owned ranch. An experimental population at this site was attempted, but failed, possibly as a result of extremely high rodent activity (Pavlik 1994). Figure 2 shows the approximate locations of the *A. grandiflora* populations at or near Site 300.

A. grandiflora was federally listed as endangered in 1985. Restoration efforts began in 1988 by researchers from Mills College. These efforts focused on determining the factors necessary for the successful establishment of additional populations of *A. grandiflora* (Pavlik 1988a and 1988b), and have resulted in the establishment of at least one apparently successful experimental population at Lougher Ridge (Pavlik 1994). Between 1993 and 1995 using funds obtained through a grant from LLNL's Laboratory Directed Research and Development Program, LLNL researchers teamed with researchers from Mills College to further investigate the causes of *A. grandiflora* rarity and to establish an additional population at Site 300. The experimental population was established near the Drop Tower natural population on a north-facing slope on the eastern fork of the Drop Tower canyon where it bifurcates around the Drop Tower facility parking lot (Figure 3). This population is known as the Drop Tower experimental population.

Research on the Drop Tower experimental population, the Lougher Ridge experimental population, and data from management of the Drop Tower natural population indicated that competition from exotic annual grasses was contributing to the decline of *A. grandiflora*, and that long term management to reduce exotic annual grass cover and restore and maintain the native perennial bunch grass community was necessary to ensure the persistence of this species (Pavlik et al. 1993, Pavlik 1994, Carlsen et al. 1999). In 1998, the United States Fish and Wildlife Service (USFWS) provided financial support to LLNL researchers for ongoing management of the *A. grandiflora* populations at Site 300. Additional support was provided by the U.S. Bureau of Reclamation in 1999. Long-term financial support is being provided through LLNL Site 300 management.

The goal of the ongoing management of the Site 300 *A. grandiflora* populations is to control the cover of exotic annual grasses while developing techniques to restore native perennial grasslands. Interim control of the annual grasses is being conducted through the applications of a dilute solution of the grass selective herbicide Fusilade®. The use of controlled burning is being investigated as a tool for developing and maintaining perennial grasslands. Finally, the impact of seed predation is being investigated to determine its impact on the population dynamics of *A. grandiflora*. This report details progress made during the 1999 federal fiscal year (October 1998 through September 1999).

Methods and Materials

Demographic Monitoring

Demographic monitoring of the Drop Tower experimental population was conducted to provide data on the long-term effects of the application of herbicide on *A. grandiflora*. Due to the large amount of disturbance that frequent trips to the field site impart on the deep soil and plant cover of such steep hillsides, demographic monitoring was limited to the experimental population, which already has well-defined compacted trails around the experimental plots. Germination of *A. grandiflora* in the Drop Tower experimental population occurred in early November. On 19 Nov 1998, six 0.64 m^2 plots were selected. Three plots were established in areas that had undergone Fusilade® herbicide treatment in January 1998 (see Carlsen et al. 1998), and three were established in areas that had not been treated with herbicide. Eleven to fourteen *A. grandiflora* seedlings were marked in each plot. Figure 4 summarizes all of the experimental treatments conducted on the experimental population. The plots labeled "Dem" are the demographic plots containing the marked *A. grandiflora* plants.

Positive field identification between different *Amsinckia* species is difficult at the seedling stage. However, as they flower, *A. grandiflora* can be easily differentiated from congeneric species. When the marked plants were positively identified, some were found to be congeners. Subsequent to correct identification, sample sizes were adjusted to reflect the corrected number of *A. grandiflora* plants. As a result, the number of marked plants in each plot varied from five to eleven individuals. It is possible that individuals that died prior to flowering (precluding correct identification) may have been from congeneric species, and thus may be included in the pre-flowering demographic data.

The plants were marked by looping a piece of string loosely around the base of each seedling and placing a pin flag next to the seedling. This ensured that the same plants were monitored during each observation date. The flags were trimmed to measure approximately 0.5 cm^2 and were positioned at approximately the same height as the surrounding senesced plant material from the previous year so as not to add significant shading to the seedlings.

Height and survivorship of the plants were measured on 19 Nov 98, 12 Dec 98, 12 Jan 99, 12 Feb 99, 12 Mar 99, 2 Apr 99 and 16 Apr 99. In addition, forb, grass, and overall herbaceous cover were estimated in all six plots on 12 Feb 99, 12 Mar 99, 2 Apr 99, and 17 May 99. Cover estimates were used to characterize the general community composition in treated versus untreated plots.

Establishment of Perennial Bunch Grass Plots

On 27 Oct 98, twenty plots were sited in areas adjacent to the existing plots in the experimental population which had been burned in June 1998 (Fig. 5). These plots were arranged in five blocks of four plots each. Each plot measured approx. 2m × 2m. A 1 m buffer area was established between each plot to provide for burn breaks. Between 25 Jan and 29 Jan 99, the center 1 m^2 of each plot was manually restored with *Poa secunda*. This was done by manually excavating all *P. secunda* tussocks from within the plot. Each tussock was divided into 3 cm diameter plugs and transplanted into the center 1 m^2 of the plot. *P. secunda* was excavated from areas outside the plot if additional plugs were needed. The center 1 m^2 was restored to a density of 33 plants/m^2 in an hexagonal pattern in 6 rows, with each row alternating between 5 and 6 plants. This density has been shown to be most favorable to *A. grandiflora* persistence (Carlsen et al. 1999).

Bunch grass establishment was monitored throughout February 1999. Plugs lost to rodent herbivory were replaced during this time. All plugs established successfully, and many were flowering by 16 Apr 99, with plants beginning to go dormant by 5 May 99. However, additional rodent damage has been sustained by many of the plots. These will be restored at the time of *A. grandiflora* transplantation into these plots in the fall of 1999.

Spring Census

The experimental and native Drop Tower populations as well as the Draney Canyon population were censused during April 1999. All three areas were surveyed completely. *A. grandiflora* plants were flagged and demographic data were collected.

The census of the experimental Drop Tower population took place on the 19 Apr 1999. The flower morph, plant height, and inflorescence number were recorded for each plant. The identity of the nearest species (nearest neighbor) was also recorded. In addition, biomass samples (0.1

m^2) were collected from the center of 10 plots (0.64 m^2) on 10 May 99. These plots were selected using a randomized block design. Biomass was collected from five sample plots from the area that was selected for burning and five sample plots from the area that would not be burned. These plots are shown on Figure 4 as "Biom". Plots are further identified as to whether they were annual grass plots (labeled as A) or perennial grass plots (labeled as P) when the population was originally established in 1993. Perennial bunch grasses were counted in each plot on 7 May 99 to monitor long-term establishment.

The native Drop Tower population census was conducted on 19 Apr 1999. Flower morph, plant height and branch number were recorded for each plant. Branch number is defined as the number of major branches off the main stem. Nearest neighbor data were also collected for every plant. No biomass samples were taken from the native population.

Draney Canyon was surveyed along the entire length of the canyon on 16 Apr 1999.

Predation Study

The predation study was initiated in 1998 to estimate seed loss to predators such as birds, rodents and insects. In 1999, the study was replicated in the experimental population. Round 1 was conducted prior to the controlled burn and round 2 was conducted following the burn. Each round was conducted in the same manner, with different plots chosen for each round to prevent predator training.

Due to concerns about possible negative impacts of disturbance in the native site, nutlets were placed in only the experimental Drop Tower population. The population was divided into two sub-areas, one sub-area designated for spring burning, the second sub-area designated to remain unburned. Each sub-area contained five blocks arranged in rows that were perpendicular to the slope (Fig. 4), thus each block represented a unique elevation along the slope. Within each block, two treatments were established. The open treatment was designed to allow access to all predators and thus no exclosures were used. The netted treatment was designed to exclude birds. Stakes were placed at the corners of the netted treatment plots, and polypropylene netting with 3/4” by 3/4” mesh was placed over each plot. The netting was secured to prevent bird entry into the plot by air or ground.

Ten plots in each half (sub-area) were selected. A randomized block design was used to designate the open and netted plots. For round 1, plots that had been treated with herbicide or from which biomass samples had been collected were excluded from plot selection. For round 2, plots from which biomass was collected were used from the sub area which had been burned. Round 1 treatments are shown on Figure 4 as Open-1 and Net-1. Round 2 treatments are shown on Figure 4 as Open-2 and Net-2. Each plot contained twenty-five 3 1/2 inch galvanized nails spaced 15 cm apart in five rows of five nails. A 10 cm buffer zone was present between the edge of the plot and the outermost nails. Double stick tape was placed on the nail head, and each nail was pressed into the soil so as the nail head was flush with the soil surface. A single nutlet was lightly pressed onto the tape. In round 1, the nails were placed in the field on 26 Apr 99. The nails were censused on 4 May 99, 11 May 99, 17 May 99, and 1 June 99. For round 2, nails were placed in the field on 30 June 99. The nails were censused on 2 July 99, 6 July 99, 12 July 99, and 19 July 99.

Spring Burn

A controlled burn at the experimental Drop Tower population was conducted on 28 Jun 99. The burn was conducted in the early afternoon. The temperature was around 90°F and the wind was 14 mph. The relative humidity was around 20%. Figure 4 shows the area within the experimental population which was burned.

Results and Discussion

Demographic Monitoring of the Experimental Drop Tower Population

Plots treated with Fusilade in 1998 generally had less total plant cover (Figure 6), and less dead cover than plots that were left untreated. The differences between treated and untreated plots for dead cover and total plant cover were significant in the first month of measurement (November) ($df = 19$, $p < 0.05$). Differences in survivorship and height between *A. grandiflora* in treated vs. untreated plots (Figs. 7 and 8) were not great. Survivorship was poor for all plots. Out of the 78 plants originally marked on November 19, six plants survived to March 12 (all vegetative), three through April 12 (one flowering and two with floral buds), and only a single flowering plant remained at the April 19 census. Plants in treated plots showed slightly greater survivorship through April 3 (Fig. 7). Figure 8 shows the average height of *A. grandiflora* plants in treated and untreated plots. Although it would appear that the height of *A. grandiflora* in the untreated plots was greater, this is driven by the height of a single surviving plant. Effects of the treatments were expected to be less strong this year, because the herbicide treatment occurred two growing seasons ago. Because of the extremely low survivorship of all of the *A. grandiflora* plants, the long-term effects of the herbicide treatment are extremely difficult to define. The plants in both treated and untreated plots in general were again very small, thin-stemmed, unbranched plants, as compared to the large, thick-stemmed, multi-branched plants observed in this population in years previous to 1998.

Spring Census

Figure 9 shows the general locations and flower morph of *A. grandiflora* plants observed in the experimental population. Figure 10 shows the census history for this population. As can be seen, numbers of individuals in this population compared to previous years have declined dramatically, with only 42 plants observed this year compared to the high of 720 plants observed in 1996. The population is currently at an all time low. Although the standing biomass within the plots is lower than it was last year, it is still much larger than the amount of biomass present when the population was initially established in 1994 (Table 1). Besides the small numbers, the *A. grandiflora* plants were very small, with only single inflorescences for the most part (Table 2). Using a regression equation developed in 1994 (unpublished data), it would appear that this population will again produce essentially no nutlets this year. While this regression equation may underestimate the amount of nutlet production as it was developed using plants that were multi-branched (that is, very few of the plants used to create the regression had single inflorescences, and thus data at this end of the regression curve may be less reliable), similar regression equations developed for the native population and other experimental populations have suggested that a minimum branch or inflorescence number is required for significant nutlet production (Pavlik 1991b).

Six-year persistence of *Poa secunda* in the experimental plots is shown in Table 3. Survivorship appears to be between 15 and 22% over the six-year period of 1993-1999, except for the low-density, non-planted *Poa* plots, which had a persistence of 45%.

Figure 11 shows the general locations of *A. grandiflora* plants observed in the native Drop Tower population in 1997, 1998, and 1999. Figure 12 shows the census history for this population. Like the experimental population, this population has declined dramatically to an all time low, down to 6 plants compared to the high of 1, 949 plants observed in 1996. The estimate of nutlet production for this population is also essentially zero (Table 2). This decline appears to be a widespread phenomenon, with the Lougher Ridge experimental and Carnegie Canyon native populations also experiencing dramatic declines (Pavlik, personal observations). In addition, in the immediate area of the native and experimental *A. grandiflora* populations, extremely low numbers of congeneric *Amsinckia* species were observed. Only six *Amsinckia* congener individuals were observed in the immediate area of the core of the native *A. grandiflora* population. Moving south along the hillside, eleven congeneric *Amsinckia* plants were observed in the area where the most southerly *A. grandiflora* plants had been observed in previous years. *Amsinckia* congeners were more numerous on the warm, dry part of the hill that turns and faces directly south. A total of 78 congeneric *Amsinckia* plants were observed in the experimental site. In previous years, hundreds of congeneric *Amsinckia* plants were observed at both sites (Carlsen, personal observations).

The six *A. grandiflora* plants found did not occur in the areas that were treated with herbicide in 1998 (Fig. 13). The numbers of plants are too few to make sweeping generalizations from this lack of geographic overlap between *A. grandiflora* presence and herbicide treatment, but we can take this opportunity to reexamine our methodology and more deeply explore the temporal limits of using herbicide as a restoration tool. The herbicide treatment applied in 1997 occurred after the spring flora had already grown into mid-sized plants. Results from earlier experiments (Carlsen, unpublished data) have shown that selective thinning of annual grasses performed too late in the year has no effect on *A. grandiflora* survivorship. Also, the desired effect of herbicide use is to increase *A. grandiflora* size and survivorship. Herbicide use may not directly affect establishment, but by encouraging more, larger, higher fecundity plants at herbicide-treated locations and increasing nutlet rain in those areas, herbicide use may have indirect long-term effects. As the fecundity of *A. grandiflora* plants at the native site was fairly low in 1998 (only 8400 total nutlets produced, Carlsen et al. 1998), any indirect, multi-year effects of a single herbicide treatment could not be determined for 1999.

Figure 14 shows the census history for the Draney Canyon population. A large amount of water flowed through the canyon in 1997, causing a landslide in the area of the *A. grandiflora* population. In that year, only one *A. grandiflora* plant was found. In 1998, further erosion was observed at the site of the population. Flags that once marked *A. grandiflora* plants from previous censuses were located, but no *A. grandiflora* plants were found. The canyon was hiked again in 1999, and although the flags were once again found, and congeneric *Amsinckia* were flowering, no *A. grandiflora* were observed. It seems likely that this population has been extirpated.

Spring Burn

As previously mentioned, the half of the experimental population containing no *A. grandiflora* was burned in the spring of 1998 to encourage *A. grandiflora* nutlet dispersal and plant establishment into this area. No *A. grandiflora* plants were observed in this area in 1999.

Figure 15 shows the estimate of plant biomass in the experimental population plots nearly a year after the burn treatment. The burned plots contained significantly less thatch biomass compared to the unburned plots (df = 4, $p < 0.025$). Although the differences are not significant, burned plots contained less annual grass biomass and also showed the only identifiable perennial grass cover. This lack of perennial grass cover in unburned plots is not confirmed in the counts of *Poa* made in May 1999 at all plots in the experimental site. Table 3 shows the counts for each plot type, and the burned area did not seem to have any more *Poa* plants than the unburned area. *Poa* leaves are small and are not easily identifiable without an attached inflorescence. The plants may simply have not have been seen in the high-cover, unburned plots during biomass collection. To further encourage perennial grass cover and reduce the amount of annual grasses present, the 1998 burned area within the flashing of the experimental population was again burned in June 1999. This area will continue to be monitored for the presence of *A. grandiflora*.

Predation Study

Results of the predation study are expressed as cumulative predation intensity, weekly predation intensity, weekly predation rate and estimated weekly predation rate. Cumulative predation intensity is defined as the total number of nutlets removed divided by the total number of nutlets originally placed into the field, expressed as a percentage. Weekly predation intensity is defined as the total number of nutlets removed divided by the number nutlets remaining since the previous observation, normalized to a week and expressed as a percentage. Weekly predation rate is defined as the number of nutlets removed during the observation interval divided by the total number of nutlets originally placed into the field, normalized to a week and expressed as the percentage of nutlets removed per week. Estimated weekly predation rate is defined as the final observed cumulative predation intensity (that is, the percentage of the total number of nutlets removed from the total number of nutlets originally placed into the field), divided by the total number of weeks the nutlets were in the field, expressed as the percentage of nutlets removed per week. The majority of statistical analyses were performed on the weekly predation intensity data. These data are the only data that meet the assumptions of the ANOVA. Data collected at each point in time is independent from the time point preceding it, which is not the case for cumulative predation intensity or for the weekly predation rate. Percentage data were arcsine transformed prior to performing the ANOVAs. T- tests were performed on the cumulative predation intensity for the last data collection date only. Assumptions of equal variances were tested, and if not met, a Cochran adjusted t-test was used.

Table 4 summarizes the results of the statistical analysis of the overall 1999 predation experiment conducted at the Drop Tower experimental population both prior to (round 1) and subsequent to (round 2) the burn. The effect of the burn and treatments was not significant when measured as weekly predation intensity (Table 5 and 6). In round 1, (pre-spring burn) data collected on the first collection date were significantly different from the other data collection dates, regardless of treatment (Table 7).

After the spring burn of 1998, there was a significant difference between burned netted and burned open plots in the first week for weekly predation intensity (Figure 16). We hypothesized that this difference was due to the easy visibility of nutlets to birds after the burn, but that rodents were not able to take advantage of the high nutlet visibility due to the lack of cover in the burned plots (Carlsen et al. 1998). The lack of difference observed this year between netted and open plots in the burned area seems to indicate that rodent population pressure is so high that rodents are more willing to forage in more "dangerous" areas. Our lack of differential results post burn in 1999 may be an indirect indication of a larger rodent:bird predation ratio than what existed in 1998.

The difference in final cumulative predation intensity was significant between the years 1998 and 1999 (Table 8). Cumulative predation intensity (Fig. 17) and weekly predation intensity (Table 9) was much higher for unburned, open plots in 1999 compared to 1998.

The same overall patterns in cumulative predation intensity were observed between years (Figure 17) and between rounds, burns and treatments in 1999 (Figs. 18, 19, 20, and 21), where rates rose sharply for the first two observation dates and then rose more gradually for the remaining observation dates.

No significant effects were observed between burned and unburned or netted and open plots when cumulative predation intensities were compared (Tables 9 and 10), although the higher cumulative predation intensity in the burned plots was nearly significant (Table 10) in round 1 (pre- spring 1999 burn). The difference in cumulative predation intensity for netted versus open plots in round 1 was also nearly significant (Table 11). In phase 1 (pre burn) of the 1998 study, the predation pressure in the netted plots was lower than that of the open plots (Table 12), and this difference was significant. In round 1 (pre burn) of the 1999 study, the predation pressure was higher in the netted plots than in the open plots, but not significantly so. This difference between years could again point to the possibility of a higher rodent:bird predation ratio in 1999 compared to 1998, although the methodology was slightly different between the years in the pre-burn round.

Round 2, post- burn predation pressure was higher than the pressure observed in round 1. This pattern was observed in both cumulative intensity (Figs. 17, 18 and 19) and in weekly predation rate (Table 13). Table 14 shows that predation in 1998 and 1995 has been higher, rather than lower, earlier in the season. Table 14 also shows a possible problem with using an estimated weekly predation rate: predation rates tend to be lower over longer experimental periods. If patterns observed in 1998 and 1999 are relatively universal, then most predation occurs in the first two weeks. Thus, the longer the study, the greater the difference between the estimated weekly rate and the actual weekly rate. The differences in estimated weekly predation rate between early season and late season observed in 1998 and 1995 could mostly be due to the time interval over which the study took place.

Recommendations and Future Work

Population numbers at both the native and experimental Drop Tower locations have continued a three-year decline. It appears that increased competition from neighbor biomass and increased predation pressure may be contributing to these declines. The several winters of above average rainfall resulted in high levels of standing biomass, which in turn may have provided increased food to predators, possibly contributing to greater predator numbers. If biomass can be used as an indicator of rodent population size, and therefore as a predictor of seed predation pressure, this year's reduced biomass compared to 1998 may foreshadow a decrease in seed predation next year. An observed increase in the number of lupines (*Lupinus albifrons*) at the native site may also be connected to the population's decline. For the years 1989 through 1995, only two lupines were observed in the main area of the native Droptower population. In 1996, the number of lupines grew to five. By 1998 there were sixteen lupines and in 1999 thirty were counted. The dramatic increase of lupines in the years 1996–1999 is inverse to the dramatic decline in *A. grandiflora* over the same time period.

It is important to monitor both predator pressure and standing biomass at the *A. grandiflora* populations. Biomass samples should be collected each spring from the *A. grandiflora* populations, taken in such a way to minimize impact to the *A. grandiflora* plants. In addition, a less-invasive method to monitor predator pressure should be developed. We fear that the frequent human disturbance necessary to carry out this careful study may negatively impact the *A. grandiflora* populations. Effort will be made to develop an informative, yet more time- and possibly space-compressed refinement of our predation monitoring methods. Reasons for and consequences of the lupine expansion will be explored. A method for monitoring lupine development will be researched.

It may be necessary to control grass competition, lupine expansion and predator pressure to ensure persistence of the populations, particularly during the early establishment phase of experimental populations. Ground dwelling predators were controlled during the first two years of the Drop Tower experimental population, which may have allowed the large numbers of plants to establish during these years. Predator control has not been conducted in recent years. In addition, although herbicide treatment has been conducted at the Drop Tower experimental population to control exotic annual grasses, this has not been done at a large scale, and has not been performed on a yearly basis. Thus, the standing biomass at this site has dramatically increased since the initial population establishment.

Controlled burning is probably the most feasible method for controlling biomass amount and composition. The expansion of the experimental population with the recently established *Poa secunda* plots will be used to investigate the effects of fire frequency for maintaining intermediate densities of native perennial bunch grasses. In 2000, *A. grandiflora* plants will be transplanted into the center of each plot containing the *P. secunda*. These plots will then be subjected to controlled burns either annually, every other year, or every 5th year and will be monitored for spread of *P. secunda* and *A. grandiflora* from the nucleus into the rest of the plot.

Continued management of the existing native and experimental Drop Tower *A. grandiflora* populations will also continue, and will be modified based on data collected from biomass samples and predation monitoring.

Acknowledgments

The authors would like to acknowledge the dedicated support of Erin Bissell, S. Eric Walter, and Steve Gregory, who labored with us in the field, often in extreme temperature conditions. We are also thankful for the support of Site 300 management, especially Jim Lane, who does his best to fill funding gaps when they arise. We also thank the LLNL Fire Department, particularly Chief Ralph Burklin, for their professional conduct of the spring controlled burn. The support of the management of LLNL's Environmental Restoration Division, which provides the necessary infrastructure to conduct such work, is also greatly appreciated. Finally, we would like to recognize the U. S. Fish and Wildlife Service and the U.S. Bureau of Reclamation, for without their financial support, this work would not have been possible. Work performed under the auspices of the U. S. Department of Energy by Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

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Figures

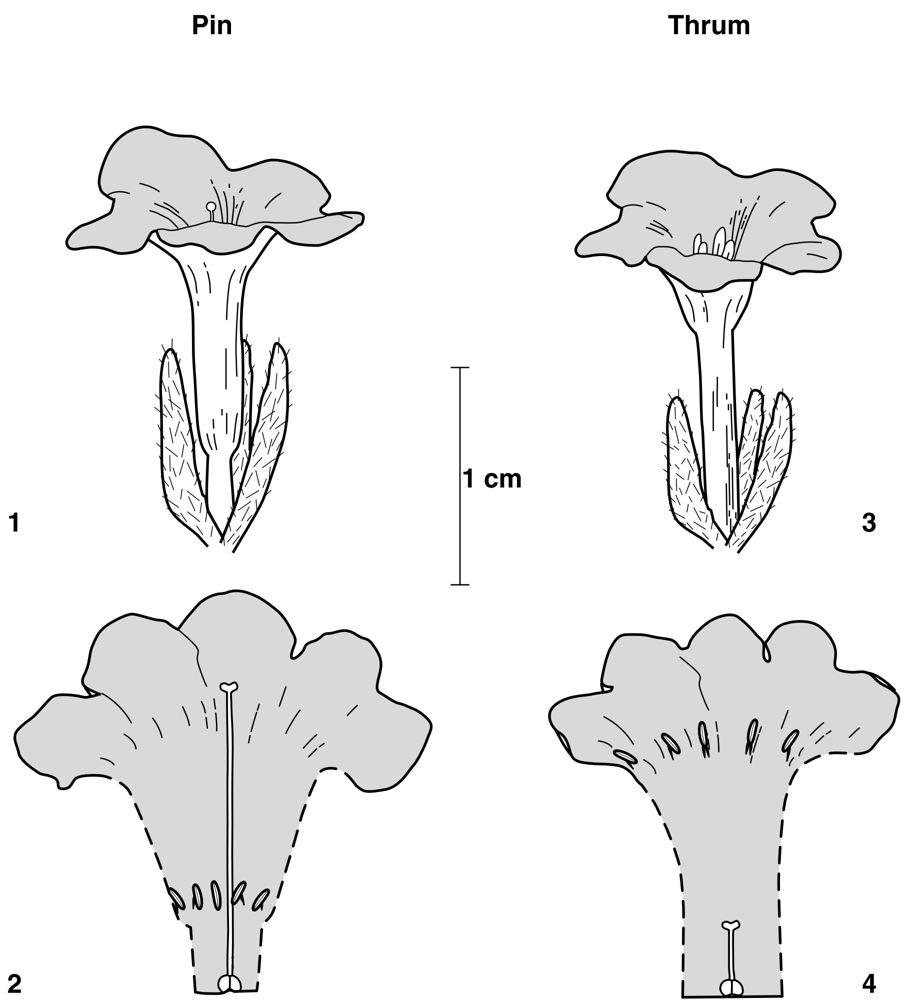

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Figure 1. Flowers of *A. grandiflora.* 1. Intact pin flower. 2. Dissected pin flower. 3. Intact thrum flower. 4. Dissected thrum flower. (from Ornduff 1976)

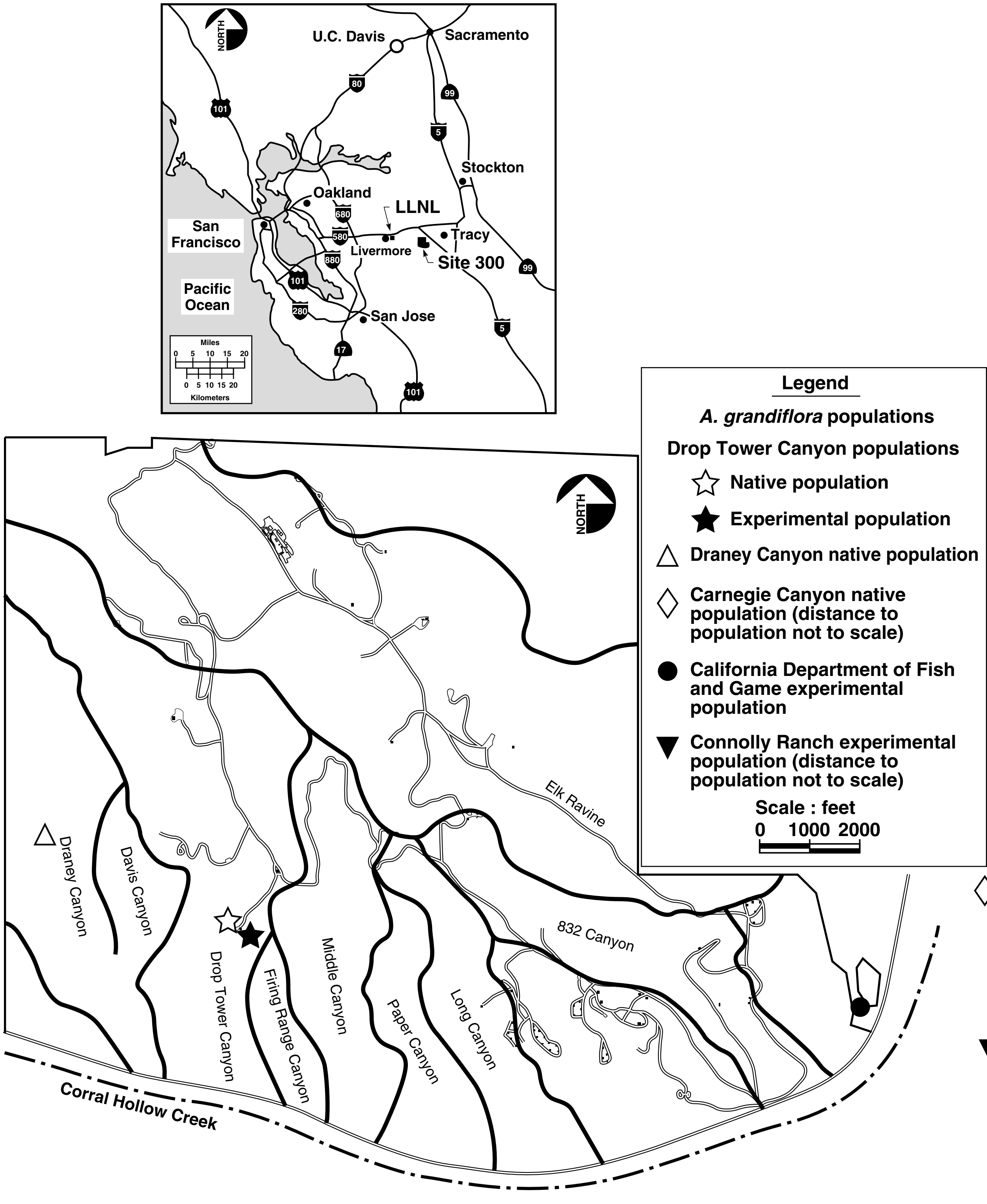

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Figure 2. Locations of *A. grandiflora* populations at or near Lawrence Livermore National Laboratory (LLNL) Site 300.

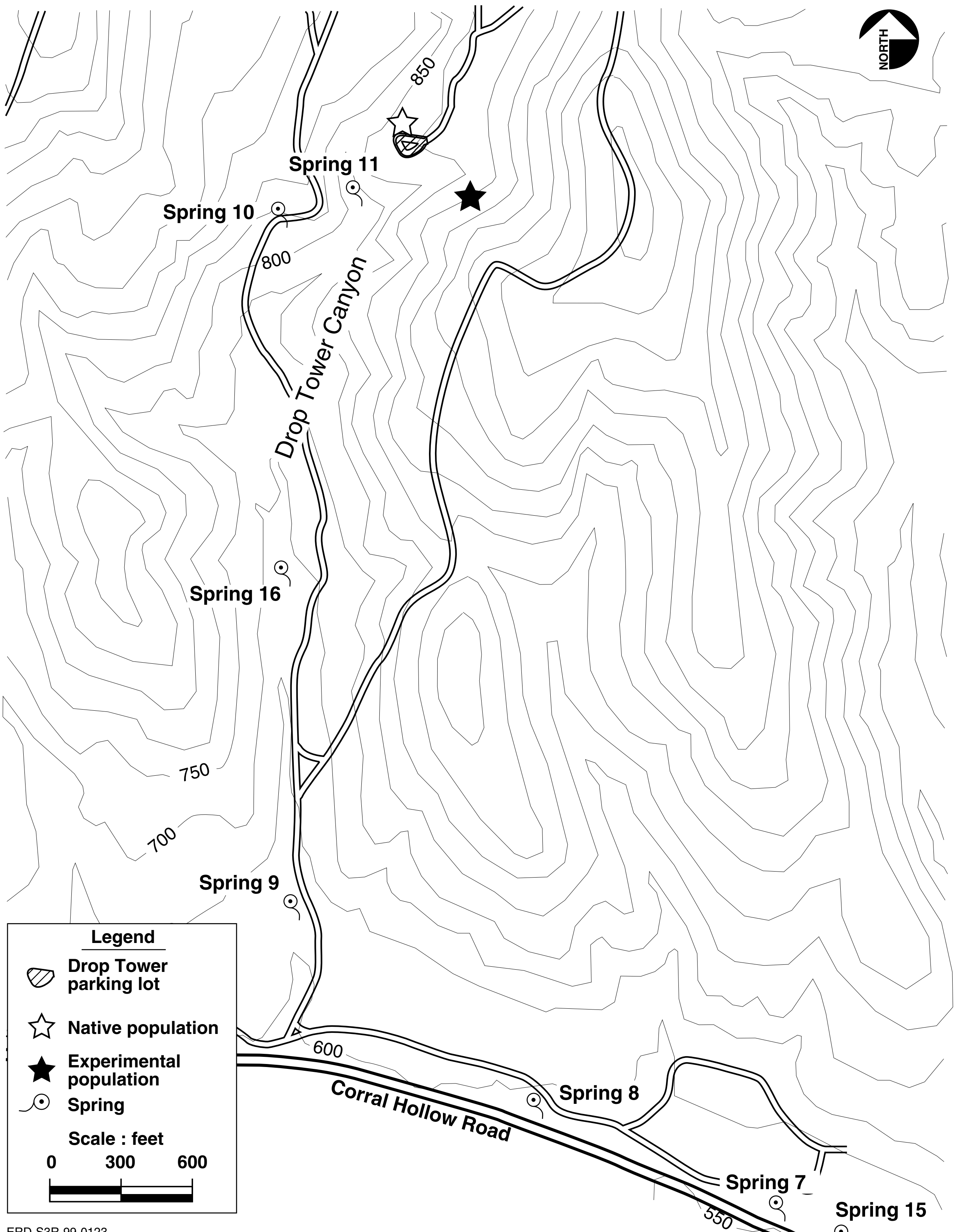

Figure 3. Location of native and experimental *A. grandiflora* populations in Drop Tower Canyon.

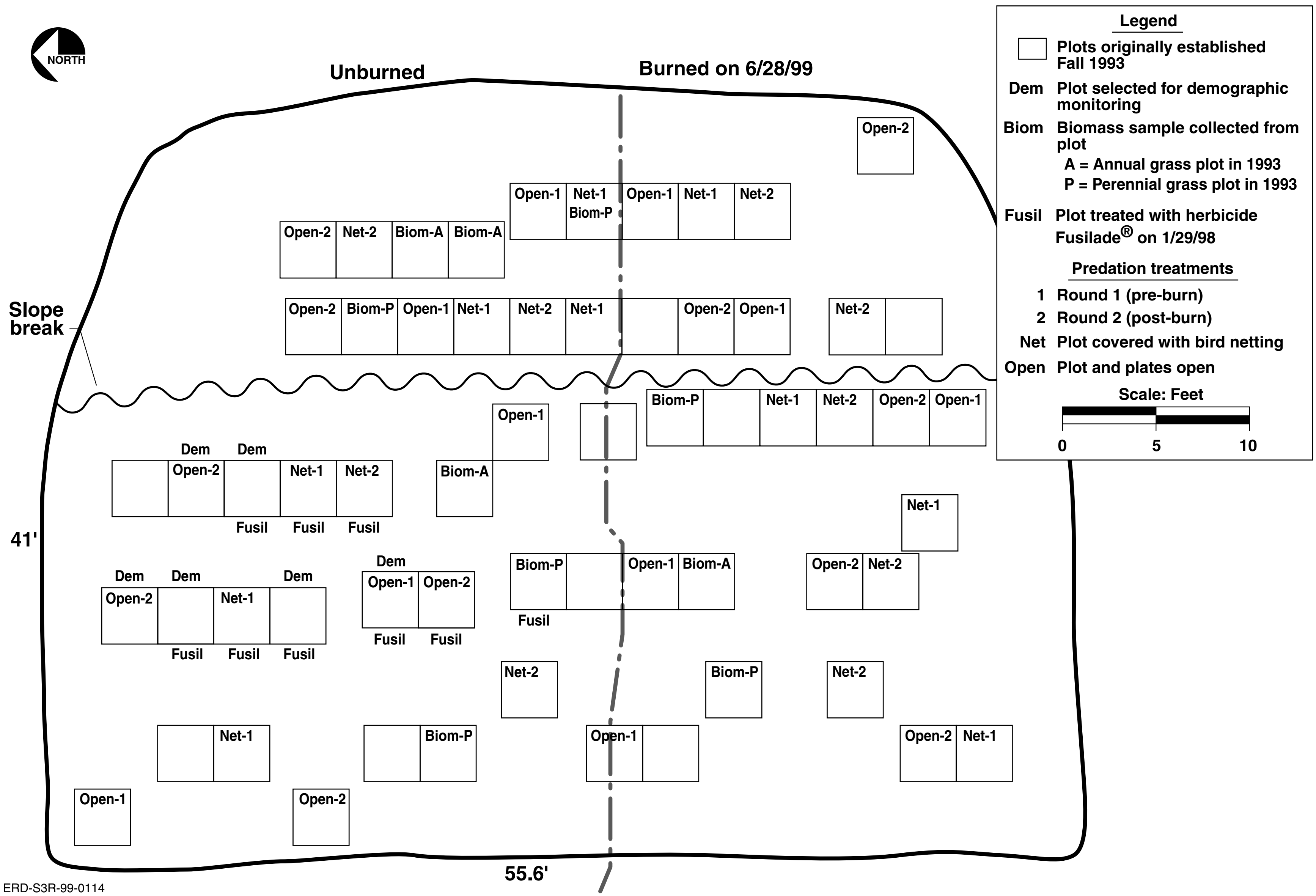

Figure 4. Summary of experimental treatments at the *A. grandiflora* experimental population.

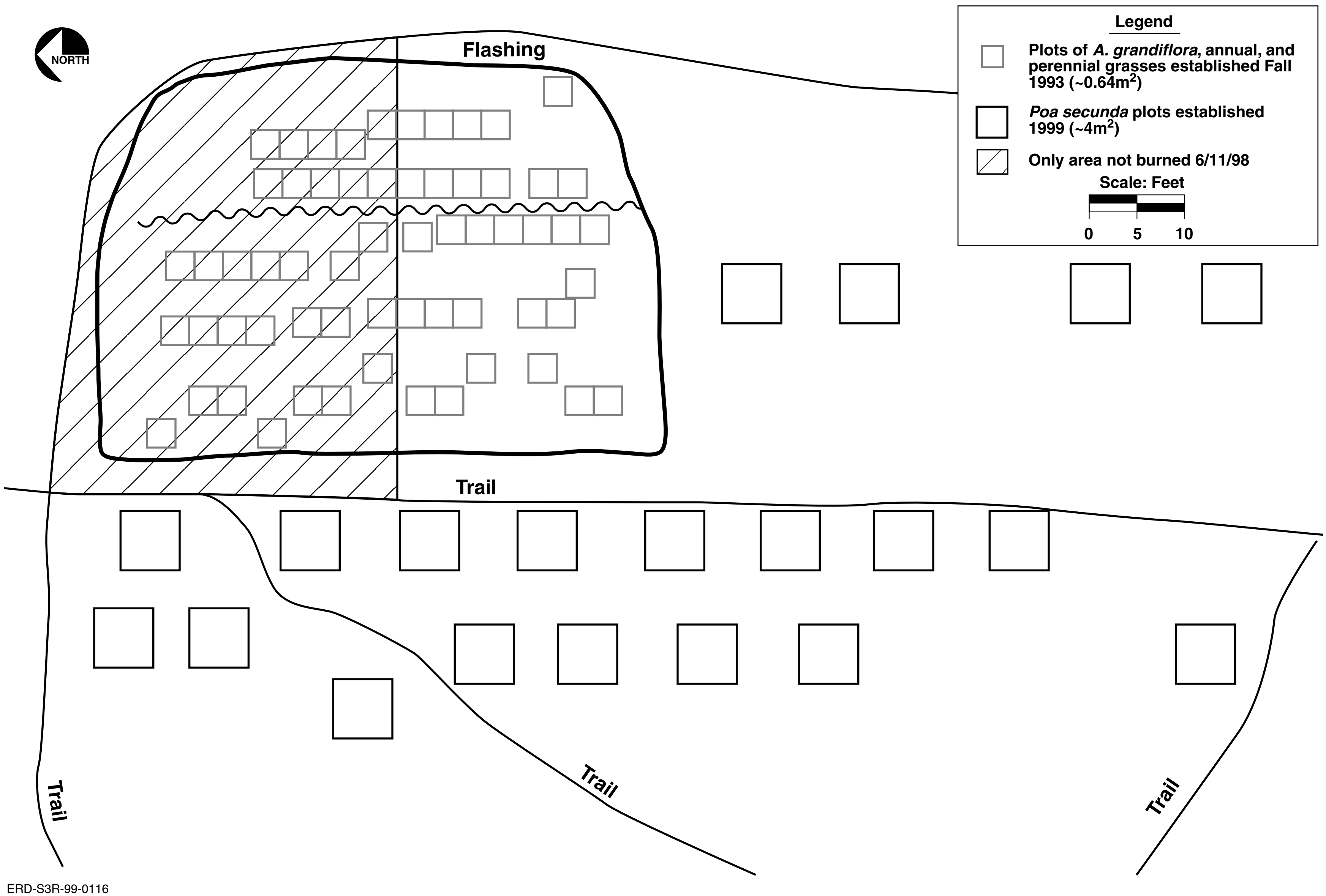

Figure 5. Map of restored *Poa secunda* plots established January 1999.

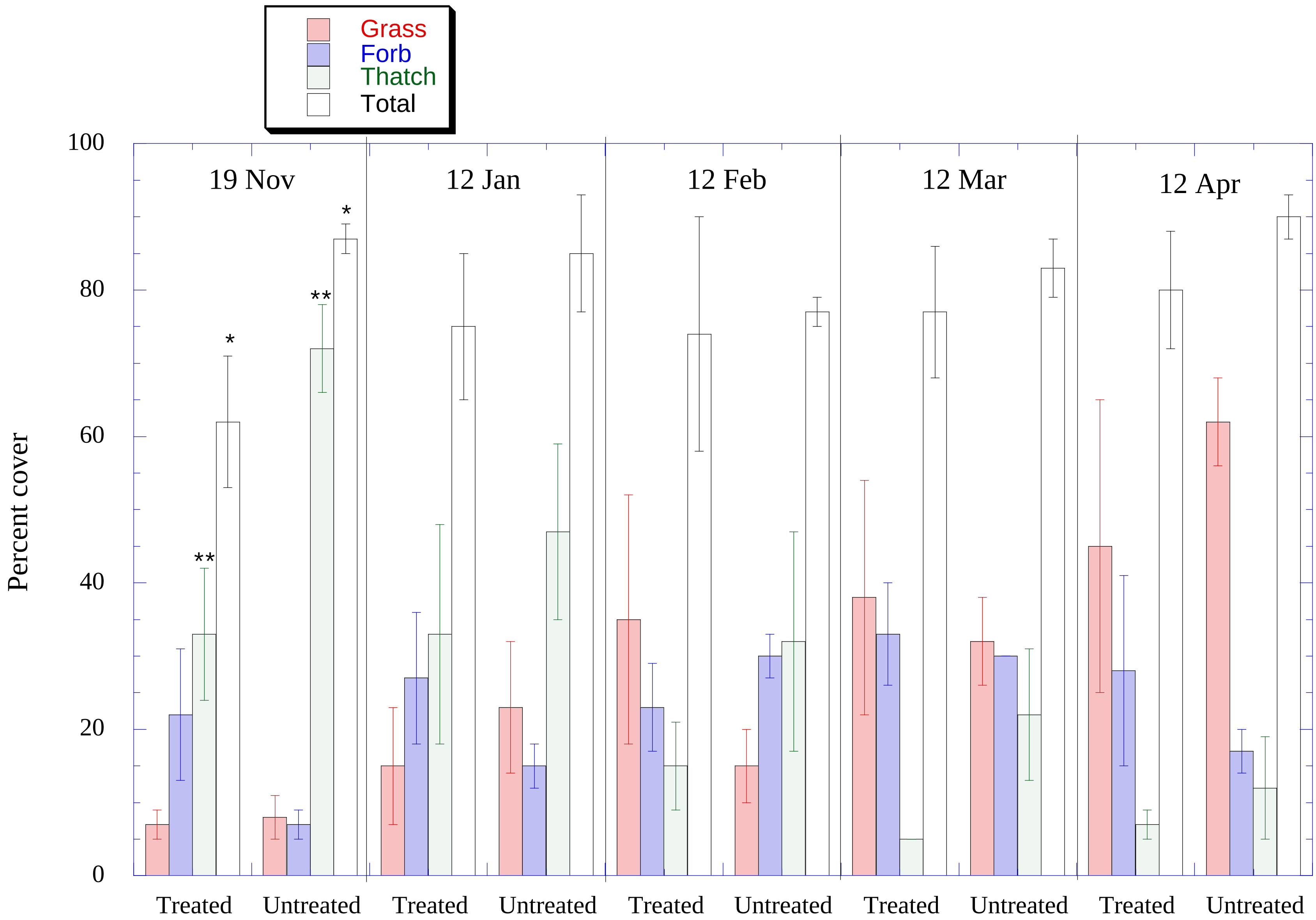

Figure 6. Plant cover estimates for *A. grandiflora* experimental population plots for 19 Nov 98, 12 Jan 99, 12 Feb 99, 12 Mar 99, and 2 Apr 99. Bars represent one standard error, n=3. * = treatments significantly different at p<0.05. ** = treatments significantly different at p<0.025.

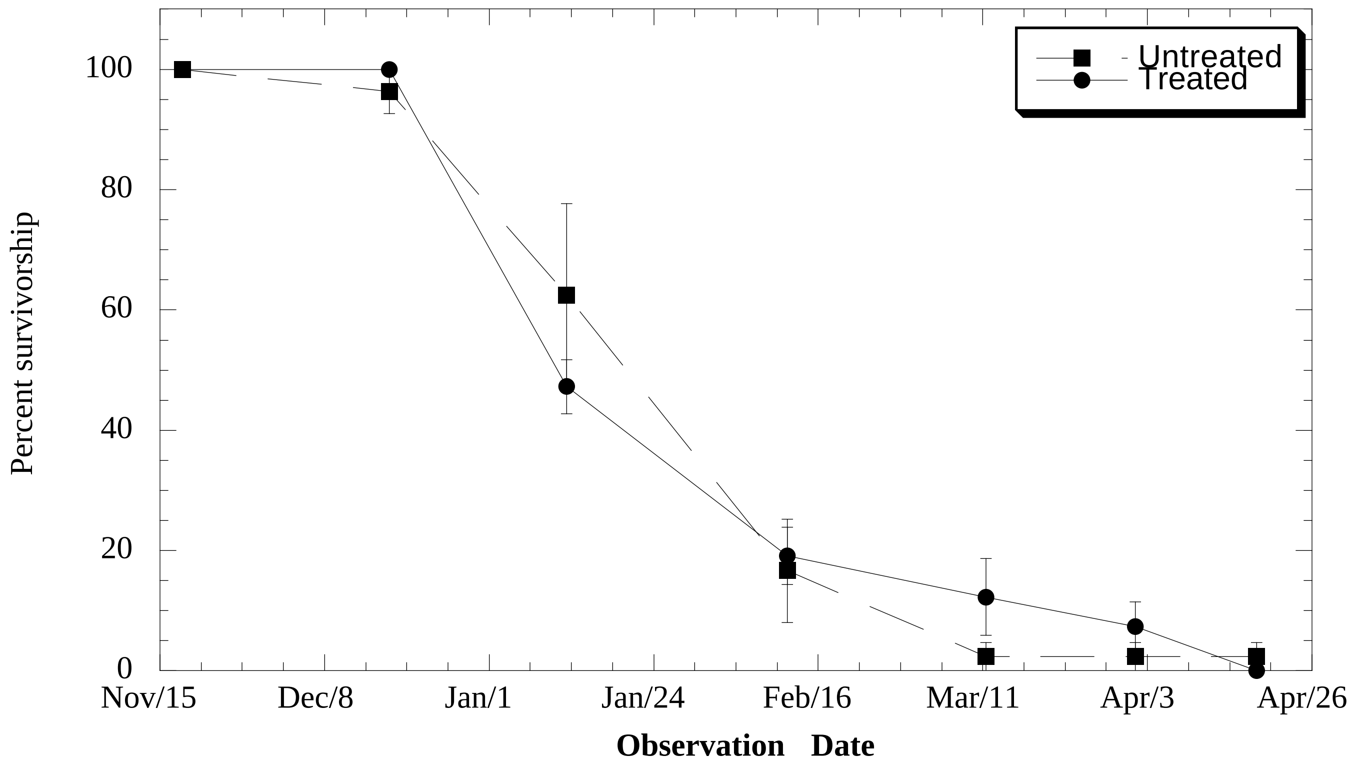

Figure 7. Mean survivorship of *A. grandiflora* plants marked on 15 November 1998. Bars represent one standard error, n=3.

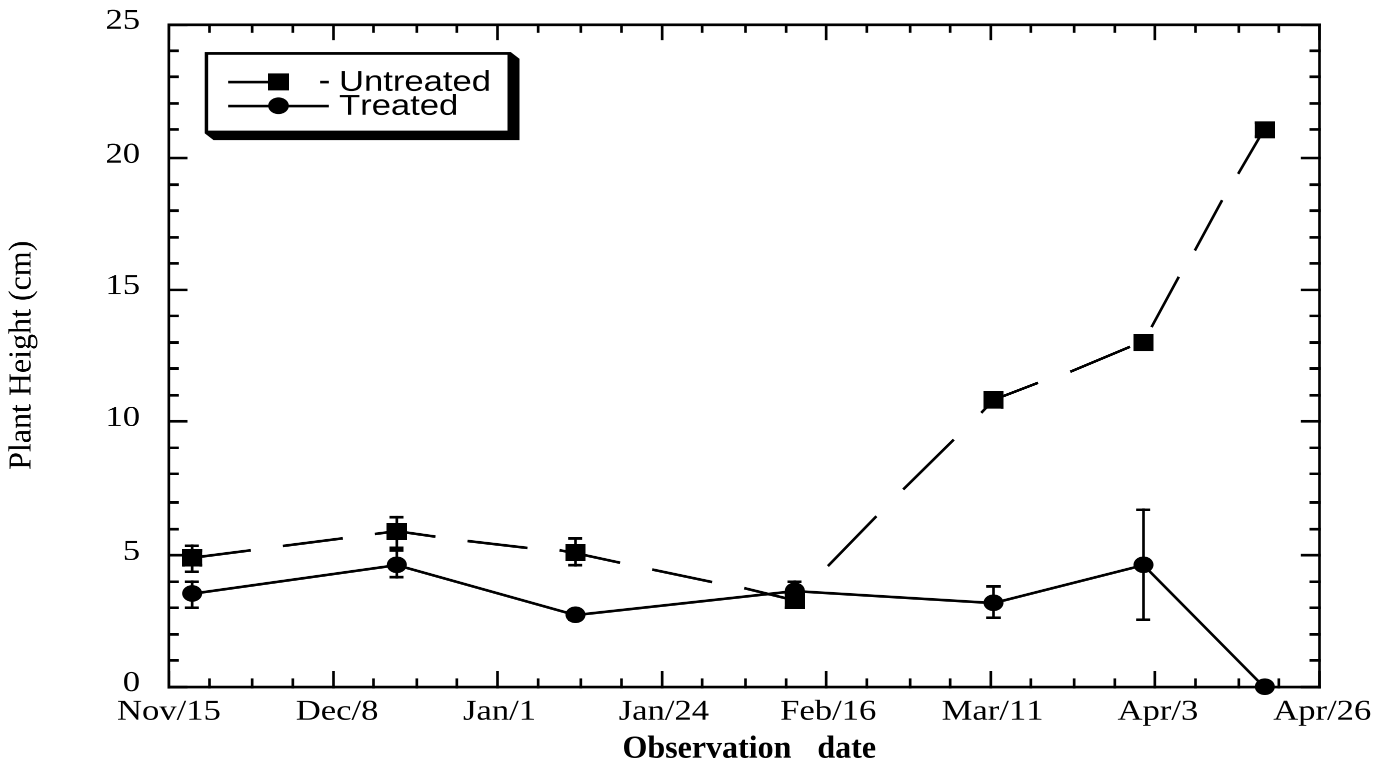

Figure 8. Mean height of *A. grandiflora* plants marked on 15 November 1998. Bars represent one standard error, n= 3.

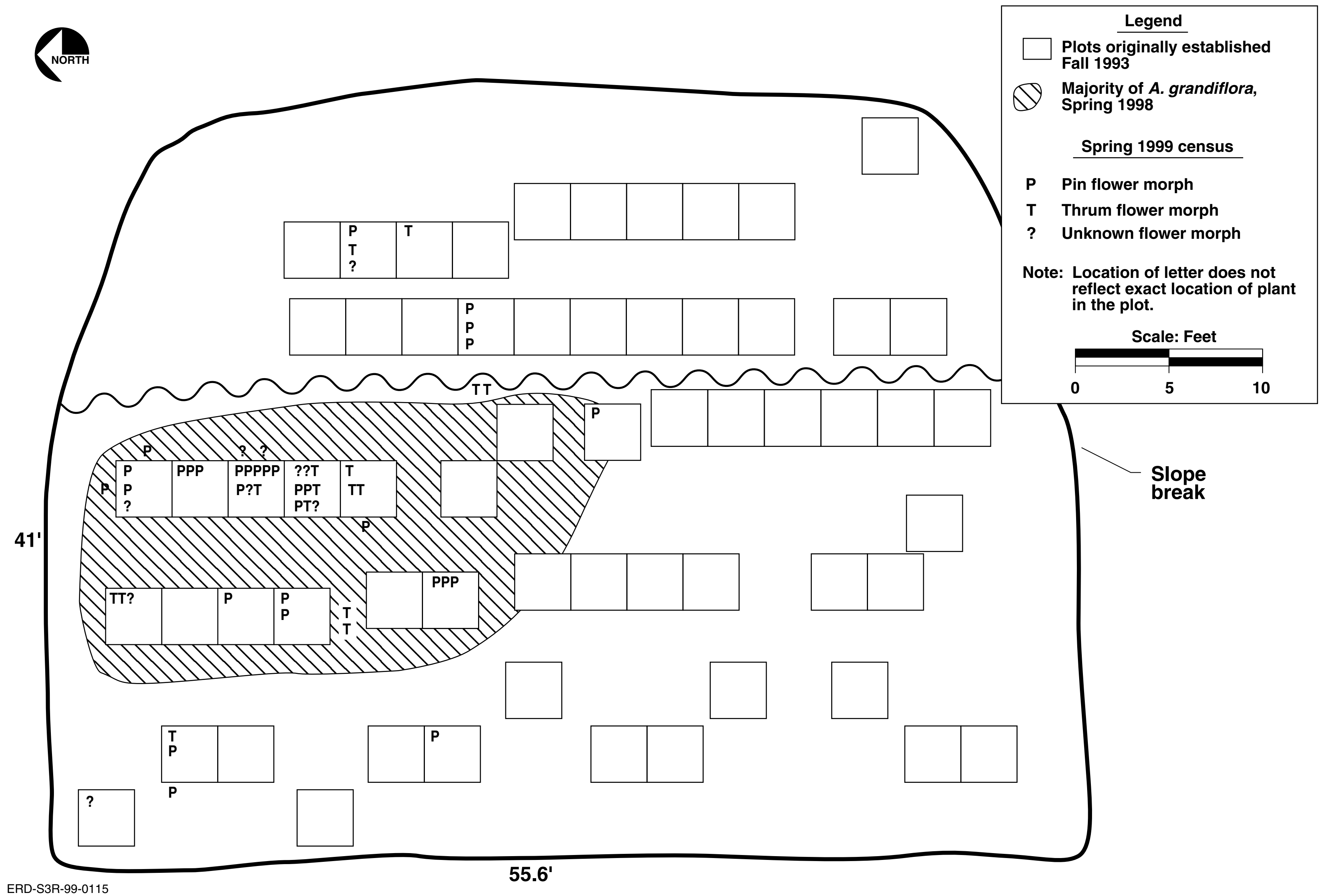

Figure 9. Spring (April 19, 1999) census of the *A. grandiflora* experimental population.

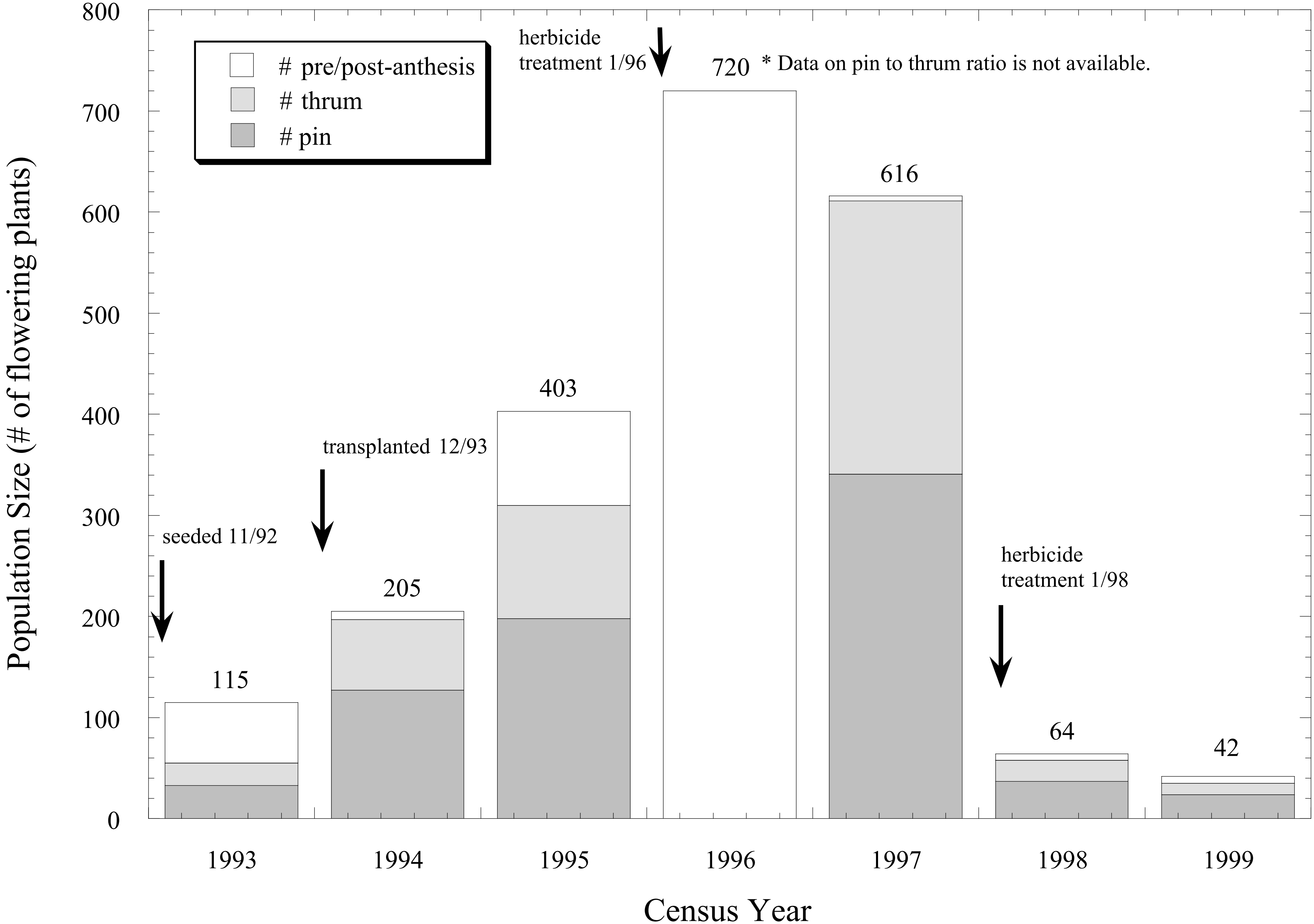

Figure 10. Historical spring census data of the Site 300 experimental Drop Tower population. Total population size is given above each bar. Approximate timing of herbicide treatments as well as seeding and transplanting efforts is shown.

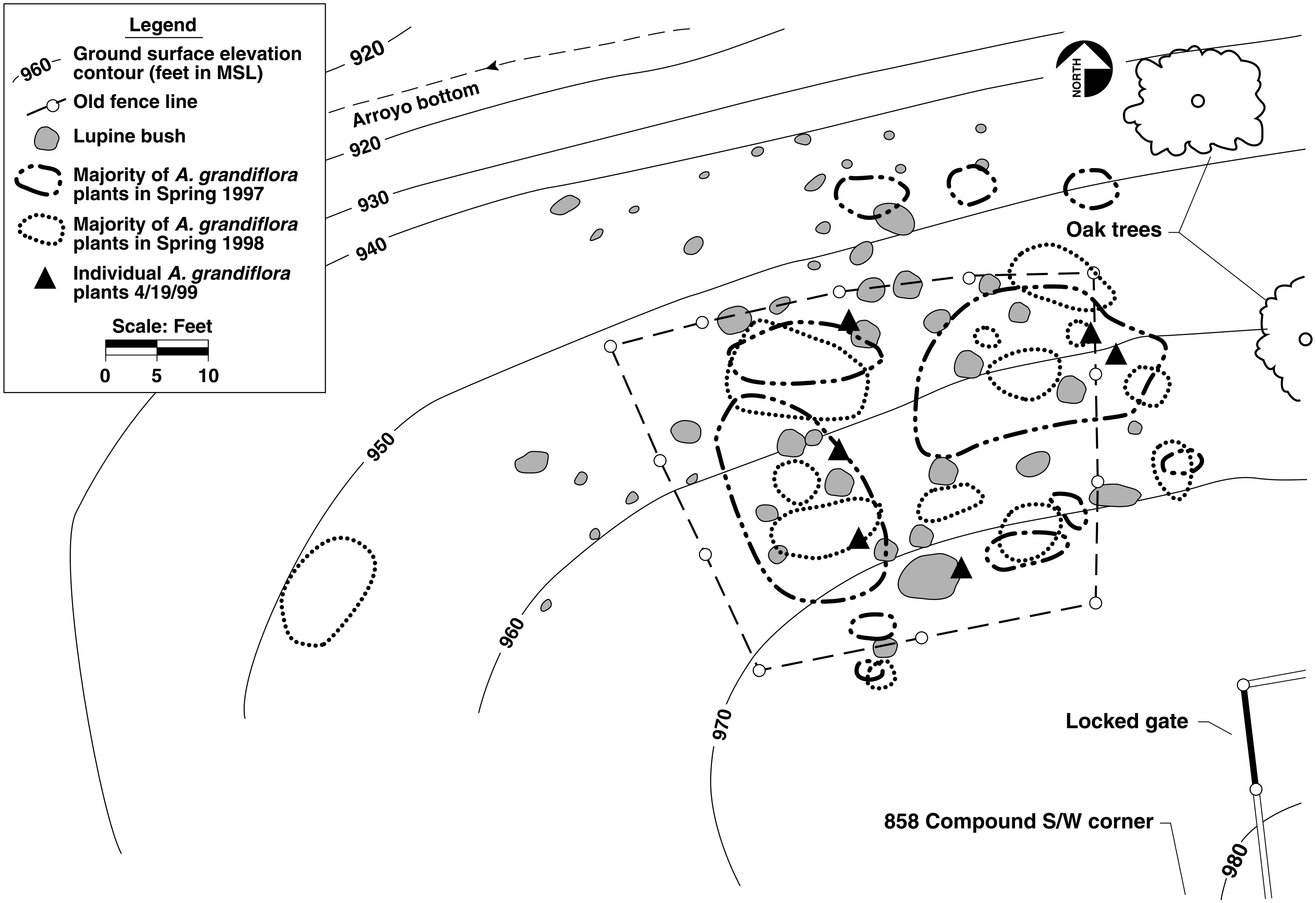

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Figure 11. Spring (April 15, 1998) census of the *A. grandiflora* native population at the Building 858 Drop Tower.

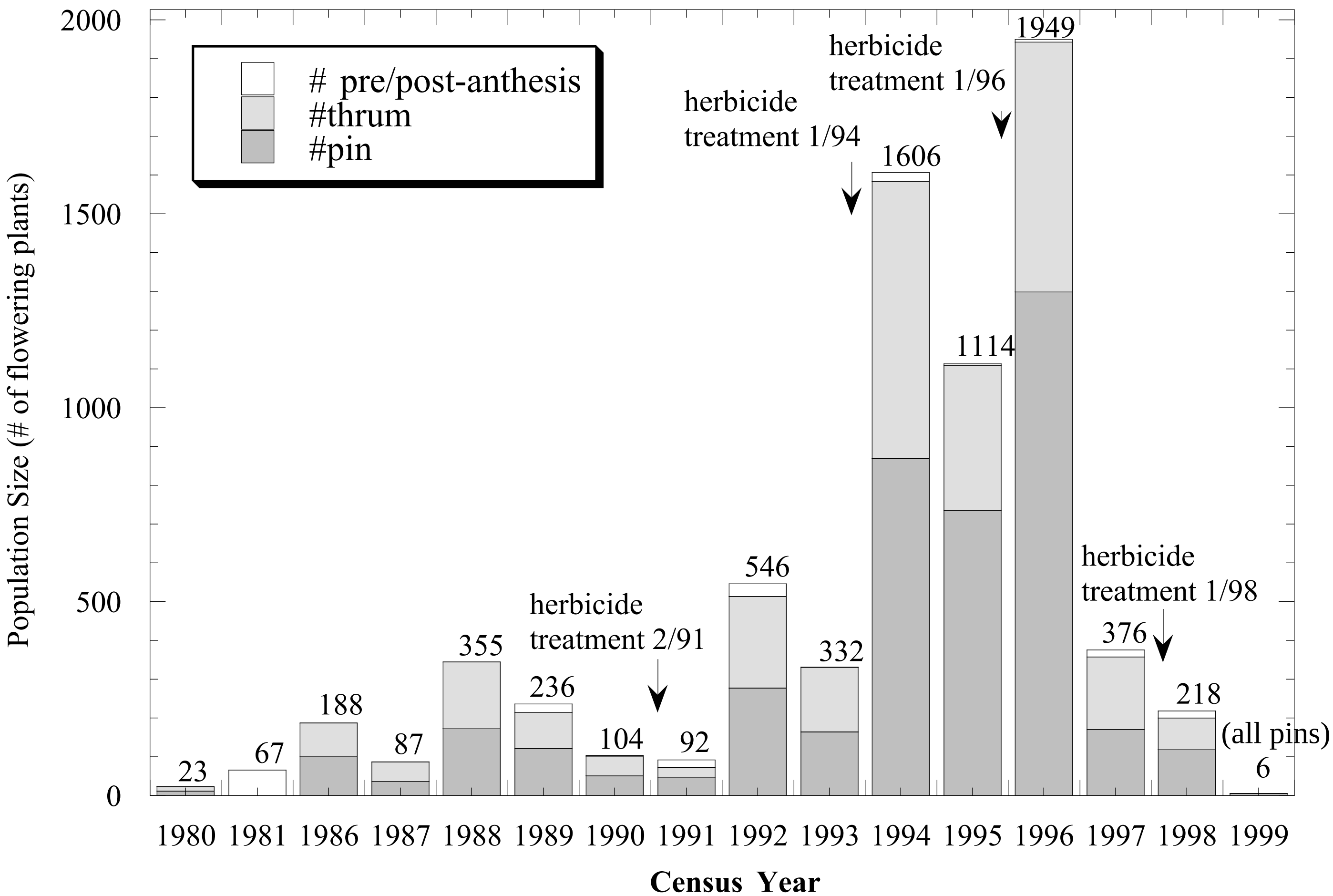

Figure 12. Historical sping census data of the Site 300 native Drop Tower population. Total population size is given above eachbar. Approximate timing of herbicide treatments to reduce competition from annual grasses is shown. Rainfall in inches for each year is shown above plot.

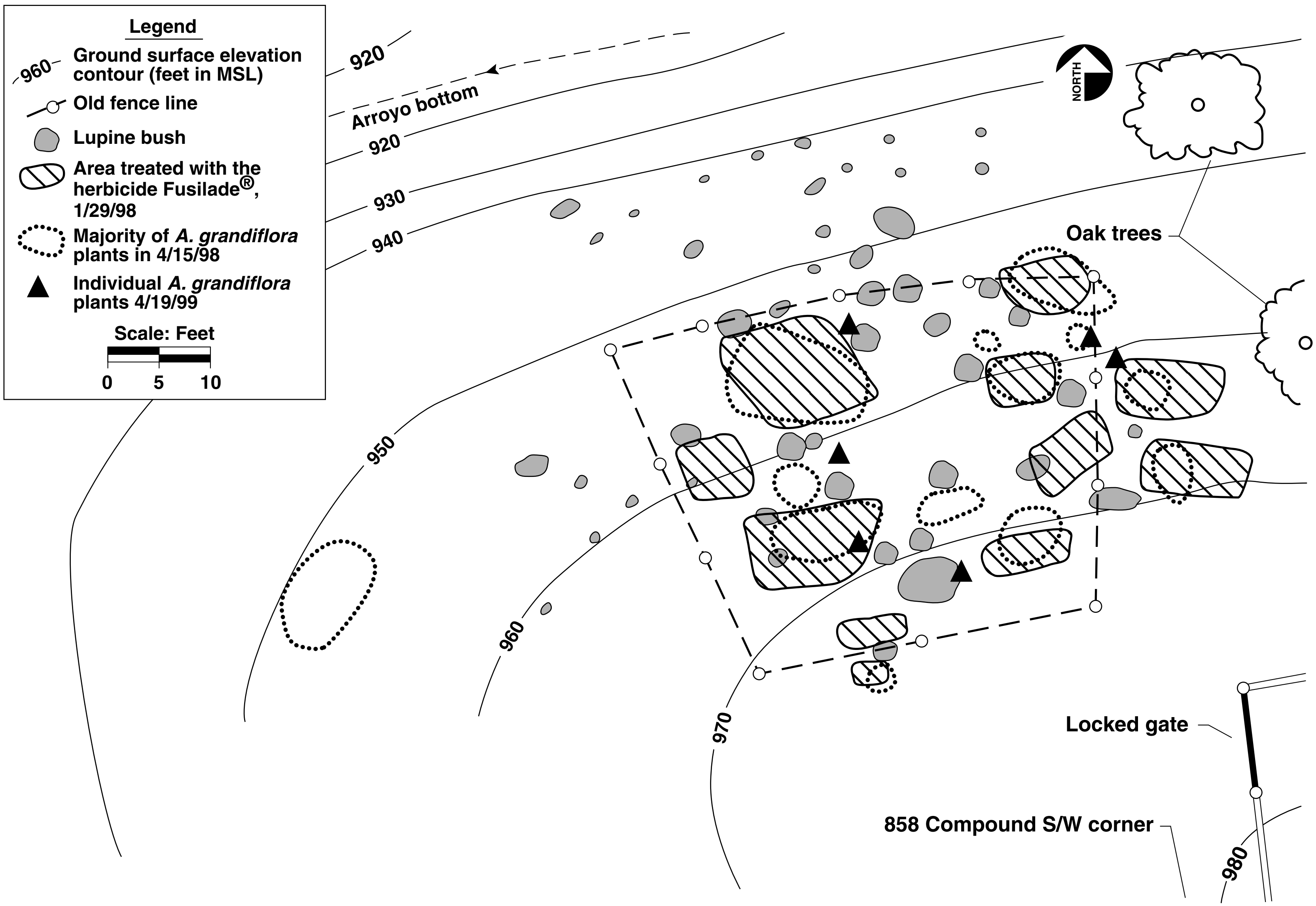

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Figure 13. Location of *A. grandiflora* plants in Spring 1998 and 1999 at the native population at Building 858 in comparison to area treated with herbicide on 1/29/98.

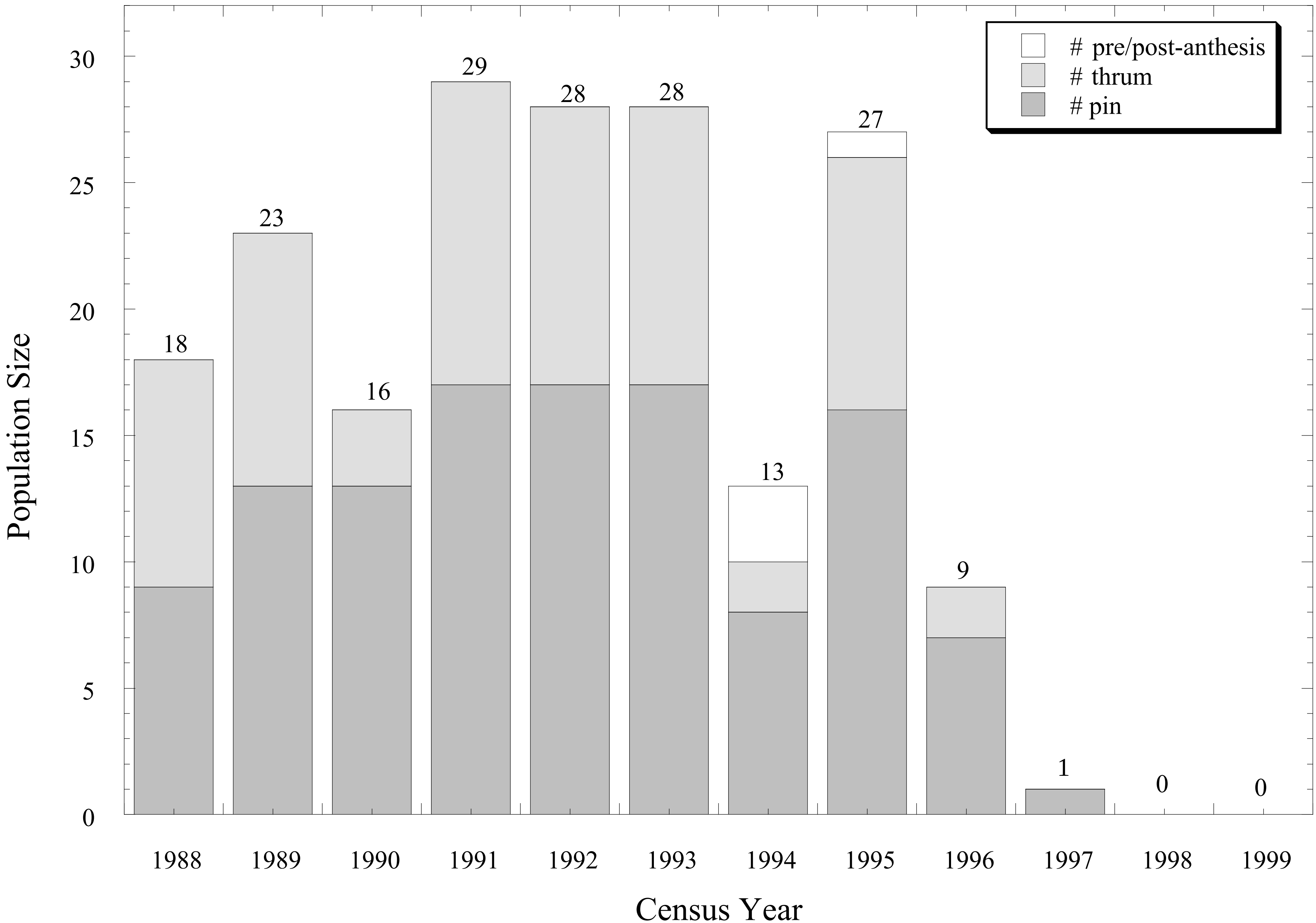

Figure 14. Historical spring census data of the Site 300 Draney Canyon Population. Total population size is given above each bar. This population was not subject to herbicide treatments or any other management efforts.

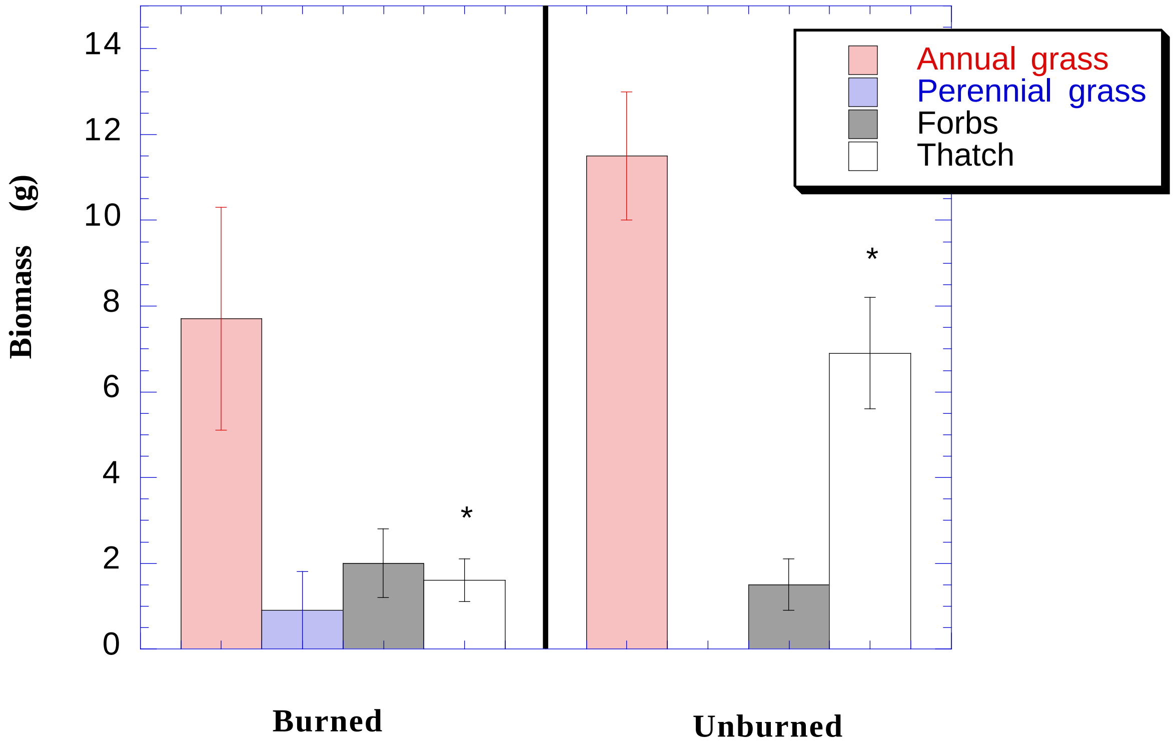

Figure 15. Weight of biomass collected from burned and unburned plots on 10 May 99. Bars are one standard error. n=5. * indicates difference between burned and unburned, p<0.025.

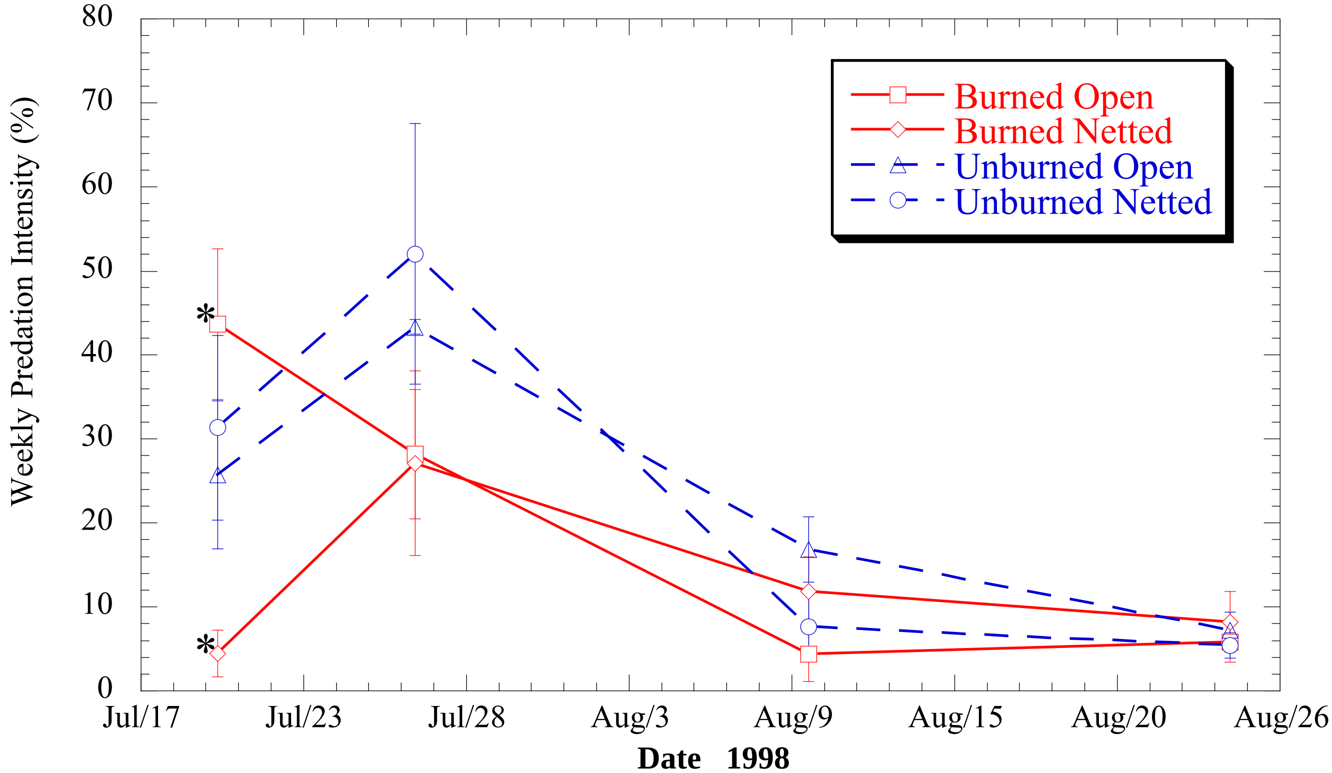

Figure 16. 1998 weekly predation intensity by treatment, post burn. Bars represent one standard error, n=5. Data points marked with * are significantly different at $p < 0.05$ for that observation date.

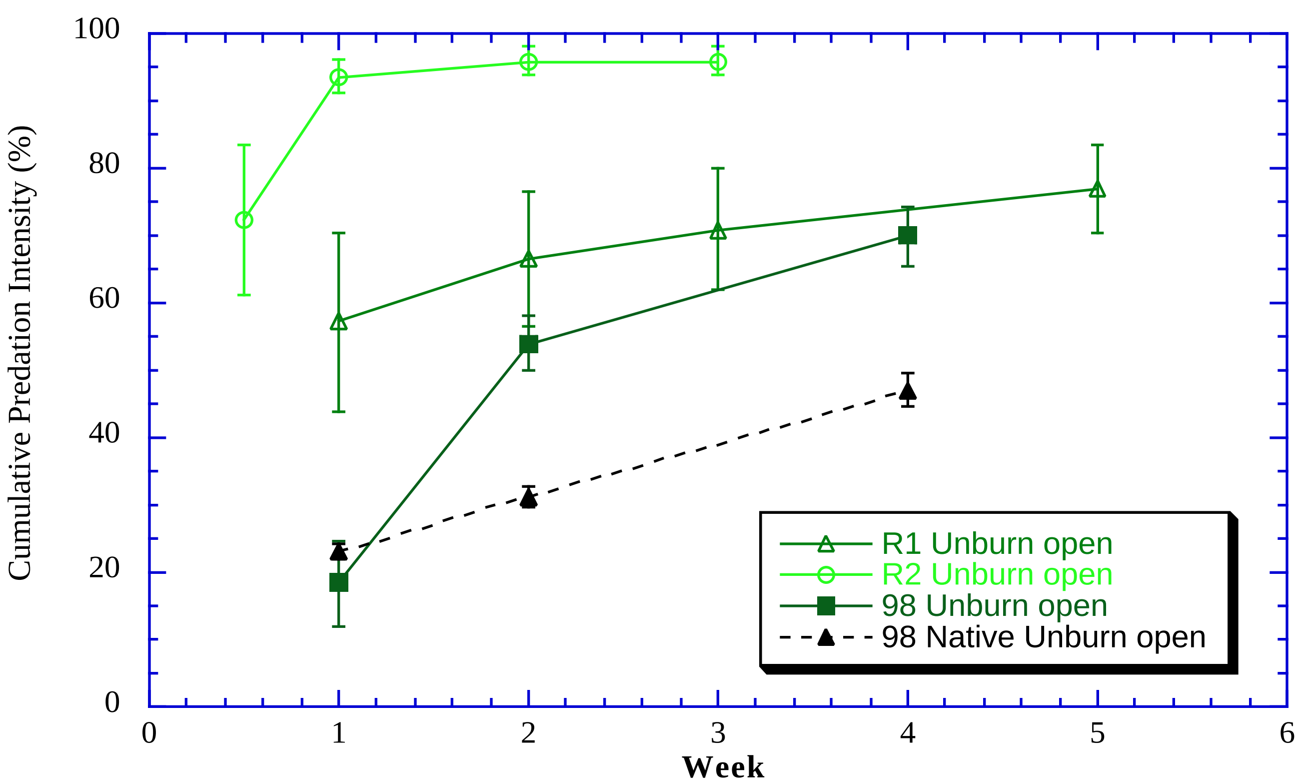

Figure 17. Cumulative predation intensity in the unburned open plots: 1999 round 1 and round 2, 1998 phase 2 experimental and native. Bars represent one standard error.

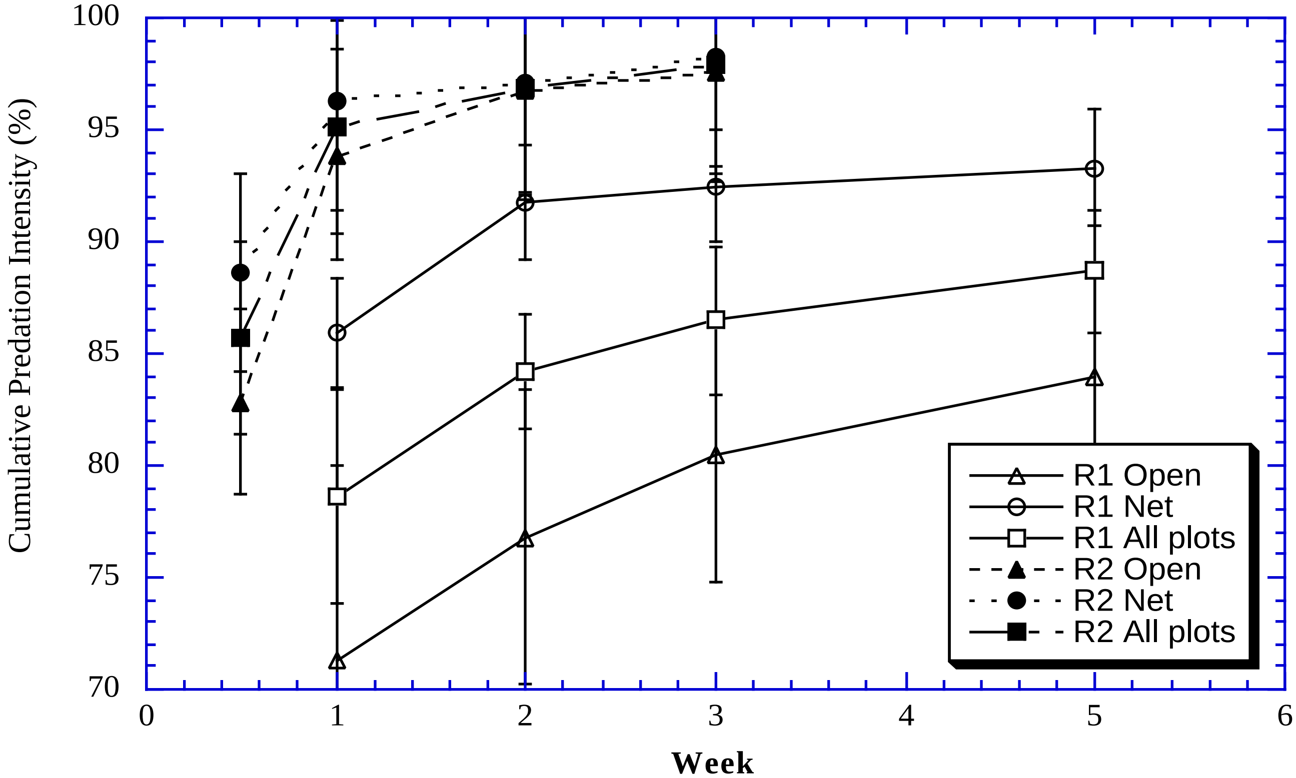

Figure 18. 1999 cumulative predation intensity by round and treatment. Bars represent one standard error, n=10 for open and netted values, n=20 for all-plot values.

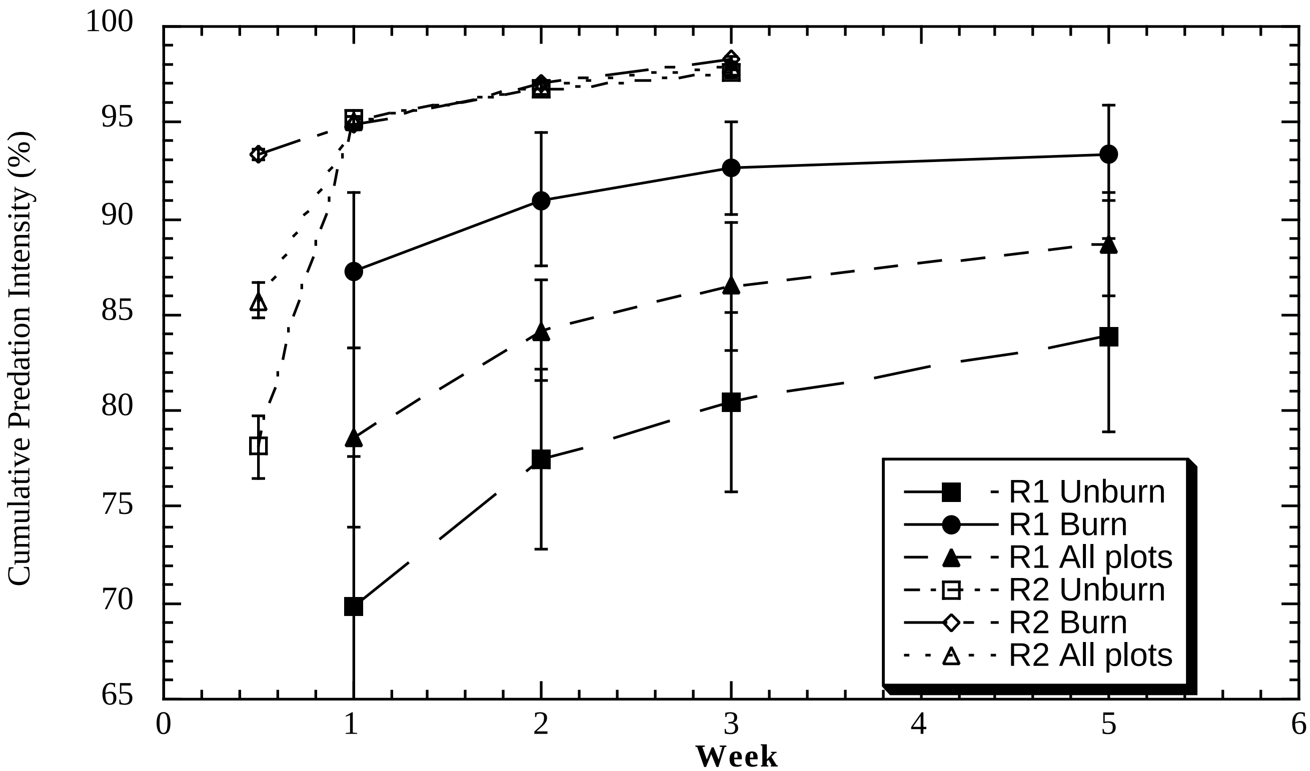

Figure 19. Cumulative predation intensity by burn status, rounds 1 and 2, 1999. Bars represent one standard error, n=10 for burned and unburned values, n=20 for all-plot values.

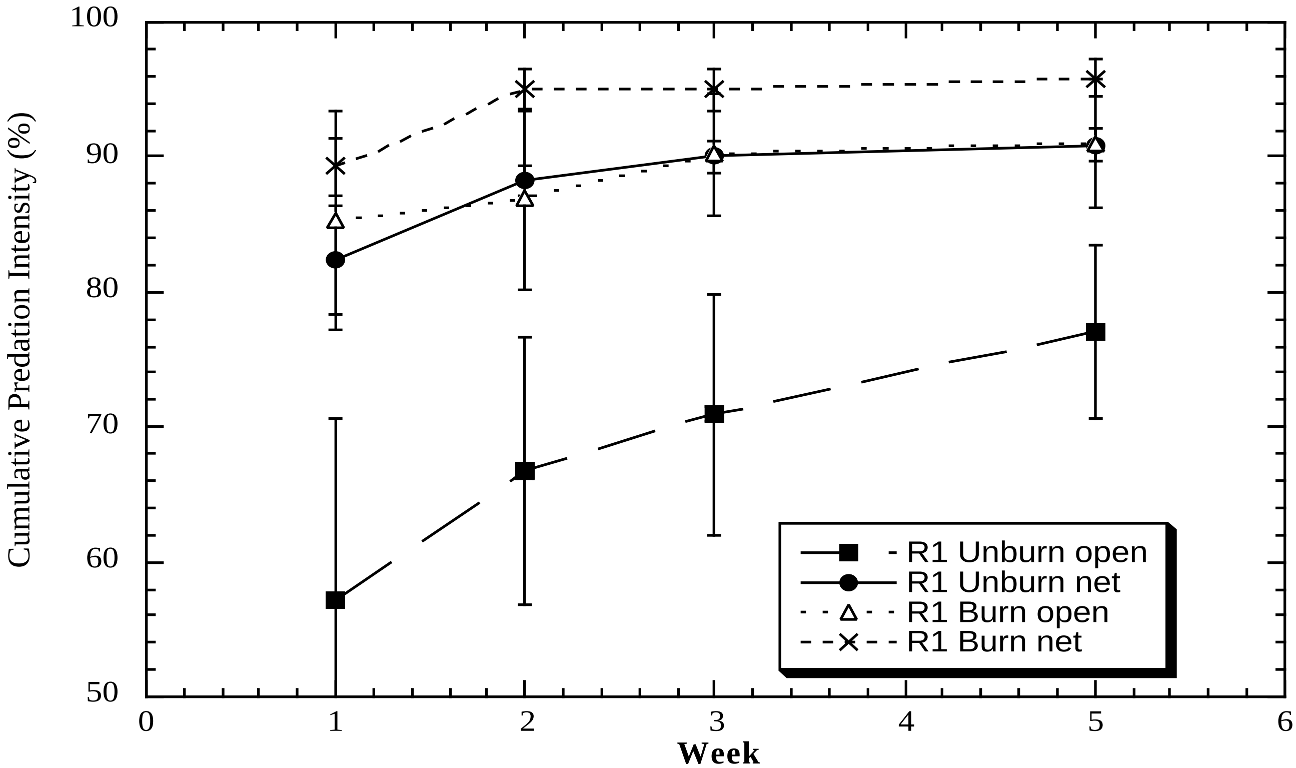

Figure 20. Cumulative predation intensity by treatment in the burned versus unburned plots, round 1, 1999. Bars represent one standard error, n=5

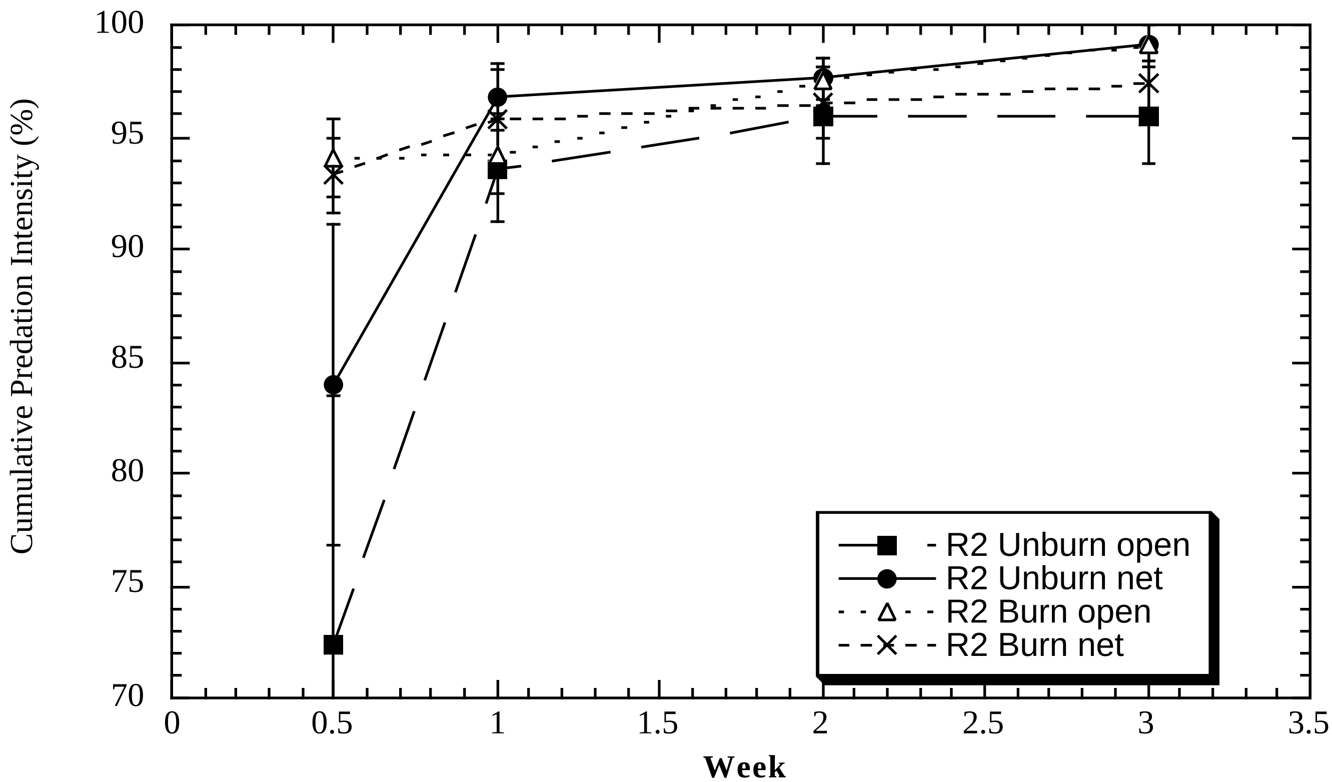

Figure 21. Cumulative predation intensity by treatment in the burned versus unburned plots, round 2, 1999. Bars respresent one standard error, n=5.

Tables

Table 1. Summary of dry biomass by dominant grass type at the Site 300 Drop Tower experimental population.

	Plots with high densities of *Poa secunda*		Plots with high densities of annual grasses	
Year	Final dry biomass (g/m^2)[a]	n	Final dry biomass (g/m^2)[a]	n
1999	135 ± 31	5	206 ± 82	5
1998	285 ± 22	6	217 ± 59	4
1994	99 ± 9.1	13	87 ± 8.9	20

[a] Biomass samples were collected from a 0.1 m^2 area located in the center of each 0.8 m^2 plot. Samples were collected in May 1994, June 1998, and May 1999. Results are presented ± one standard error.

Table 2. Summary of demographic data collected from the Site 300 Drop Tower experimental and native populations in 1998.

Population	Total # of plants	P/T ratio[a]	Average height[b]	Average # of branches per plant[b]	Estimated average seed production per plant[b]	Estimated total seed production per population[g]
Native	6	all P	15.3 ± 2.98	1.0 ± 0[c]	0[e]	0
Experimental	42	2.18	13.3 ± 0.83	1.0 ± 0.02[d]	0[f]	0

[a] Calculated using the number of pin versus thrum plants in the entire population. Does not include plants that were senescent or had not flowered at the time of the census.

[b] Results are presented ± one standard error.

[c] In the native population, branch number was defined as the number of stems branching from the main stem.

[d] In the experimental population, branch number was defined as the number of inflorescences per plant.

[e] The number of nutlets per plant in the native population was estimated using the regression equation, # nutlets/plant = 3.42*(shoot length in cm)-65.46, r=0.86, p<0.01 (Pavlik, 1991a). If the estimated seed production for an individual plant was a negative number, it was defined as zero.

[f] The number of nutlets per plant in the experimental population was estimated using the regression equation, # nutlets/plant = 16.81*(# of inflorescences)-36.76, r=0.96, p<0.0001 (unpublished). If the estimated seed production for an individual plant was a negative number, it was defined as zero.

[g] Total seed production per population was estimated by multiplying the average seed production per plant by the total number of plants in the population.

Table 3. Summary of *Poa* counts in experimental plots established in 1993.

Number of *Poa* in 1993		Number of *Poa* in 1999			1993–1999
Planted *Poa* plots[b]	**Total[a]**	**Total[a]**	**Unburned**	**Burned**	**Persistence**
Low Density	**11**	**2.4+.93**	**2.4+.93 (N=5)**	**N/A**	**22%**
Medium Density	**22**	**3.2+.92**	**2.5+1.5 (N=2)**	**3.7+0 (N=3)**	**15%**
High Density	**45**	**9.8+4.4**	**12.3+7.3 (N=3)**	**6+3 (N=2)**	**22%**
Existing *Poa* plots[c]					
Low Density	**4**	**1.8+.37**	**2 (N=1)**	**1.75+.71(N=4)**	**45%**
Medium Density	**5.6**	**1.2+.49**	**1.3+.67 (N=3)**	**1+1 (N=2)**	**21%**
High Density	**10.6**	**1.6+1.36**	**0.3+0.3 (N=3)**	**3.5+3.5 (N=2)**	**15%**
Plots cleared of perennial grass[d]	**0**	**.68+.19**	**0.87+.21 (N=15)**	**0.5+0 (N=10)**	**N/A**

[a] **For all totals, N= 5, except plots cleared of perennial grass, where N= 25.**

[b] **Plots planted in fixed densities in 1993 and maintained at these densities through 1994.**

[c] **Plots created around existing *Poa* plants. No new plantings occurred in these plots.**

[d] **Plots cleared of perennial grass were cleared only through 1994.**

Table 4. Summary of statistical analysis of Drop Tower experimental population 1999 predation study.[a] Dependent variable: weekly predation intensity.

Source	DF	Type I SS	Mean square	F value	*p* > F
1999–Rounds 1 and 2 combined					
Trt	1	6.05764	6.05764	0.19	0.6647
Burn	1	10.54809	10.54809	0.33	0.5675
Blk	4	124.29097	31.07274	0.97	0.4281
Date	7	471.75449	67.39350	2.10	0.0514
Trt*Date	7	76.17713	10.88245	0.34	0.9334
Trt*Burn	1	70.01843	70.01843	2.19	0.1429
Trt*Blk	4	134.74177	33.68544	1.05	0.3854
Burn*Blk	4	149.40683	37.35171	1.17	0.3313
Burn*Date	7	72.64757	10.37822	0.32	0.9411
Trt*Burn*Date	7	576.40105	82.34301	2.57	0.0187
Blk*Date	28	1010.24359	36.08013	1.13	0.3292
1999–Round 1 (prior to burn)					
Trt	1	0.00119	0.00119	0.01	0.9413
Blk	4	0.61527	0.15381	0.70	0.5923
Date	3	9.70089	3.23363	14.82	0.0001
Burn	1	0.52041	0.52041	2.38	0.1286
Trt*Blk	4	0.56904	0.14226	0.65	0.6282
Trt*Date	3	1.10547	0.36849	1.69	0.1809
Trt*Burn	1	0.02953	0.02953	0.14	0.7145
Burn*Date	3	1.20976	0.40325	1.85	0.1500
Burn*Blk	4	0.65879	0.16469	0.75	0.5595
Trt*Burn*Date	3	0.59802	0.19934	0.91	0.4410
1999–Round 2 (subsequent to burn)					
Trt	1	11.10265	11.10265	0.16	0.6865
Blk	4	242.16884	60.54221	0.90	0.4719
Date	3	412.10947	137.36982	2.04	0.1203
Burn	1	12.10933	12.10933	0.18	0.6734
Trt*Blk	4	259.82957	64.95739	0.96	0.4354
Trt*Date	3	75.68855	25.22951	0.37	0.7718
Trt*Burn	1	135.38082	135.38082	2.01	0.1625
Burn*Date	3	56.58053	18.86017	0.28	0.8396
Burn*Blk	4	312.29564	78.07391	1.16	0.3402
Trt*Burn*Date	3	485.76373	161.92124	2.40	0.0785

Notes:

Trt = Treatment. The treatments considered the open and netted plots.

Burn = Differentiates between burned and unburned plots.

Blk = Block.

[a] **All data were arcsine transformed prior to statistical analysis.**

Table 5. Summary of statistical analysis for burned plots only: 1998 and 1999 predation studies, Drop Tower experimental population.[a] Dependent variable: weekly predation intensity.

Source	DF	Type I SS	Mean square	F value	*p* > F
1999, Round 1 (pre-spring burn)					
Treatment[b]	1	0.03268	0.03268	0.16	0.6900
Date	3	7.92831	2.64277	13.13	0.0001
Block	4	0.37218	0.09304	0.46	0.7628
Treatment*Date	3	1.36721	0.45573	2.26	0.1029
1999, Round 2 (post-spring burn)					
Treatment[b]	1	28.13343	28.13343	1.03	0.3193
Date	3	95.45231	31.81743	1.16	0.3416
Block	4	104.56789	26.14197	0.96	0.4472
Treatment*Date	3	94.70355	31.56785	1.15	0.3450
1998, Phase 2					
Treatment[b]	1	0.08666	0.08666	2.29	0.1416
Block	4	0.37802	0.09450	2.50	0.0656
Date	3	0.64523	0.21507	5.68	0.0036
Treatment*Date	3	0.87701	0.29233	7.72	0.0007

[a] All data were arcsine transformed prior to statistical analysis.

[b] The treatments considered the open and netted plots.

Table 6. Summary of statistical analysis for unburned plots only: 1998 and 1999 predation studies, Drop Tower experimental population.[a] Dependent variable: weekly predation intensity.

Source	DF	Type I SS	Mean square	F value	*p* > F
1999, Round 1 (pre-spring burn)					
Treatment[b]	**1**	**0.02468**	**0.02468**	**0.11**	**0.7431**
Date	**3**	**2.97788**	**0.99262**	**4.41**	**0.0117**
Block	**4**	**0.93776**	**0.23444**	**1.04**	**0.4038**
Treatment*Date	**3**	**0.25587**	**0.08529**	**0.38**	**0.7691**
1999, Round 2 (post- spring burn)					
Treatment[b]	**1**	**100.99670**	**100.99670**	**0.95**	**0.3394**
Date	**3**	**365.44805**	**121.81601**	**1.14**	**0.3503**
Block	**4**	**409.21122**	**102.30280**	**0.96**	**0.4462**
Treatment*Date	**3**	**515.73658**	**171.91219**	**1.61**	**0.2101**
1998, Phase 2					
Treatment[b]	**1**	**0.01066**	**0.01066**	**0.15**	**0.7045**
Block	**4**	**0.09161**	**0.02290**	**0.32**	**0.8653**
Date	**3**	**1.55729**	**0.51909**	**7.15**	**0.0010**
Treatment*Date	**3**	**0.10496**	**0.03498**	**0.48**	**0.6976**

[a] **All data were arcsine transformed prior to statistical analysis.**

[b] **The treatments considered the open and netted plots.**

Table 7. A *priori* comparison: Observation date 1 versus all other dates, 1999 predation study, Round 1. Dependent variable: weekly predation intensity.

Source	DF	Type I SS	Mean square	F value	*p* > F
Dependent variable: cumulative predation intensity					
Date	**1**	**7.49702**	**7.49702**	**30.45**	**0.0001**
Treatment	**1**	**0.00002**	**0.00002**	**0.00**	**0.9921**
Block	**4**	**0.61576**	**0.15394**	**0.63**	**0.6460**
Burn	**1**	**0.51946**	**0.51946**	**2.11**	**0.1507**

Table 8. Summary of statistical analysis of predation studies, comparison of Drop Tower experimental population years 1998 and 1999. Cochran's t-test comparison of all plots, 1999, Round 2 and 1998, Phase 2 (both post-spring burn). Dependent variable: final cumulative predation intensity.

Year	N	Mean	Standard deviation	df	*p*
1998	20	61.95600	18.65243	19	< 0.01
1999	20	97.93500	3.37393		

Table 9. 1998 and 1999 weekly rates of predation at the Site 300 Drop Tower experimental and native populations.[a]

	Experimental site[a] 1999	Experimental site[a] 1998	Native site[a] 1998
Average weekly rate[b]	39.07 ± 10.51	17.82 ± 7.74	12.66 ± 4.42
Estimated weekly rate[c]	26.75 ± 2.67	12.86 ± 0.57	9.02 ± 1.90

[a] Data are from open, unburned plots. 1999 Rounds 1 and 2 together. 1998 Phase 2 only, standard spacing.

[b] Results are presented ± one standard error.

[c] Average of the individual weekly rates, n=4.

[d] Estimated weekly rate is obtained by dividing the final cumulative predation intensity by the total number of weeks, n=5.

Table 10. T-test comparison of burned versus unburned plots, 1999 Rounds 1 and 2. Dependent variable: final cumulative predation intensity.

	N	Mean	Standard deviation	df	*p*
Round 1					
Burned	10	93.39	7.91221	18	0.081
Unburned	10	83.91	14.18194		
Round 2					
Burned	10	98.29	2.95689	18	0.6505
Unburned	10	97.58	3.87407		

Table 11. T-test comparison of netted versus open plots, 1999 Rounds 1 and 2. Dependent variable: final cumulative predation intensity.

Treatment	N	Mean	Standard deviation	df	*p*
Round 1					
Net	**10**	**93.32**	**8.16929**	**18**	***0.0864***
Open	**10**	**83.98**	**14.08748**		
Round 2					
Net	**10**	**98.29**	**2.95689**	**18**	**0.6505**
Open	**10**	**97.58**	**3.87407**		

Table 12. Final cumulative predation rates, Drop Tower experimental population, pre-burn data from 1998 and 1999.

	Net	Open
1999, Round 1	**93.33 ± 2.58**	**83.99 ± 4.45**
1998, Phase 1	**65.18 ± 11.49**[a]	**72.54 ± 10.01**[a]

[a] **In 1998, the treatments differed significantly, $p < 0.05$.**

Table 13. 1999 weekly rates of predation at the Site 300 Drop Tower experimental population.[a]

	Round 1[b]	Round 2[b]
Average weekly rate[c]	**36.48 ± 6.48**	**44.58 ± 7.20**
Estimated weekly rate[d]	**22.2 ± 2.72**	**32.65 ± 0.18**

[a] **Includes combined results from open and netted treatments.**

[b] **Results are presented ± one standard error.**

[c] **Average of the individual weekly rates, n=4, Round 1, n=3, Round 2.**

[d] **Estimated weekly rate is estimated by dividing the final cumulative predation intensity by the total number of weeks, n=20.**

Table 14. Predation of *A. grandiflora* nutlets in 1995, 1998, and 1999.

Site	Year	Time interval	No. of weeks	Estimated weekly predation rate[a,b]	Pre/post burn	n
Drop Tower Experimental	1995[c]	Apr 3–Apr 10	1	20.0 ± 22.1	N/A	5
CDFG Experimental	1995	Apr 3–Apr 10	1	39.0 ±33	N/A	5
Drop Tower Experimental	1995	Jul 20–Sep 22	9	3.8 ± 3.7	N/A	10
CDFG Experimental	1995	Jul 20–Sep 22	9	7.2 ± 3.7	N/A	8
Drop Tower Experimental	1998	Apr 29–May 8[d]	1.25	36.2 ± 12.5	Pre	10
Drop Tower Experimental	1998	Apr 29–Jun 1[e]	4.5	19.6 ± 1.5	Pre	10
Drop Tower Experimental	1998	Jul 15–Aug 25[f]	5.25	12.86 ± 1.3	Post	5
Drop Tower Native	1998	Jul 15–Aug 25	5.25	9.02 ± 4.3	N/A	5
Drop Tower Experimental	1999[g]	Apr 26–Jun 1	5	13.59 ± 8.31	Pre	5
Drop Tower Experimental	1999	Jun 28–Jul 20	3	30.98 ± 4.39	Post	5

[a] All data ± one standard deviation.

[b] Predation rate is the percentage of nutlets lost per week, and represents the estimated rate (i.e. cumulative loss divided by number of weeks).

[c] In 1995, individual plates each containing 20 nutlets on double-stick tape were placed at random locations throughout the two experimental sites.

[d] These are data from open plots during the first time interval in Phase 1, Round 1, with rate normalized to one week.

[e] These are data from Phase 1, Round 1 from the open plots (each plot containing 5 plates).

[f] Data from these dates are Phase 2, standard spaced, unburned, open plots.

[g] In 1999, data are from unburned open plots.