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Restoration of the Large-Flowered Fiddleneck (*Amsinckia grandiflora*) at Lawrence Livermore National Laboratory Site 300
Project Progress Report Fiscal Year 1998
October 1997–September 1998

Authors

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****Erin Bissell**
*****Bruce Pavlik**

September 1998

***Lawrence Livermore National Laboratory, Livermore, CA**
****Associated Western Universities, Salt Lake City, UT**
*****Mills College, Oakland, CA**

Environmental Protection Department
Environmental Restoration Division

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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 1998 federal fiscal year (October 1997 through September 1998).

A grass-selective herbicide was applied to the Drop Tower natural and experimental populations in the early winter of 1998 in an effort to control exotic annual grass competition. Monitoring of plants in the experimental population indicated higher survivorship of *A grandiflora* plants in the treated areas, although these plants were on average smaller compared to plants in the untreated area. It is possible that the reduced competitive pressure in the treated areas allowed smaller plants to survive, where as only the more robust plants could tolerate the competition in the untreated areas. In general, more *A. grandiflora* plants were found in the herbicide treated areas during the spring census compared to untreated areas in both populations. Numbers of individuals in both populations have declined in recent years, with only 64 plants observed in the experimental population and 218 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 had resulted in an increase in standing biomass (approx. 285 g/m^2), likely contributing to increased competition. No plants were located at the Draney Canyon population site. Heavy rains during the 1996/1997 winter resulted in a landslide in the area of the population. Only one plant was observed in the spring of 1997. Further erosion occurred during 1998. It is likely this population has been extirpated.

High nutlet predation pressure was observed in both Drop Tower sites this year, possibly contributing to the decline in population numbers. Predation was highest in the experimental site, with up to 93% nutlet removal during the early spring, and 75% removal during the summer, corresponding to estimated predation rates of 19.6 and 12.8% nutlet removal per week, respectively. The highest predation rates were observed during the first week of nutlet placement in the field. Rodent predation is most important in areas that have not been cleared by burning, where as bird predation was important in areas that had been burned. The natural site experienced 50% removal of nutlets during the summer, corresponding to an estimated predation rate of 9.0% nutlet removal per week.

A controlled burn was conducted at the experimental site in June 1998, after *A. grandiflora* had senesced. The half of the site containing fewer plants was burned to encourage dispersal of

A. grandiflora into this area. In addition, an area adjacent to the experimental population was burned. This area will be used to establish plots containing restored perennial bunch grass and *A. grandiflora*, which will be burned at varying frequencies and monitored for bunch grass and *A. grandiflora* persistence and dispersal. In preparation for establishment of *A. grandiflora* into these plots, germination tests were conducted on several *A. grandiflora* nutlet sources collected over the years from experimental populations. In general, older nutlets germinated more readily and synchronously, suggested an after-ripening requirement. Younger nutlets can be stimulated to germinate through cycles of repeated wetting and drying. Such germination dynamics could help contribute to an age-structured seed bank in the field, but could hamper establishment of experimental populations until the time in which such a seed bank has developed.

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). 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 (Fig. 1). Characteristic of the genus, each flower type has four ovaries at the base of the style, each of which matures into a single-seeded fruit, known as a nutlet. Thus, each flower can produce a maximum of four nutlets.

A. grandiflora is currently 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. A large *A. grandiflora* population has also been discovered on private rangelands near the southeast border of Site 300. This population is known as the Carnegie Canyon population. 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, 1988 a and b), and have resulted in the establishment of at least one apparently successful experimental population at Lougher Ridge, located in the Black Diamond Mines Regional Preserve in Contra Costa County (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 for *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 (Fig. 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., 1998). In 1998, the United States Fish and Wildlife Service (USFWS) began providing financial support to LLNL researchers for ongoing management of the *A. grandiflora* populations at Site 300. Additional 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 1998 federal fiscal year (October 1997—September 1998).

Methods and Materials

Germination Test

Establishment of additional experimental populations of *A. grandiflora* within any managed or restored perennial grasslands will require the use of nutlets that have been collected from *A. grandiflora* experimental populations over the years. Therefore, germination tests were conducted on *A. grandiflora* nutlets that have been collected from several experimental populations over time. Mature and intact *A. grandiflora* nutlets were selected from nutlets collected from the Drop Tower experimental population in the spring of 1993, 1994, and 1995, and from the CDFG experimental population in the spring of 1995. For comparison, nutlets collected from *A. tessellata* plants growing sympatrically with *A. grandiflora* at the Drop Tower location in 1993 and 1995 were also included in the test. Germination was initiated on 18 Feb 1998 for nutlets collected in 1993 and 1994 and on 20 Feb 1998 for nutlets collected in 1995.

Nutlets were germinated in plastic Petri plates on Whatman 80 filter paper moistened with distilled water. The plates were then sealed with parafilm to reduce water evaporation. Each plate generally contained 20 nutlets, although some contained fewer due to limitations of the nutlet supply.

The plates were stored in a dark cooler at room temperature and removed periodically to monitor for germination. Germination data were collected from 20 Feb 1998 through 17 Apr 1998. Germinules were removed from the plates and transplanted into pots as they germinated. The transplanted plants were cultivated in a greenhouse until flowering was first observed. The plants were then moved outside to allow for pollination. Nutlets were collected from the plants for use in subsequent investigations.

During the course of the germination experiment, moisture was lost from the filter paper within the plates, either as a result of opening the plates to remove the germinules or through moisture permeation through the parafilm seal. Because of this, the filter paper was rewetted before resealing any plates that had been opened. In addition, all plates (including those that had never been opened) were rewetted on 3 Mar 1998, 27 Mar 1998, and 9 Apr 1998.

Demographic Monitoring

Demographic monitoring was initiated to provide data on the effects of the application of herbicide on *A. grandiflora*. Due to the large amount of disturbance frequent trips to the field site imparts on the deep soil and plant cover of such steep hillsides, it was limited to the Drop Tower experimental population, which already has well-defined compacted trails around the experimental plots. Germination of *A. grandiflora* in the Drop Tower experimental population was observed on 21 Nov 1997. On 11 Dec 1997, six 0.64 m^2 plots were selected. Plot selection was based on two criteria. First, the plots were selected to coincide with the location of the *A. grandiflora* population from the previous season. Second, the plots also contained the majority of the seedlings observed at the time of selection. 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. We attempted to mark ten *A. grandiflora* seedlings in each plot, but were unable to find exactly ten in every plot. As a result, one plot contained twelve marked plants and two plots contained nine. The total number of plants was the same as it would have been had ten plants been marked in each plot.

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 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 16 Dec 1997, 23 Jan 1998, 11 Feb 1998, 6 Mar 1998, 1 Apr 1998, and 15 Apr 1998. In addition, forb, grass, and overall herbaceous cover were estimated in all six plots on 6 Mar 1998 and 25 Mar 1998. Cover estimates were used to characterize the general community composition in treated versus untreated plots.

Herbicide Treatment

Treatment of both the native and experimental Drop Tower populations with dilute solutions of grass-selective herbicide was conducted as an interim measure to control the amount of exotic annual grass cover. The herbicide treatment was conducted on 29 Jan 1998. It rained on the morning of the treatment. Rain had ceased by afternoon when the herbicide was applied. The temperature remained around 60°F with a slight wind.

Ninety milliliters (ml) of Fusilade® concentrate and 10 ml of surfactant were dissolved into 7.6 L of water. The herbicide solution was applied at an approximate rate of 150–200 ml/m^2. Approximately 2 L of herbicide were applied in the experimental population and 5 L in the native population. Fusilade® is a grass-specific herbicide which should not impact forb species.

Figure 4 shows the areas treated with herbicide in the experimental population (labeled Fusil). Three of the demographic plots were treated with herbicide and three were left untreated. Herbicide was applied to the plots that contained the highest density of exotic annual grasses. The untreated plots contained a high density of native perennial bunch grasses. Five plots adjacent to the demographic plots were treated as well, for a total of eight treated plots.

The sites treated in the native population are shown in Figure 5. Herbicide was applied to areas that contained the highest densities *of A. grandiflora* plants observed in the spring of 1997, as shown in Figure 6. Previous work (Pavlik, 1994) has shown Fusilade treatments to be effective in increasing *A. grandiflora* numbers in the Drop Tower population. Because the density of *A. grandiflora* had dropped significantly in 1997 compared to 1996 (333 plants, down from 1,949 in 1996), at Dr. Pavlik's advice, the majority of the areas containing *A. grandiflora* plants were treated in 1997.

Spring Census

The experimental and native Drop Tower populations as well as the Draney Canyon population were censused during April 1998. All three areas were surveyed completely. Identified *A. grandiflora* plants were flagged and demographic data were collected.

The census of the experimental Drop Tower population took place on the 15 Apr 1998. The flower morph, plant height, inflorescence number and general location of each plant were recorded. When an inflorescence had bifurcated, a separate inflorescence was counted when the inflorescence was at least 5 centimeters (cm) long. Inflorescence number was collected from the experimental population to be consistent with previous data collected by LLNL researchers (Carlsen et al. 1998). The identity of the nearest species (nearest neighbor) was recorded on 8 May 1998 for marked plants that had been monitored over the entire season. In addition, biomass samples (0.1 m^2) were collected from the center of 10 plots (0.64 m^2). 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. Samples were collected on 10 Jun 1998 from plots in the area designated for burning and on 18 Jun 1998, from plots in the area to remain unburned.

The native Drop Tower population census was conducted on 16 Apr 1998. 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. This was collected instead of inflorescence number to be consistent with data collected by Mills College researchers in the past. 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 1998.

Predation Study

The predation study was initiated to estimate seed loss to predators such as birds, rodents and insects. Phase 1 was conducted prior to the controlled burn and Phase 2 was conducted following the burn. Concerns over the original experimental design in Phase 1 led to the development of an alternate design for Phase 2.

Phase 1

Nutlets were lightly secured in the bottom of plastic Petri plates using double stick tape. Water drainage holes were placed into the bottom and side of each Petri plate. The plates were secured to the ground using a wire fastener placed through one of the drainage holes. Each plate contained 20 nutlets and 5 plates were placed into each plot. Plates were placed in the experimental Drop Tower population only.

The experimental 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, three 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-inch mesh was placed over each plot. The netting was secured to prevent bird entry into the plot by air or ground. For the covered treatment, which was designed to exclude birds and rodents, the Petri plates were placed in the plots with the lids in place. Holes were placed into the lid, sides and bottom of each Petri plate to allow access to insects. Phase 1 predation treatments are designated on Figure 4 as Open-1, Net-1, and Cvr-1 for the open plots, netted plots, and plots with plates covered with the lid allowing only insect access, respectively.

The plates were placed in the field on 29 Apr 1998. The plates were censused on 8 May 1998, 22 May 1998, and 1 June 1998. It rained often during this first period. The plates were restocked with nutlets on 1 June 1998. Control plates in which the nutlets were not secured to double stick tape were also placed in the field on this date. The plates were censused again on 10 June 1998 and removed from the field in preparation for the upcoming controlled burn.

Phase 2

Phase 2 of the predation test was conducted after the controlled burn of the experimental site (see below). Nutlets were placed in both the experimental and native Drop Tower populations. Because of concern over animals training on the sight of the Petri plates, phase 2 was designed to allow for the placement of individual nutlets into the field with a more "natural" look. At the location of each nutlet, a 3 1/2-inch galvanized nail with double stick tape on the nail head was pressed into the soil so that the nail head was flush with the soil surface. A single nutlet was lightly pressed onto the tape. The nails were placed in the field on 15 Jul 1998. The nails were censused on 20 Jul 1998, 27 Jul 1998, 10 Aug 1998, and 25 Aug 1998.

Experimental Population

Open and netted treatments similar to those described for Phase 1 of the predation study were used in the experimental population in Phase 2. Half of the site had been burned and the other half remained unburned. Each half was divided into 5 blocks as in Phase 1. Ten plots in each half (sub-area) were selected. A randomized block design was used to select the open plots, where as the netted plots were the same ones selected in Phase 1. Plots that had been treated with herbicide or had biomass samples collected from them were excluded. Phase 2 treatments are shown on Figure 4 as Open-2 and Net-2. Each plot contained 25 nails spaced 15 cm apart in five rows of five nails. There is a 10 cm buffer zone between the edge of the plot and the outermost nails.

Natural Population

Differences in the spatial distribution of the nails were used for the Drop Tower natural population treatments. There were two treatments, dispersed and non-dispersed plots (designated "dispersed" and "standard" spacing, respectively). The dispersed-spacing plots were 1 m^2 in size. They contained 9 nutlets in three rows of three nails spaced 50 cm apart. The standard-spacing plots were 0.36 m^2 in size and contained 25 nutlets spaced 15 cm apart in five rows of five nails, similar to the spatial distribution used in the experimental population.

Slope was used to divide the population into five blocks. Plot location was subjective and based on a variety of factors. We sought to minimize disturbance to the *A. grandiflora* population while still considering the location of animal burrows, tracks and cover in relation to the plots. Predation plots were established around the perimeter of the previous year's clusters of *A. grandiflora* plants. Figure 5 indicates the location of these plots.

Data Evaluation

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 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 of 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. All percentage data were arcsine transformed prior to statistical analysis.

Spring Burn

A controlled burn at the experimental Drop Tower population was conducted on 11 June 1998. The burn was conducted in the morning. The temperature was around 60°F and the wind was moving up-slope at 6 to 11 mph. The relative humidity was around 80%.

Figure 4 shows the area within the experimental population which was burned. In addition, a larger area to the south and down-slope of the experimental population was burned. This area will be used to establish the plots to investigate the frequency of controlled burns in the establishment and maintenance of perennial grasslands.

Results and Discussion

Germination Test

Figures 7 and 8 present the results of the germination tests. Total germination of *A. grandiflora* nutlets (both maternal pin and thrum) was similar to its sympatric congener *A. tessellata* for the 1993 nutlet sources. For the 1995 nutlet sources, *A. tessellata* germination was higher when compared to *A. grandiflora* collected from the Drop Tower population, but similar to the CDFG nutlet source (Fig. 7), although these differences in germination percentages were not statistically significant. Total overall germination was 92%, 96% and 62% for the 1993, 1994, and 1995 Drop Tower nutlets sources (respectively) and 92% for the 1995 CDFG nutlet source (Fig. 8). However, significant differences in germination kinetics between the nutlet sources were observed during the first 35 days after the initiation of germination, with germination percentages of 27%, 46%, 80%, and 86% for the 1995 Drop Tower, 1995 CDFG, 1994 Drop Tower, and 1995 Drop Tower nutlet sources, respectively (Fig. 8). In general, it appears that the older the nutlet source, the greater the germination during this time period. Using a Duncan's multiple range test, germination of the 1995 CDFG and Drop Tower nutlets grouped together, and was significantly lower than the germination of the 1994 and 1995 Drop Tower nutlets. This is consistent with results from germination tests on the 1994 nutlet source conducted in January 1995. This germination test resulted in around 46% germination after approximately thirty days (Carlsen and Pavlik, 1997). Thus, germination percentage had almost doubled for this nutlet source over three years of storage, supporting the observation that germination percentage is related to nutlet age. Germination also tended to be more synchronous with the older nutlet sources (Fig. 8). It would appear that *A. grandiflora* has some kind of an after-ripening requirement. While this may at times be a useful adaptive strategy in the field for mature populations by allowing the development of an age-structured seed bank, it suggests that newly established experimental populations may require several "introductions" over a period of years while the seed bank is developing to a point where it can provide nutlets each fall which are ready for germination. Interestingly, germination in all four nutlet sources responded to rewetting after a period of dryness. The response was particularly strong for the younger nutlet sources (Fig. 8). It is possible that the period of dryness mimicked the period of summer drought that nutlets in the field would experience, thus accelerating the after-ripening and thereby allowing additional germination when water was again available. This also has implications for field populations, as it suggests that should the initial germination be followed by a period of drought, the loss of seedlings could be replaced by additional germination even from younger aged nutlets. Such a strategy clearly has some adaptive potential.

Demographic Monitoring of the Experimental Drop Tower Population

Experimental population plots that were treated with herbicide in January had significantly more dicot cover and less grass cover than untreated plots in March (Fig. 9). However, the grass cover in the untreated plots contained a significant portion of a native perennial species (*Poa secunda).* While the differences in cover estimates for the treated plots between the two dates might be partly due to estimation error, it seems likely that these differences are real, as the effects of the herbicide became visually more apparent as the rapid growth of the annual flora progressed in early spring.

Differences in height and survivorship of *A. grandiflora* between treated and untreated plots also became apparent in early and late March (Figs. 10 and 11). By the end of the growing season, the height of surviving *A. grandiflora* plants in treated plots was somewhat less compared to those *A. grandiflora* plants surviving in untreated plots (Fig. 10), but this difference was not statistically significant. Overall survivorship of *A. grandiflora* plants was higher in the treated plots (Fig. 11), although again this difference was not statistically significant. There are several interpretations of these observations. First, because of presumed higher competition in the untreated plots, it may be that only the most robust *A. grandiflora* plants survived, where as in the treated plots, even the smallest *A. grandiflora* plant was able to survive as a consequence of the greatly reduced competition. It could also be that due to the reduced availability of light, *A. grandiflora* plants had hyperextended stems that grew to escape the dense grass canopy. Unfortunately, *A. grandiflora* plants in both treated and untreated plots in general were very small, thin-stemmed, unbranched plants, as compared to the large, thick-stemmed, multi-branched plants observed in this population in previous years. The type of less robust plants observed this year in the experimental population have also been observed in previous years in both natural and experimental populations. Such morphology appears to be independent of the environmental conditions present at the time. This suggests some type of developmental cue or “switch” is in operation, which is apparently activated very early in the plants development.

Spring Census

The numbers of individuals in the experimental population has have declined dramatically, with only 64 plants observed this year (Fig. 12) compared to the high of 720 plants observed in 1996 (Fig. 13). Several successive years of heavy rains have produced a large increase in standing biomass within plots of the experimental population compared to the amount of biomass in 1994 when the population was initially established in (Table 1). In addition to small population size, the *A. grandiflora* plants were very small, within only single inflorescences (Table 2). Using a regression equation developed in 1994 (unpublished data), it would appear that this population will produce essentially no nutlets this year. While this regression equation may underestimate nutlet output, as it was developed using plants that were multi-branched (that is, very few of the plants 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 inflorescences number is required for significant nutlet production (Pavlik, 1991b).

Figure 14 shows the general locations and flower morphs of *A. grandiflora* plants observed in the native Drop Tower population. Figure 15 shows the census history for this population. As in the experimental population, the natural Drop Tower population has declined dramatically, down to 218 plants in 1998 (Fig. 14) from a high of 1,949 plants in 1996 (Fig. 15). The vast majority of flowering plants occurred in the areas that were treated with herbicide earlier in the winter (Fig. 16). The estimate of nutlet production for this population was 8,400 (Table 2), down considerably from the 33,726 estimated in 1994 (Pavlik, 1994).

Figure 17 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. It seems likely that this population has been extirpated.

Spring Burn

Because of the small size of the experimental *A. grandiflora* population this year, it was not possible to design or implement an experiment to consider the effects of herbicide treatment, spring burning and fall burning simultaneously. Because half of the population had already been treated with herbicide, the area of the experimental population containing the majority of the *A. grandiflora* plants was not burned. This will allow for observation of the effects of the herbicide treatment one year post treatment. In addition, no fall burning is planned. The southern half of the experimental population containing few plants during the spring census was burned (Fig. 4), and will be monitored for dispersal of *A. grandiflora* into this area.

An area adjacent to the experimental population to the south and down-slope was also burned. This area will be used to establish plots with restored perennial grasses and *A. grandiflora* that will be burned at varying frequencies.

Predation Study

Phase 1

Table 3 summarizes the results of the statistical analysis of the predation data collected during Phase 1 of the predation study at the Drop Tower experimental population prior to the burn. Round 1 consisted of plates containing nutlets remaining in the field for approximately three weeks, at which point they were restocked for Round 2. Round 2 plates remained in the field for approximately one week. Data for the covered treatment in Round 1 were not included, as no nutlets were removed from any of the plates. In Round 1, treatment effects were significant for cumulative predation intensity and weekly predation intensity, where as date effects were significant for cumulative predation intensity, weekly predation intensity and weekly predation rate. There were no significant effects in Round 2. This included a comparison of the amount of predation experienced in plates with and without the use of the double-stick tape. Although this suggests no effect of the tape, any subtle effect the tape may have caused on predation success could have been masked by the very high predation pressure observed during this time period (see below).

During Round 1 of Phase 1, the open treatment plots had significantly higher cumulative predation intensity (93% removal of nutlets, Fig. 18) compared to the netted treatment plots (86% removal of nutlets). As would be expected, cumulative predation intensity significantly increased over time, but appeared to level off at around week three. Round 2 cumulative predation intensity is also shown on Figure 18. Although the Round 2 plates were in the field for only a week, they experienced the same overall removal of nutlets (up to 93% nutlet removal) as was observed after three weeks in Round 1, suggesting either very intense predation pressure during this time period, and/or some training by the predators on the plates. Weekly predation intensity (Fig. 19) was also greater for the open plots compared to the netted plots. Weekly predation intensity significantly increased over time, suggesting the predators find a higher percentage of the remaining nutlets as the nutlet stock decreases. This may again reflect training of the predators on the sight of the plates, or perhaps less selectivity as supply diminishes. Although overall the weekly predation rate between the two treatments were not significantly different during Round 1, the predation rate observed during the first week was significantly higher for the open treatment (Fig. 20) compared to the netted treatment. The weekly predation rate drops significantly over time. Thus, predation rate was not constant over time, with highest rates observed during the first week. Apparently, if the predators can’t find the nutlets during this initial time period, they are generally unable to locate them. Table 4 shows the overall (all treatments combined) estimated weekly predation rate, as calculated by dividing the final predation intensity by the total number of weeks in the plates were in the field (19.0% nutlet loss per week). While this number is similar to the average of all the individual weekly predation rates (18.3 nutlet loss per week), it gives the misleading impression that the predation rate is constant through time. Using this figure, if nutlets were in the field for only a week, one would expect 18% removal, where as up to 40% removal was observed in the open treatments. It is in the open treatment that the difference in predation rate over time is particularly noteworthy.

Phase 2

Experimental Population

Table 5 summarizes the results of the statistical analysis of the overall Phase 2 predation experiment conducted at the Drop Tower experimental population after the burn. Round 2 consisted of nutlets placed on nails for approximately five and one-half weeks of field exposure. The effect of burn and treatments were significant for cumulative predation intensity. In general, cumulative predation intensity was higher in the unburned plots (69% nutlet loss, Fig. 21) and higher in the open plots (67% nutlet loss, Fig. 22). However, there is a significant burn by treatment interaction. Tables 6 and 7 summarize the statistical analysis conducted separately on the burned and unburned areas, respectively. Figure 23 shows that during the first week, the burned open plots had the highest amount of predation (31% nutlet loss), where as the burned netted plots had the lowest (3% nutlet loss), with the unburned open and netted plots being intermediate to the burned plots. By the second week, the unburned plots had a higher level of predation (50 to 54% nutlet loss) compared to the burned plots (21 to 49% nutlet loss). These data suggest that during the first weeks after a controlled burn, bird predation pressure is very high, possibly due to easy access and visibility of the plots. Rodent predation pressure is quite low, due to the poor availability of cover for protection. Rodent pressure is higher in the unburned plots, where they seem to be the primary predator. In addition, rodent predation pressure in the unburned plots eventually exceeds bird predation pressure in the burned plots.

There were no significant treatment or burn effects observed for the weekly predation intensity or weekly predation rates (Tables 5–7). Although not statistically significant, the unburned plots generally had a higher weekly predation intensity (Fig. 24). Unlike that observed in Phase 1, weekly predation intensity during this phase dropped over time, although the trend was not significant. During the first week, the open plots generally had a significantly higher weekly predation intensity compared to the netted plots (Fig. 25). This is again driven by the high intensity of predation observed in the open plots (>40%) in the burned area (Fig. 26). Similar patterns are observed for weekly predation rates (Figs. 27–29).

Table 8 shows the average and estimated final weekly predation rate in the burned and unburned plots. Although the open burned plots had the highest level of predation during the first week (Figs. 23, 26, and 29), over the length of the experiment the highest predation rate was observed in the unburned plots (17.8% nutlet loss per week), with similar rates observed in the unburned open and netted plots. The open burned plots had an overall weekly predation rate similar to the open unburned plots (16.5% nutlet loss per week), where as the weekly predation rate observed in the netted burned plots was significantly lower (9.2% nutlet loss per week). Interestingly, during this phase of the predation experiment, the overall weekly predation rate is underestimated when estimated by dividing the final cumulative predation intensity by the number of weeks versus taking an average of the individual weekly predation rates.

Native Site

Table 9 summarizes the results of the statistical analysis of the overall Phase 2 predation experiment conducted at the Drop Tower native population. In general, nutlets in plots with standard spacing experienced higher predation than nutlets in plots with dispersed spacing (Figs. 30–32), but this difference was not statistically significant (Table 9). Overall cumulative predation intensity at the native site was around 50% nutlet loss (Fig. 30). A significant block effect was observed for cumulative predation intensity, with some locations experiencing higher levels of predation than others within the site, suggesting predation to be patchy. As observed in the experimental site, the largest amount of predation was experienced during the first week (Figs. 31 and 32), dropping significantly over time.

Native Site compared to Experimental Site

Table 10 summarizes the results of the statistical analysis comparing the predation levels at the experimental site to those observed at the native site. This comparison was done on open, unburned plots with standard nutlet spacing. Significantly higher cumulative predation intensity was observed in the experimental site compared to the native site (Fig. 33, Table 10). This difference was driven primarily by higher weekly intensities and rates observed during the second week at the experimental site (Figs. 34 and 35). Predation was similar between the two sites during the first week, but continued to increase at the experimental site, peaking at the second week, while declining at the native site. Weekly predation rates for the two sites are summarized in Table 11. The experimental site had an overall weekly predation rate of 17.8% nutlet loss per week, where as the native site had a weekly predation rate of 12.7% nutlet loss per week. Once again, the overall weekly predation rate is underestimated when estimated by dividing the final cumulative predation intensity by the number of weeks versus taking an average of the individual weekly predation rates.

Phase 1 compared to Phase 2

In general, weekly predation rates were higher in the open, unburned plots at the experimental site during Phase 1 compared to Phase 2 (19.6% nutlet loss per week vs. 12.9% nutlet loss per week, Table 12). This resulted in an overall cumulative predation intensity of 93% nutlet loss during Phase 1 compared to 75% nutlet loss during Phase 2 (Figs. 18 and 23, respectively). During both time periods, differences were observed between netted and open treatments, indicating both birds and ground-dwelling animals are important predators. There appeared to be a greater difference between open and netted plots during Phase 2 (Fig. 23), suggesting birds play a greater role in predation loss during the summer months than in the spring time period. It also appeared to take the ground dwelling predators longer to find the nutlets during Phase 2. This may be in part due to the difference in experimental design between the two phases. Ground dwelling predators may have been training on the sight of the Phase 1 plates. In addition, the fact that five plates were close together in each plot may have contributed to plate recognition.

Regardless, higher predation rates during the spring have been observed before. Table 12 shows data from predation experiments conducted in 1995. In these experiments, individual plates each containing 20 nutlets on double-stick tape were placed at random locations throughout two experimental populations, the Drop Tower experimental population, and the

CDFG experimental population. As can be seen, predation rates were higher during the spring week, although the low rate observed during the summer time period may be partly an artifact of the long time period involved. Unlike 1998, entire plates in 1995 were not found by the predators, as shown by predation eveness (the percentage of plates with missing nutlets). Also, at least during the 1995 summer, a significant localization effect was observed; that is, once a plate was found by a predator, all nutlets would be consumed. This was what motivated us to place several plates in each plot. Unfortunately, this probably exacerbated the training effect.

As can also be observed in Table 12, the CDFG site had much higher predation pressure in 1995 compared to the Drop Tower site. The *A. grandiflora* population at this site did not successfully establish, and such a high predation pressure may have been a contributing factor. Other experimental populations (those at Connolly Ranch, Black Diamond I and II) are believed to have failed due to very high rodent activity (Pavlik, 1994). At the Connolly Ranch population, six rodent individuals (representing at least two species) were trapped in a single night in 1996 (unpublished data). Ominously, rates observed this year at the Drop Tower experimental site were similar to those observed at the CDFG site in 1995, suggesting predator pressure has increased and may be detrimentally impacting this population.

Recommendations and Future Work

Population size at both the native and experimental Drop Tower locations has declined over the past two years. It appears that increased competition from neighbor biomass and increased predation pressure may be contributing to these declines. Several winters of above average rainfall have resulted in high levels of standing biomass, which in turn may have provided increased food to seed predators, and perhaps to greater predator numbers.

Thus, 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 method to monitor predator pressure should be developed. The extensive predation study conducted this year is not appropriate as a monitoring tool, as frequent trips to the field are quite disruptive to the habitat, particularly to the native site. While this experiment should be repeated next year at the experimental site, a smaller, less-intrusive method for accurately monitoring predation pressure at the native site should be developed.

It may be necessary, therefore, to control both grass competition 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 through trapping and encircling the area with a buried metal flashing, which may have allowed the large numbers of plants to establish during these years. Trapping has not been conducted in recent years, and it appears that the metal flashing is no longer a strong deterrent. 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 as a result, the standing biomass at this site has dramatically increased since the initial population establishment. Finally, it is possible that the timing of the herbicide application is not optimal with respect to impacting the expression of the hypothesized developmental switch which appears to be acting in *A. grandiflora*.

Controlled burning is probably the most feasible method for controlling biomass amount and composition. Plots are being established near the experimental population to investigate fire frequency for maintaining intermediate densities of native perennial bunch grasses. This community type has been shown to provide favorable habitat to *A. grandiflora* (Carlsen et al., 1998). The area for these plots were burned this past spring. In 1999, each plot (measuring approximately 2 m by 2 m) will have a nucleus of *P. secunda*, a native perennial bunch grass found at the site, transplanted into the center 0.64 m^2 of each plot. The *P. secunda* transplants will be allowed to establish during 1999. 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 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 be modified based on data collected from biomass samples and predation monitoring.

Acknowledgments

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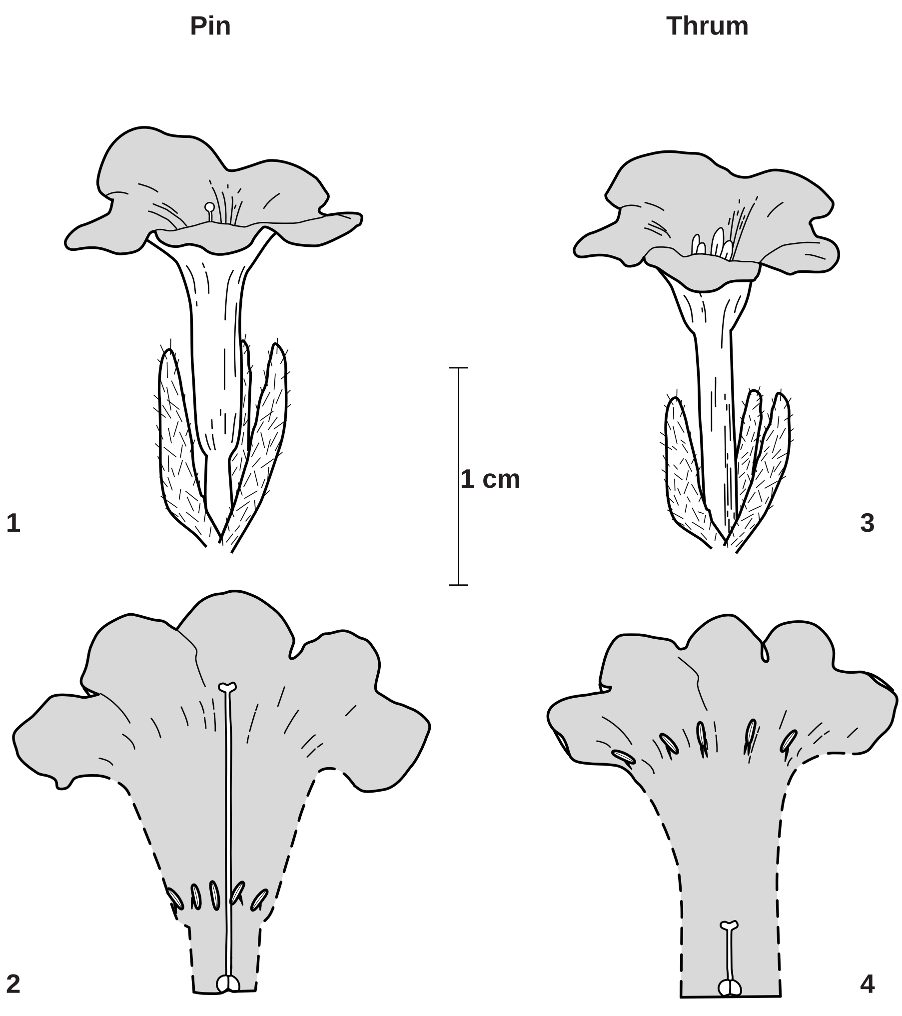
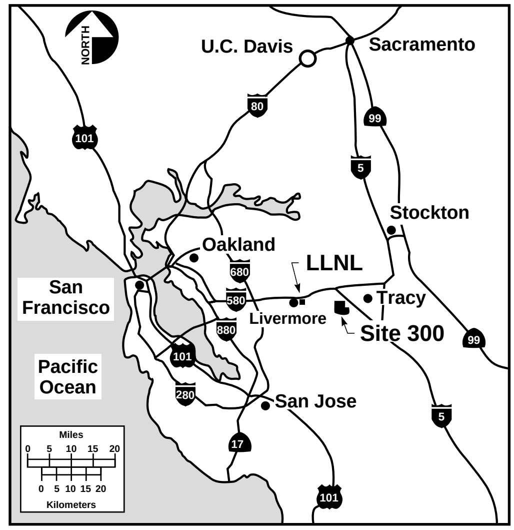
Figures



ERD-S3R-98-0168

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)



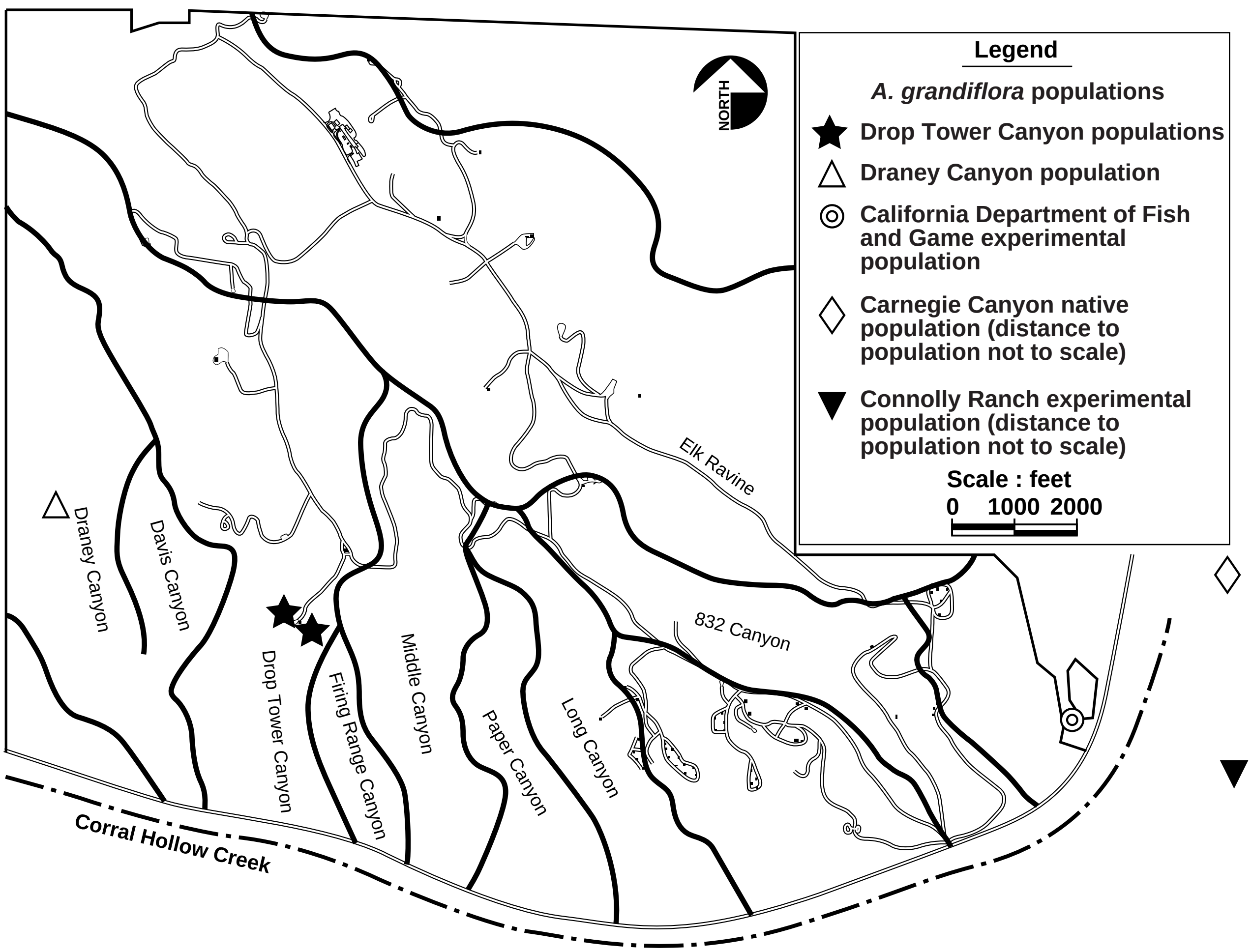


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Figure 2. Locations of *A. grandiflora* populations at or near Lawrence Livermore National Laboratory (LLNL) Site 300.

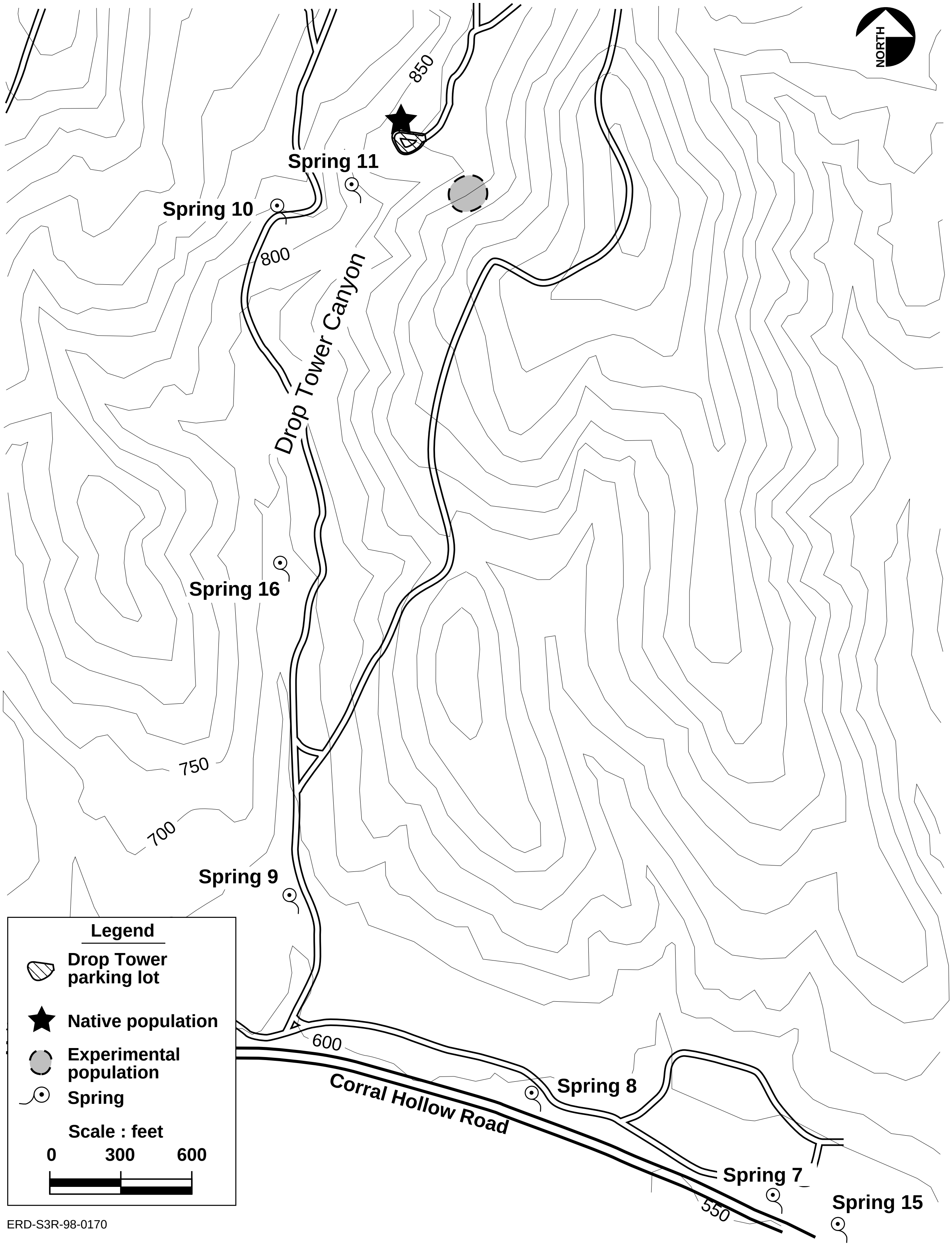

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Figure 3. Location of native and experimental *A. grandiflora* populations in Drop Tower Canyon.

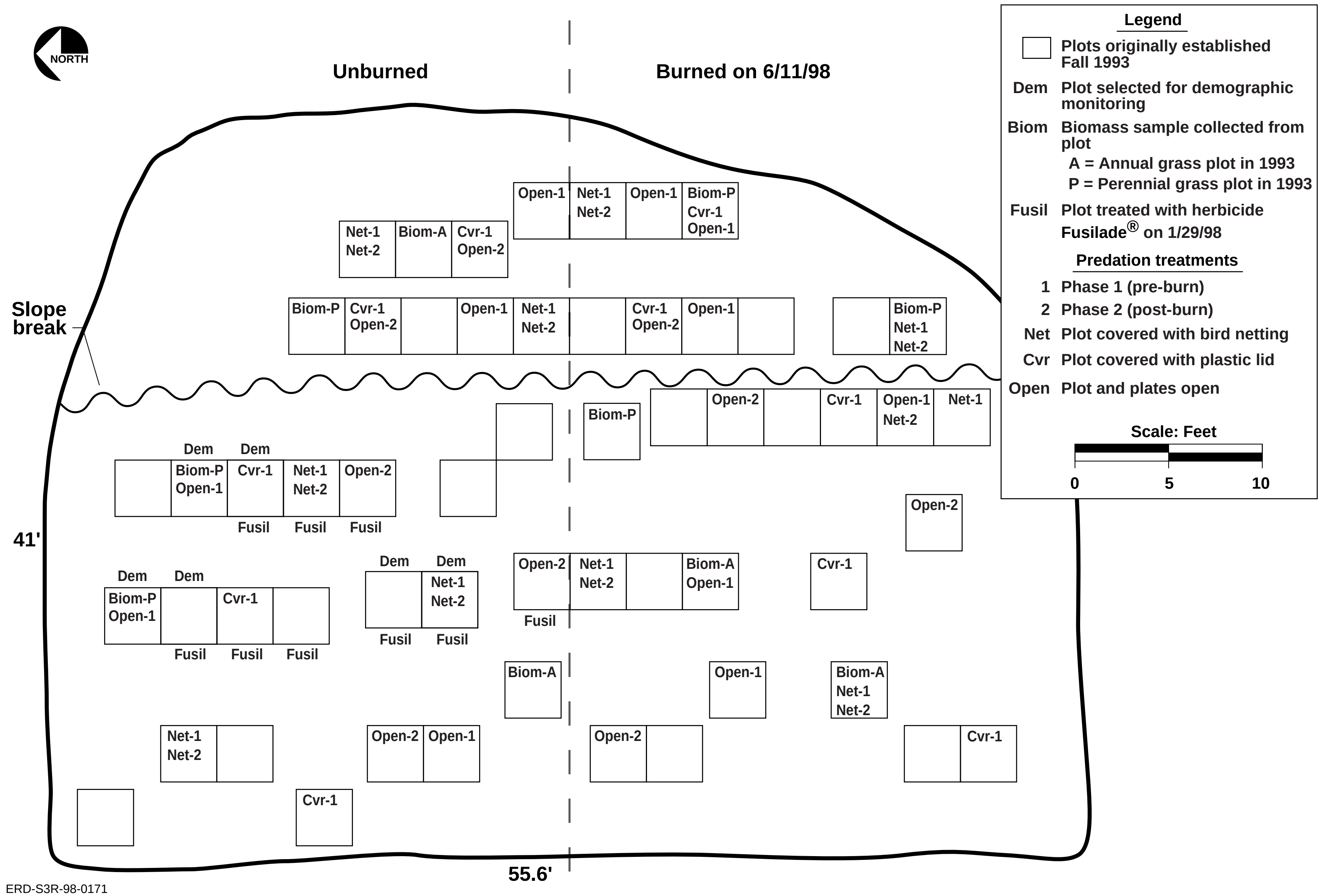

Figure 4. Summary of experimental treatments at the *A. grandiflora* experimental population.

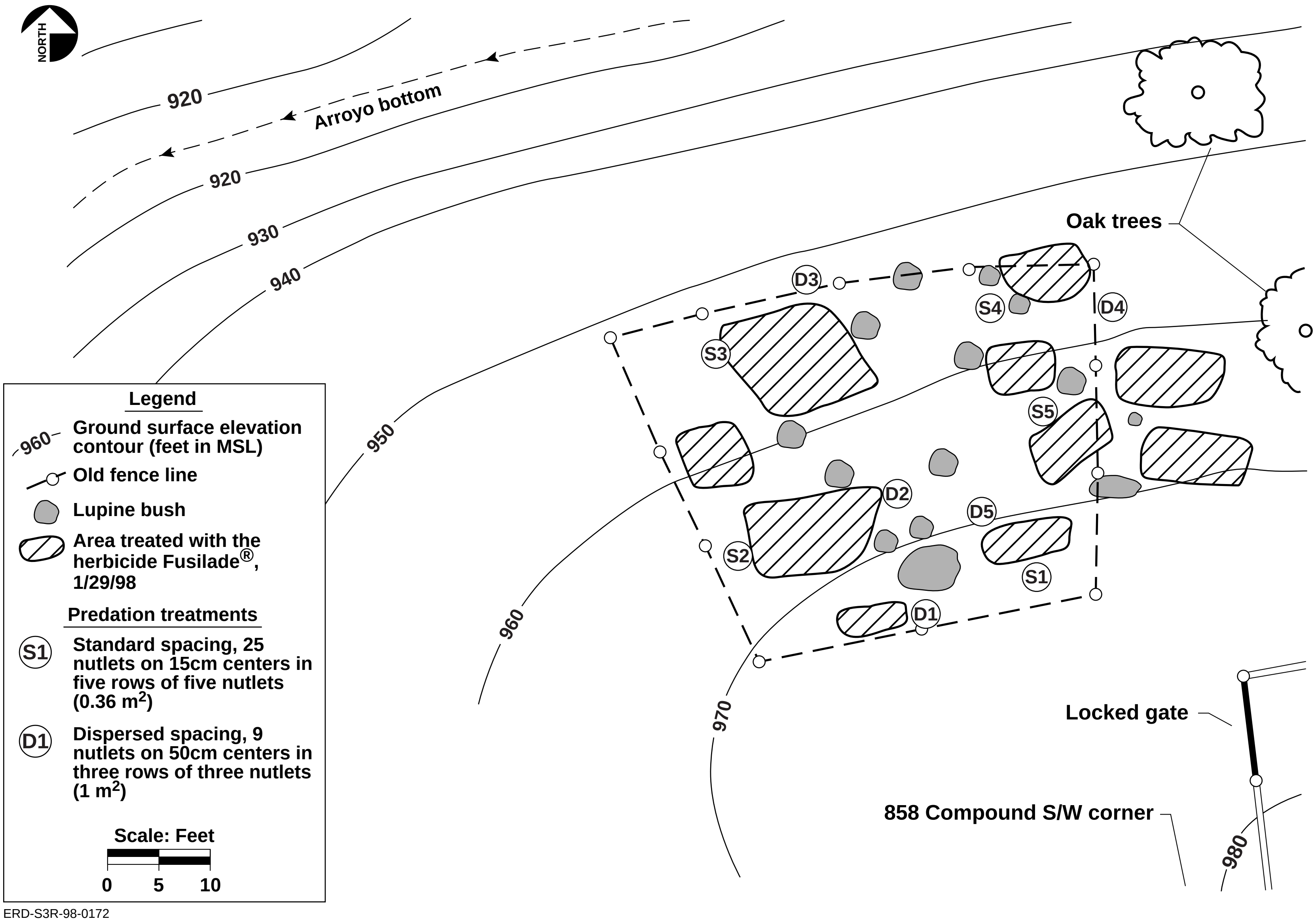

Figure 5. Summary of experimental treatments at the *A. grandiflora* native population.

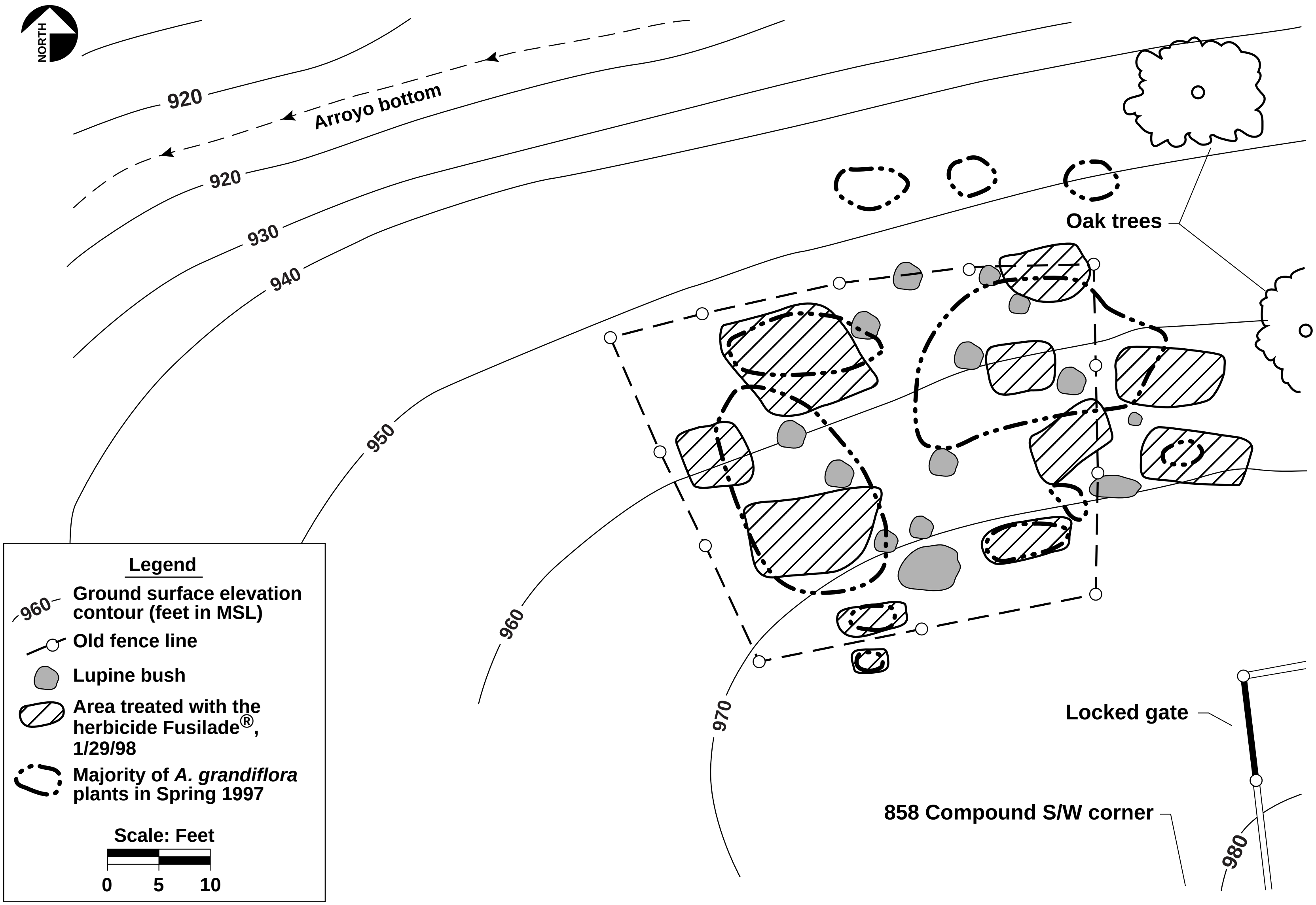

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Figure 6. Location of *A. grandiflora* plants in Spring 1997 at the native population at Building 858 in comparison to areas treated with herbicide on 1/29/98.

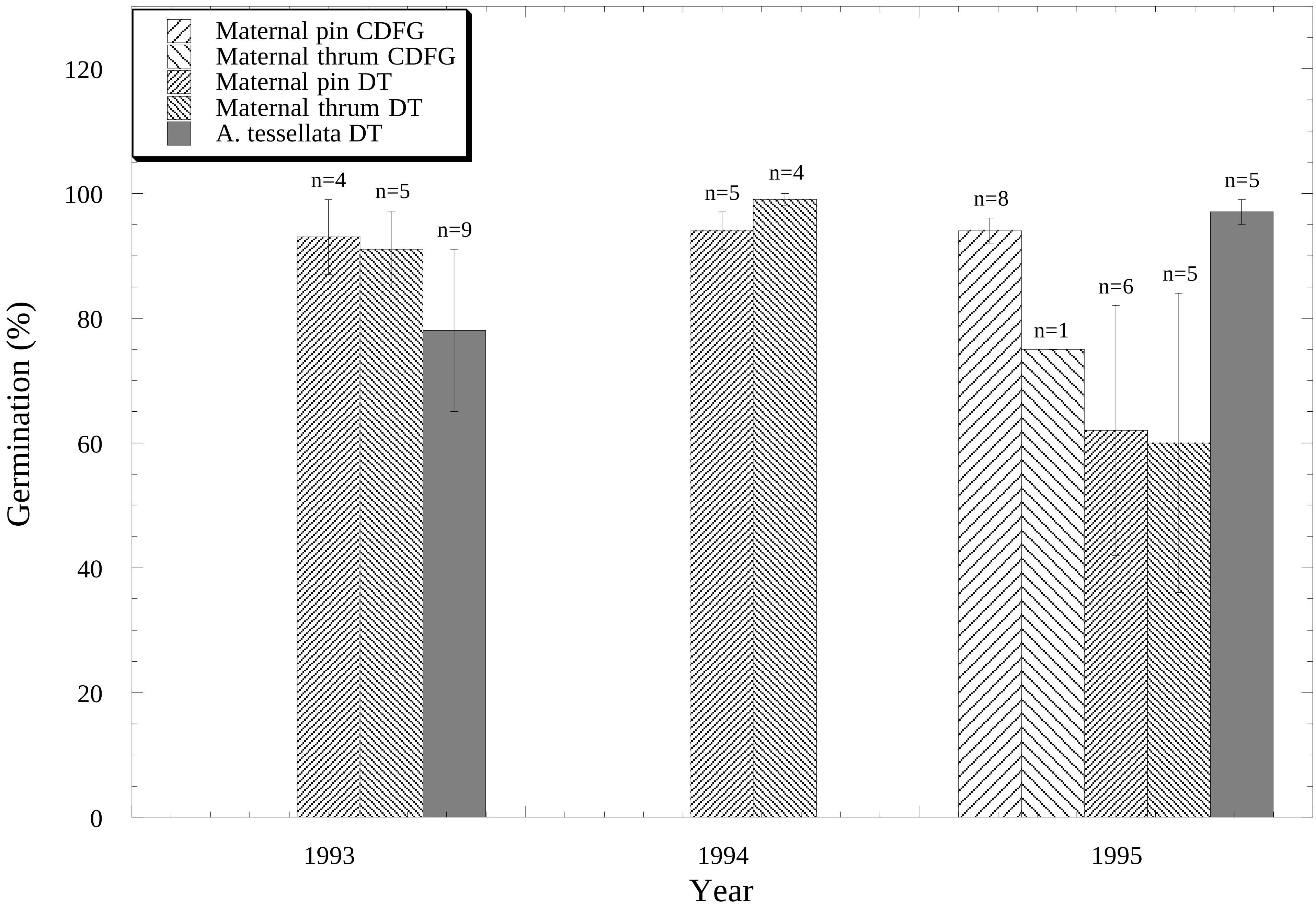

Figure 7. Total germination (%) for *Amsinckia* nutlets collected from experimental population plants in 1993, 1994, and 1995, DT=Drop Tower and CDFG=California Department of Fish and Game source populations. Bars represent one standard error, sample size is shown above error bars.

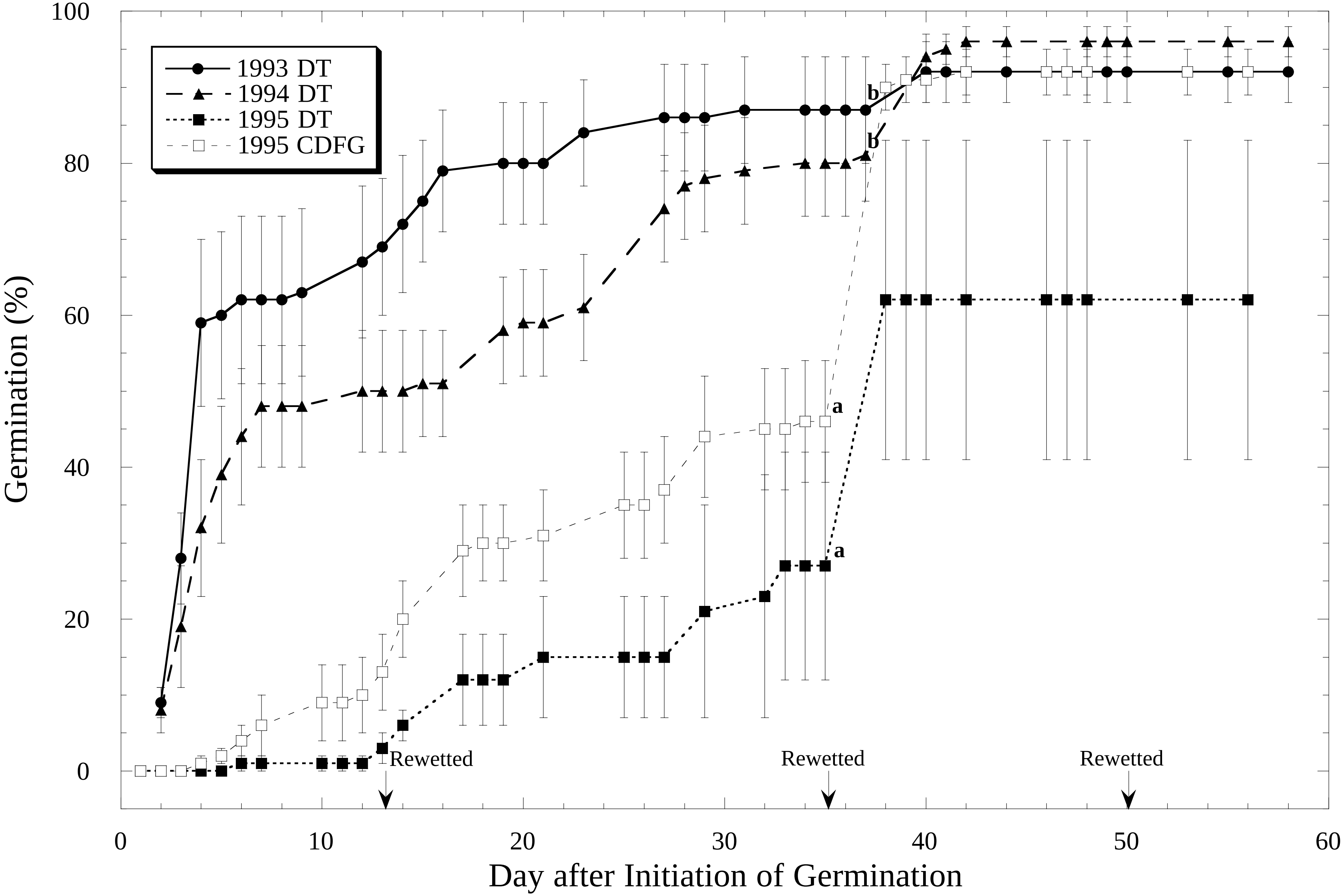

Figure 8. Germination kinetics of *A. grandiflora* nutlets collected from the Drop Tower experimental population in 1993, 1994, and 1995, and from the CDFG experimental population in 1995. Data points represent daily averages of germination in all plates from each source year. Bars represent one standard error, n=9 for 1993 and 1994 Drop Tower and 1995 CDFG, n=4 for 1995 Drop Tower. Arrows represent dates when all plates were rewetted. At day 35, data with the same letters are not significantly different at $p<0.05$.

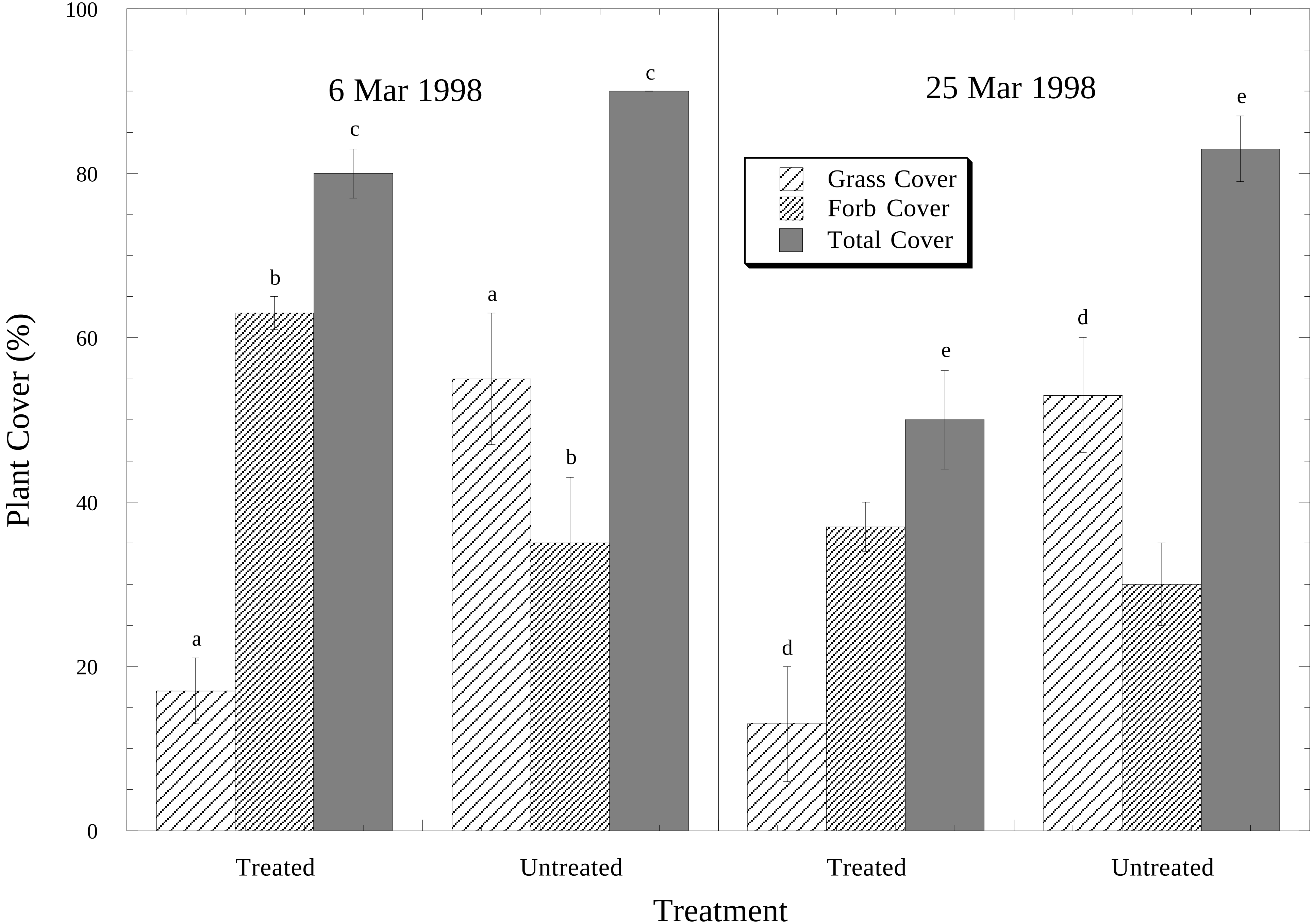

Figure 9. Plant cover estimates for *A. grandiflora* experimental population plots for 6 Mar 1998 and 25 Mar 1998. Bars represent one standard error, n=3. Treatments with the same letters are significantly different at $p<0.05$

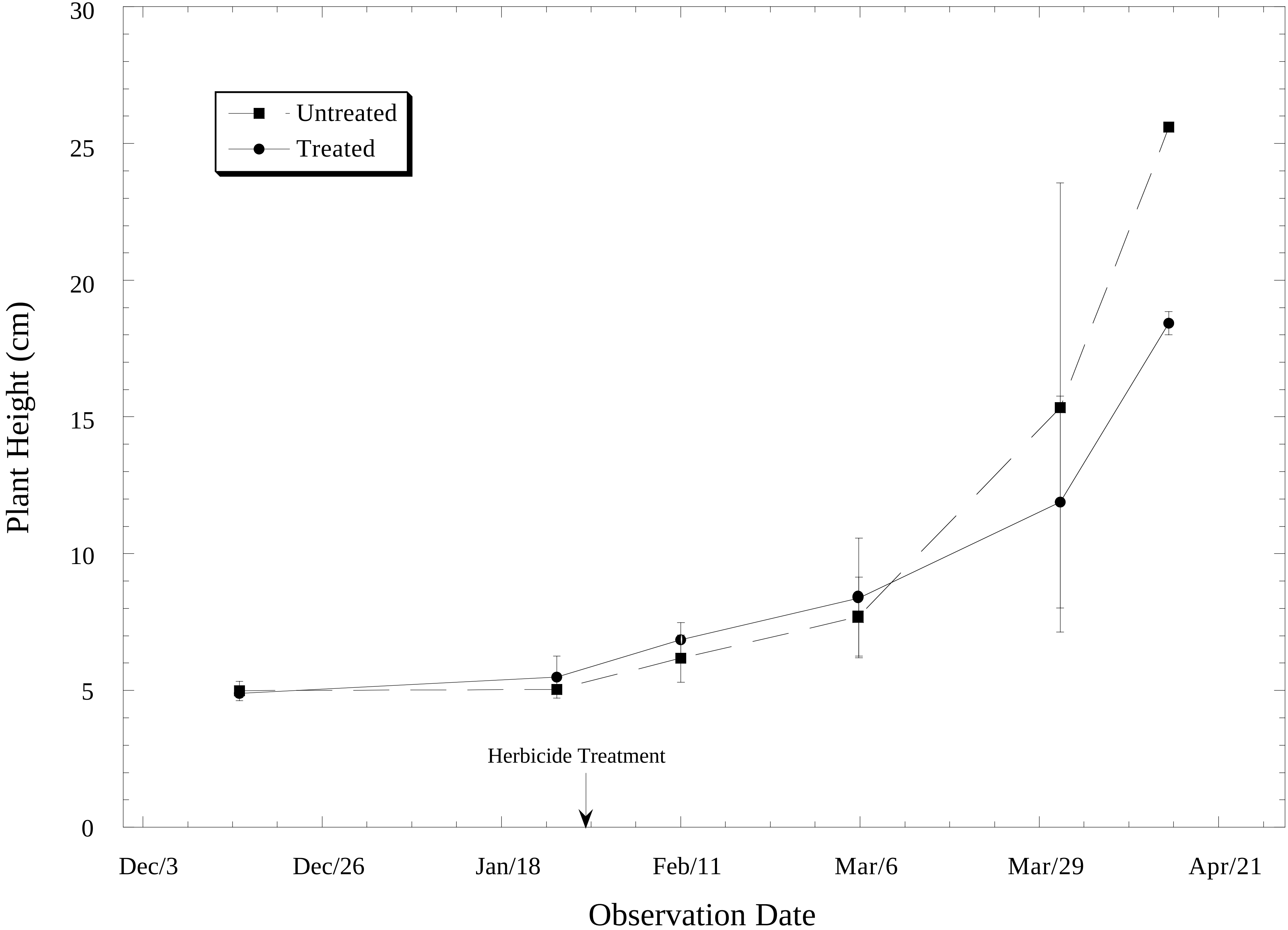

Figure 10. Mean height of *A. grandiflora* plants marked on 11 Dec 1997. Bars represent one standard error, n=3.

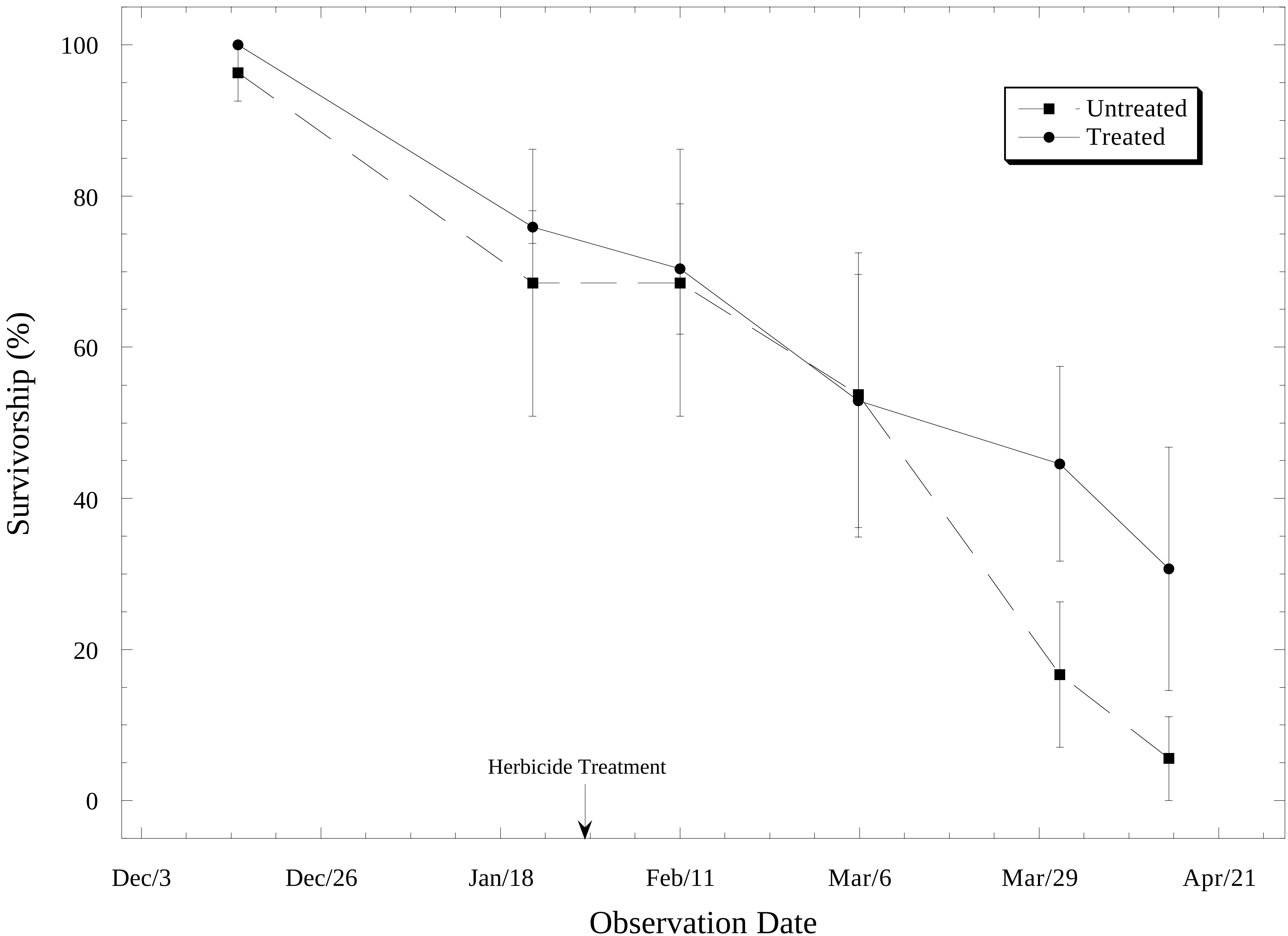

Figure 11. Survivorship of *A. grandiflora* plants marked on 11 Dec 1997. Bars represent one standard error, n=3.

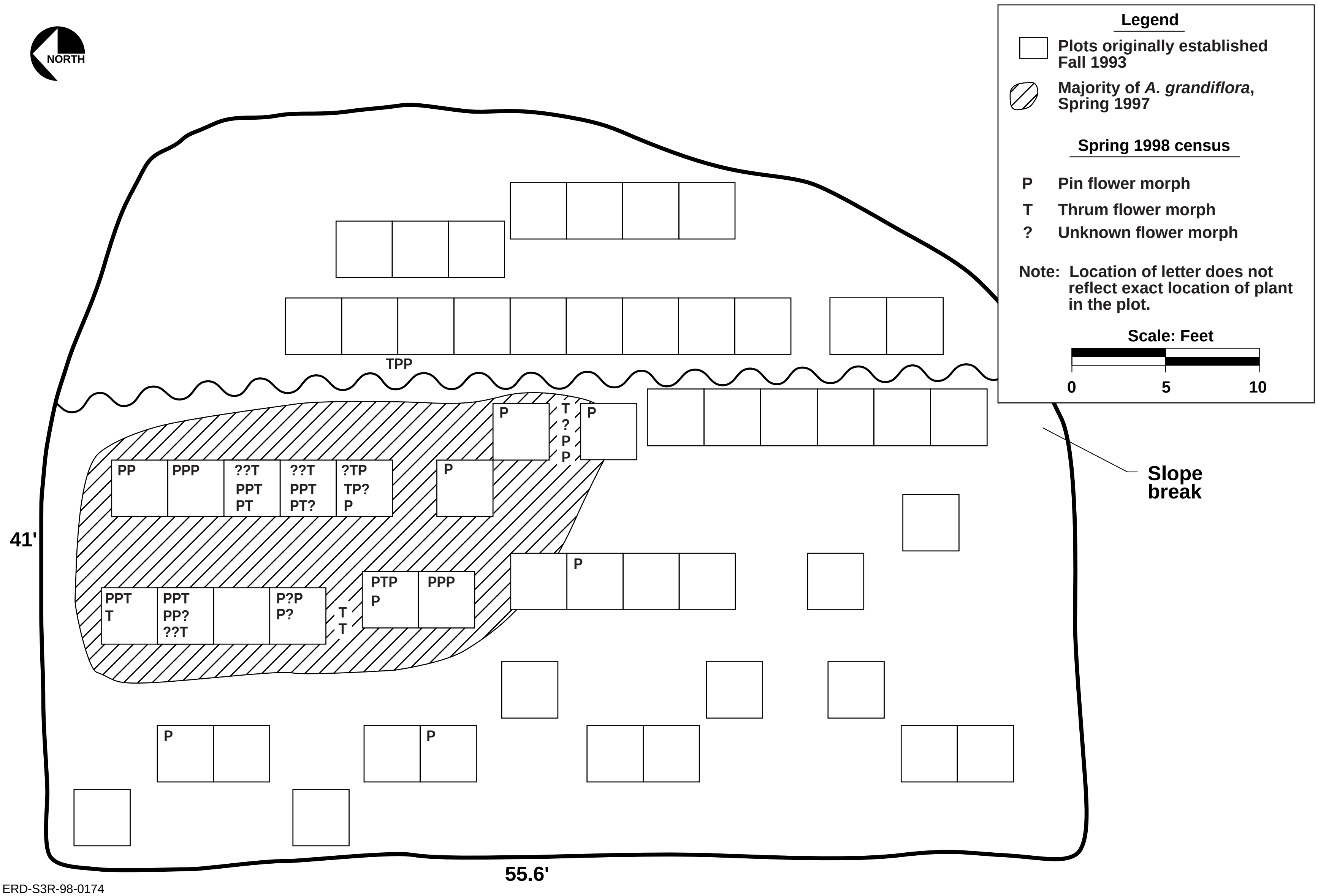

Figure 12. Spring (April 15, 1998) census of experimental treatments at the *A. grandiflora* experimental population.

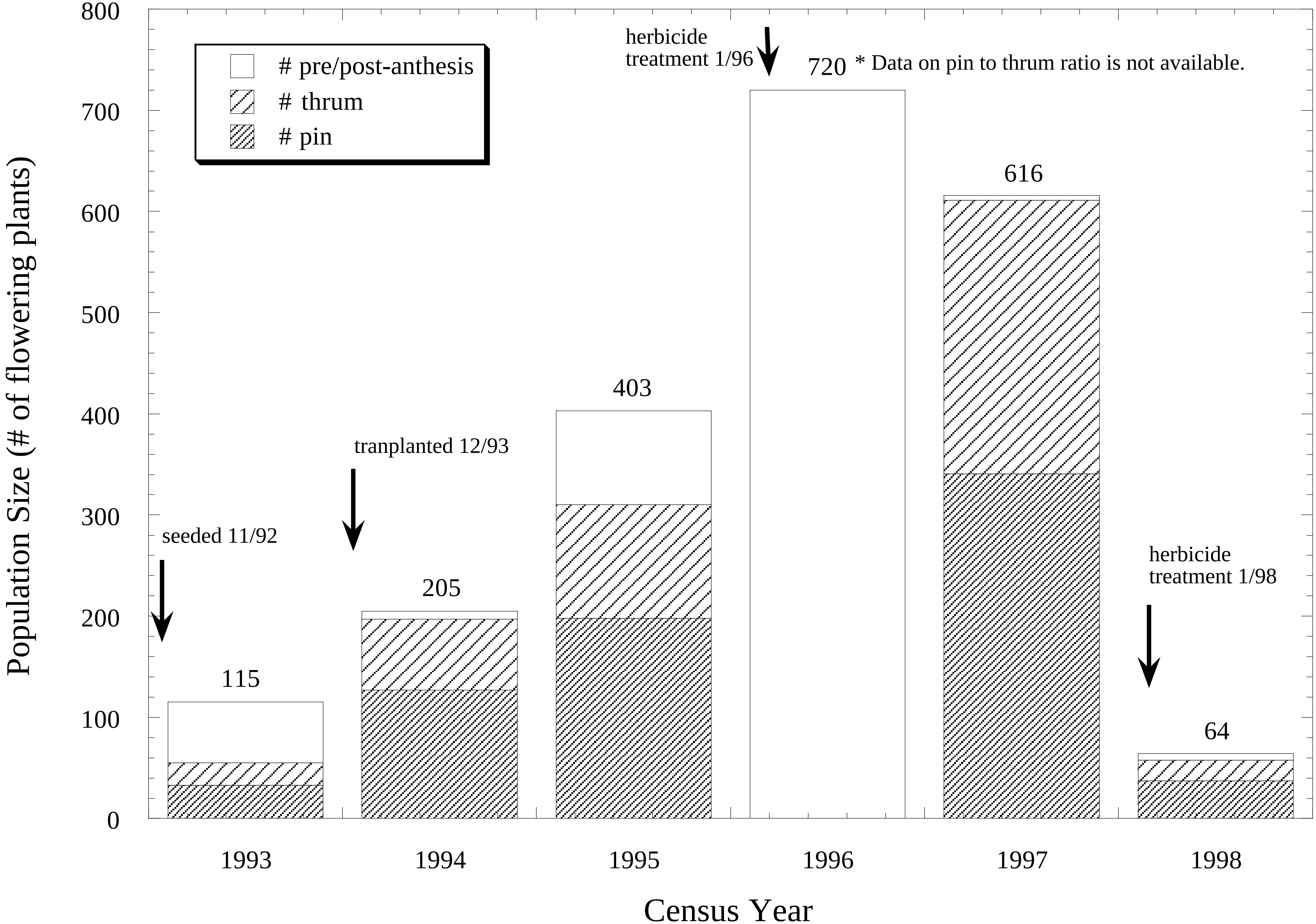

Figure 13. Historical spring census data of the Site 300 experimental Drop Tower population. Total population size is given above each bar. Approximate timing of herbicide treatments as well as seeding and transplanting efforts is shown.

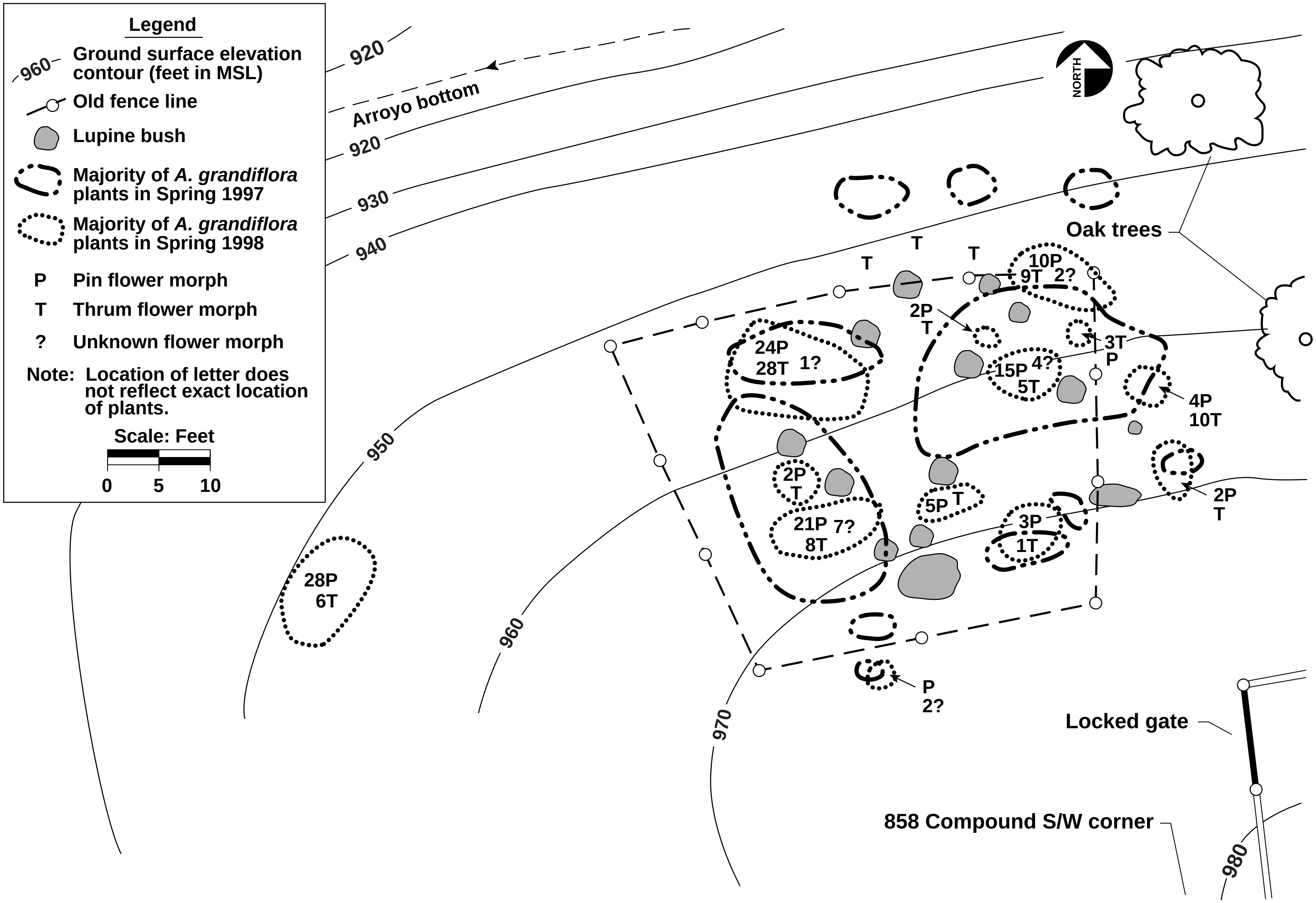

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Figure 14. Spring (April 15, 1998) census of the *A. grandiflora* native population at the Building 858 Drop Tower.

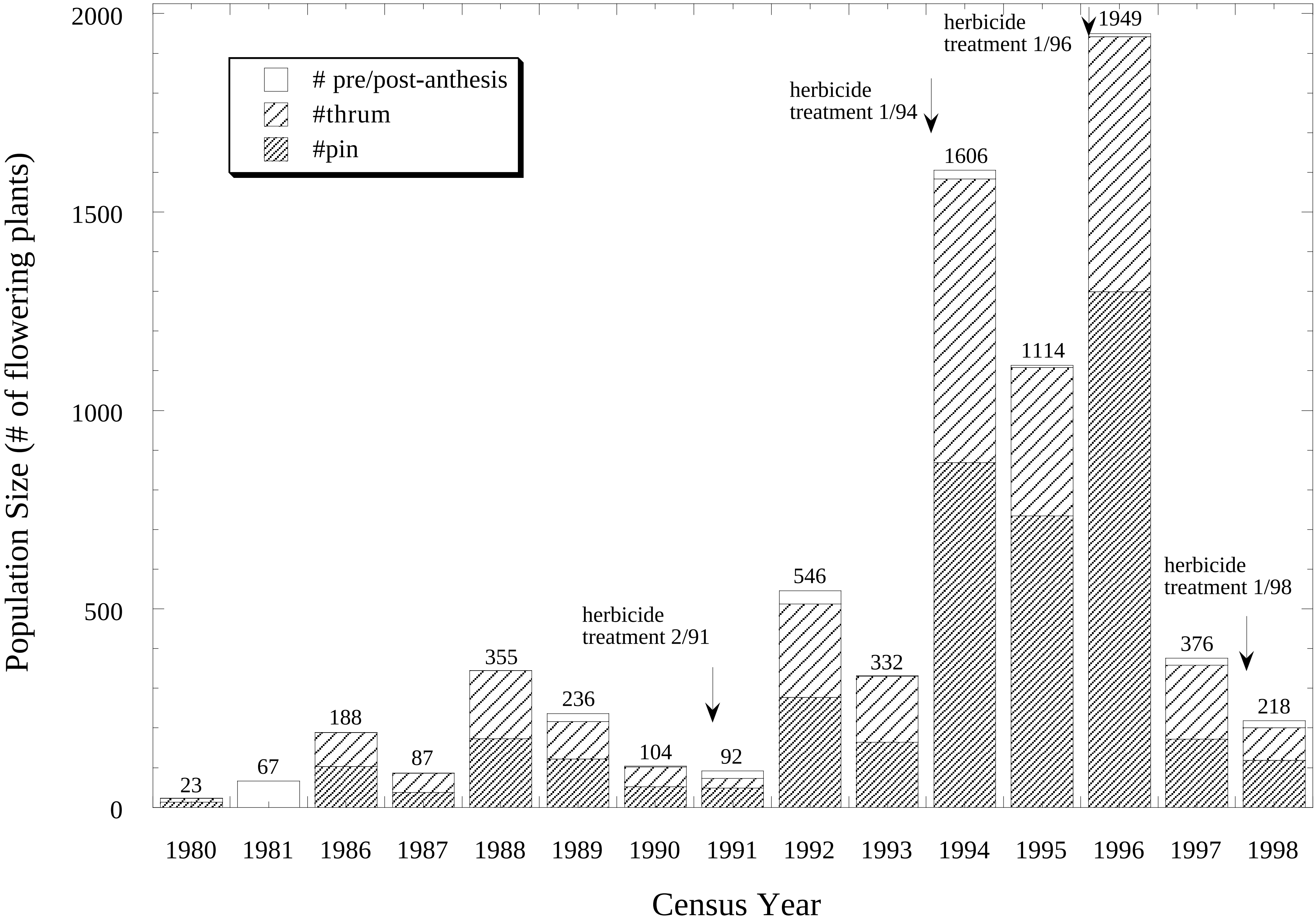
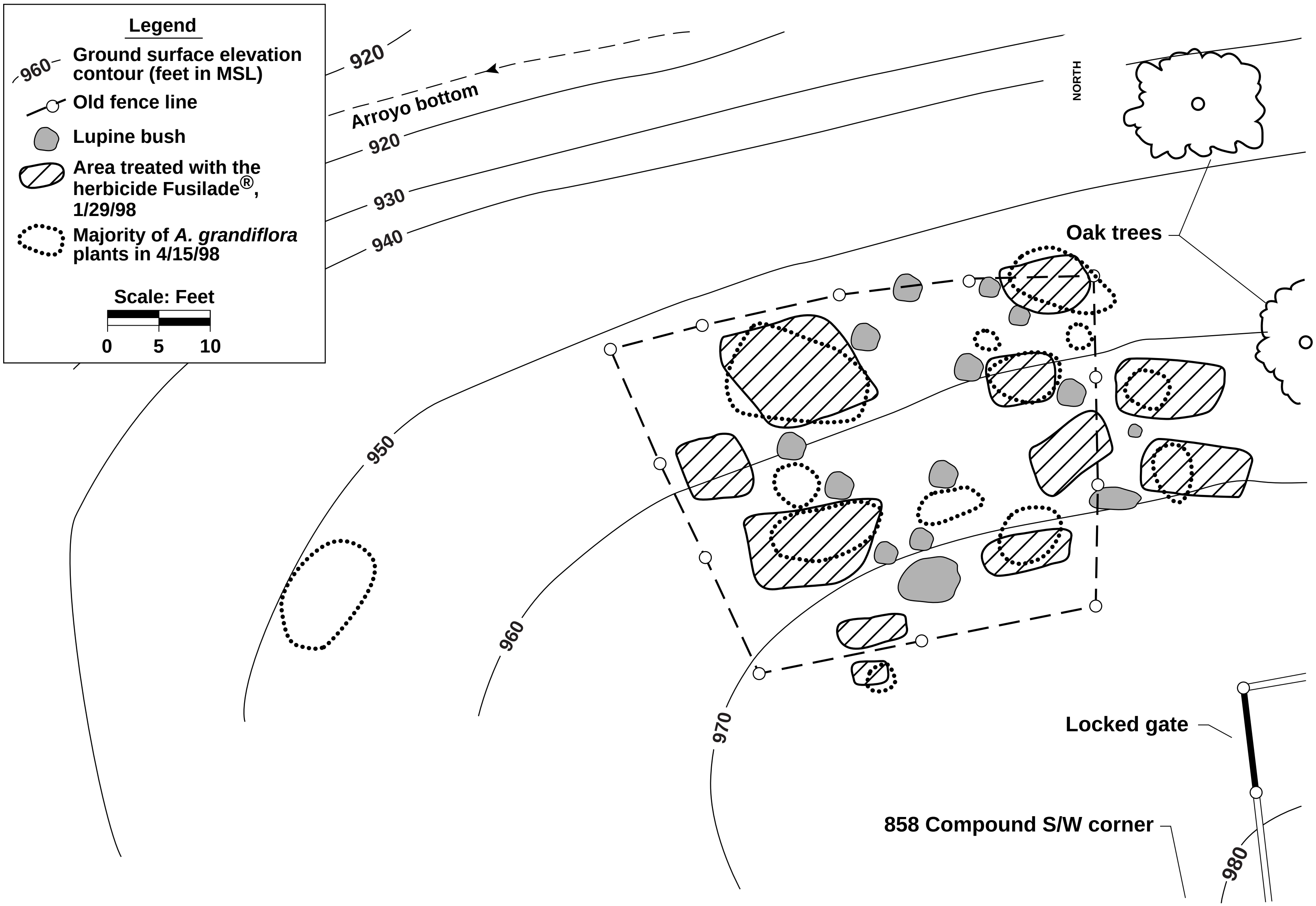


Figure 15. Historical spring census data of the Site 300 native Drop Tower population. Total population size is given above each bar. Approximate timing of herbicide treatments to reduce competition from annual grasses is shown.



ERD-S3R-98-0176

Figure 16. Location of *A. grandiflora* plants in Spring 1998 at the native population at Building 858 in comparison to area treated with herbicide on 1/29/98.

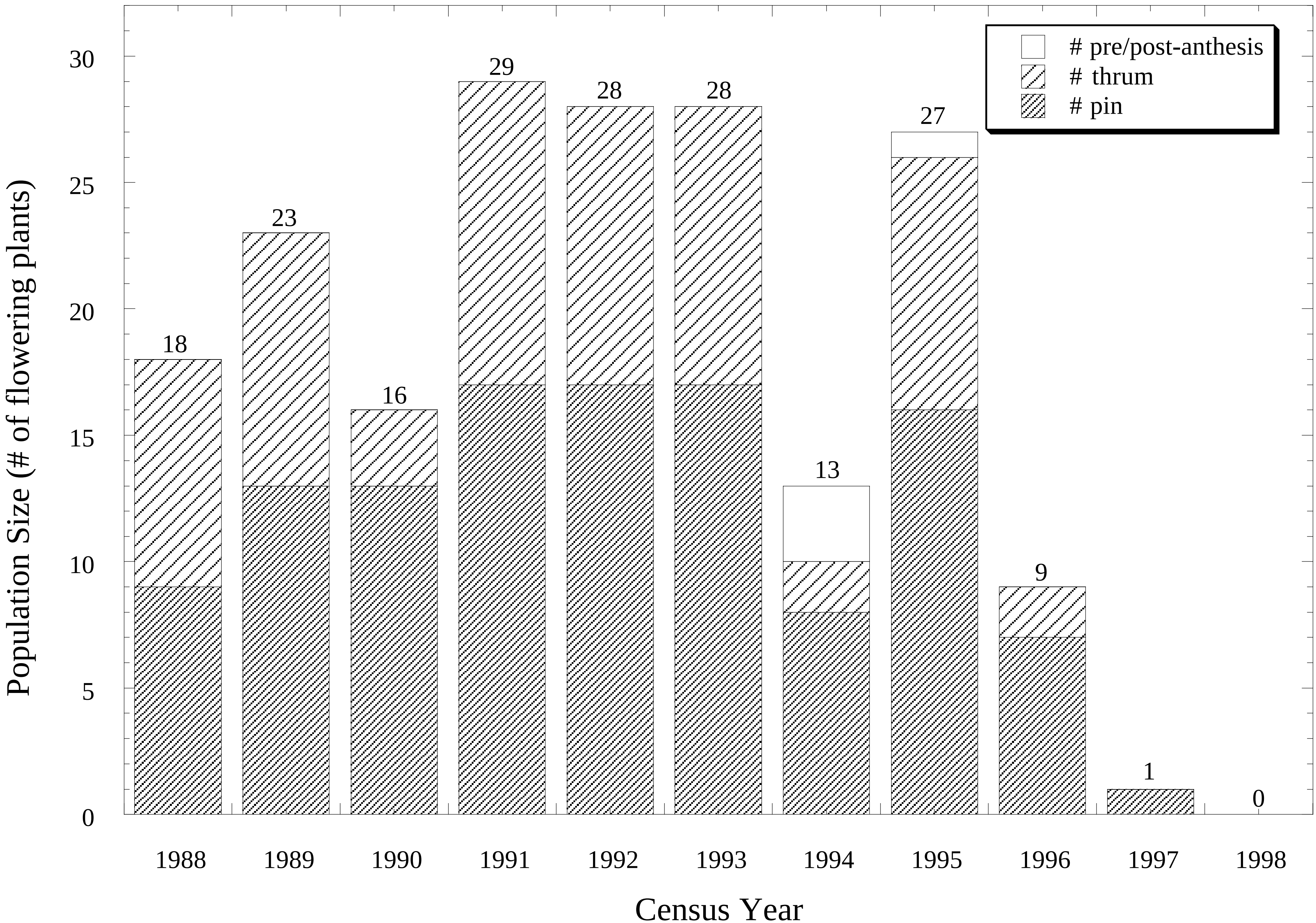


Figure 17. Historical spring census data of the Site 300 Draney Canyon population. Total population size is given above each bar. This population was not subject to herbicide treatments or any other management efforts.

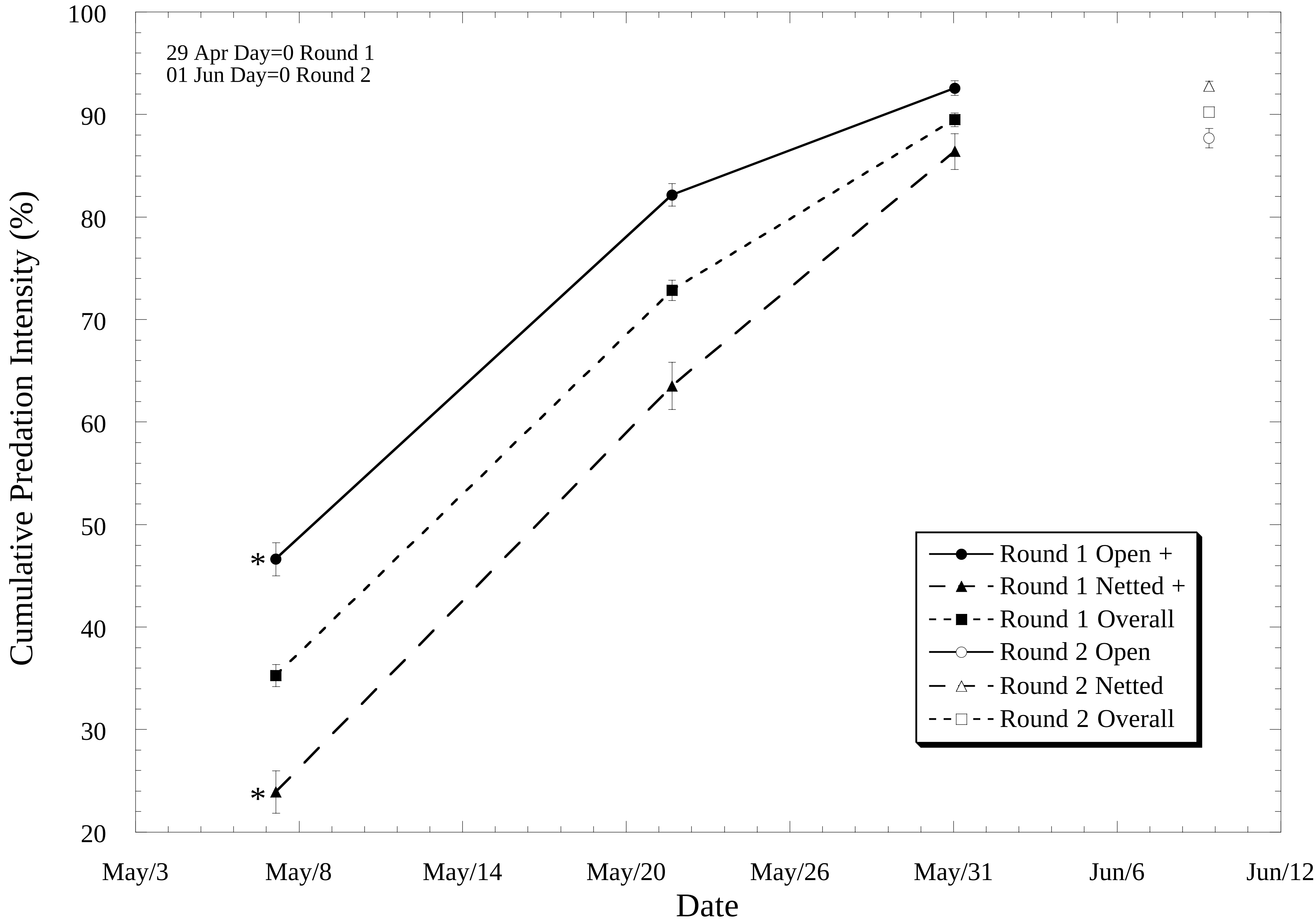


Figure 18. Cumulative predation intensity (% nutlets removed from total nutlet stock) by round and treatment at the Drop Tower experimental population, phase 1. Bars represent one standard error, n=10 for open and netted values, n=20 for overall values. Data points marked with * are significantly different at $p<0.05$ for that observation date. Treatments marked with + are significantly different at $p<0.05$ overall.

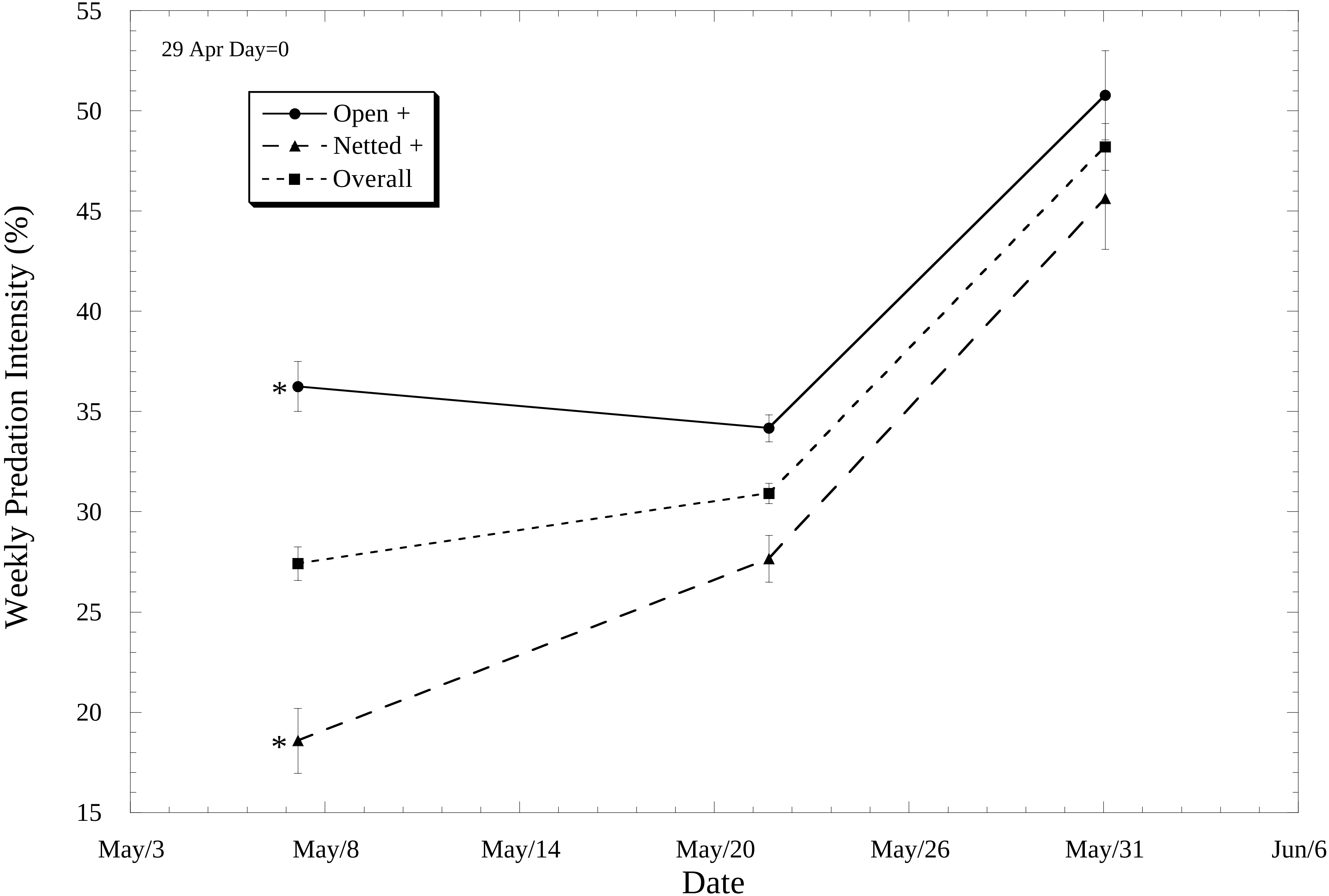


Figure 19. Weekly predation intensity (% nutlets removed per week from remaining nutlet stock) by treatment at the Site 300 Drop Tower experimental population, phase 1, round 1. Bars represent one standard error, n=10 for open and netted values, n=20 for overall values. Data points marked with * are significantly different at p<0.05 for that observation date. Treatments marked with + are significantly different at p<0.05 overall.

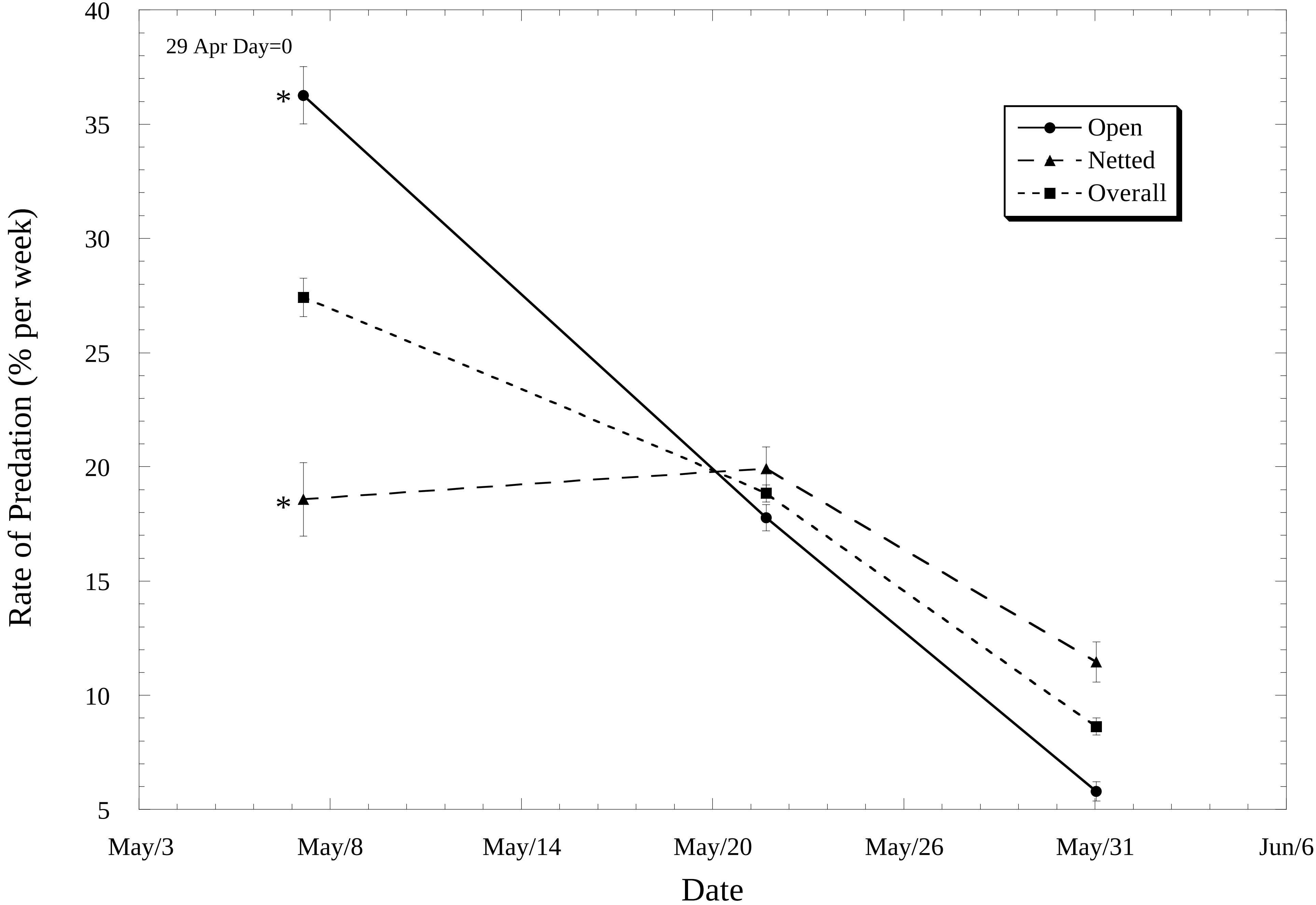


Figure 20. Weekly rate of predation (actual % nutlets removed per week from total nutlet stock) by treatment at the Site 300 Drop Tower experimental population, phase 1, round 1. Bars represent one standard error, n=10 for open and netted values, n=20 for overall values. Data points marked with * are significantly different at $p<0.05$ for that observation date.

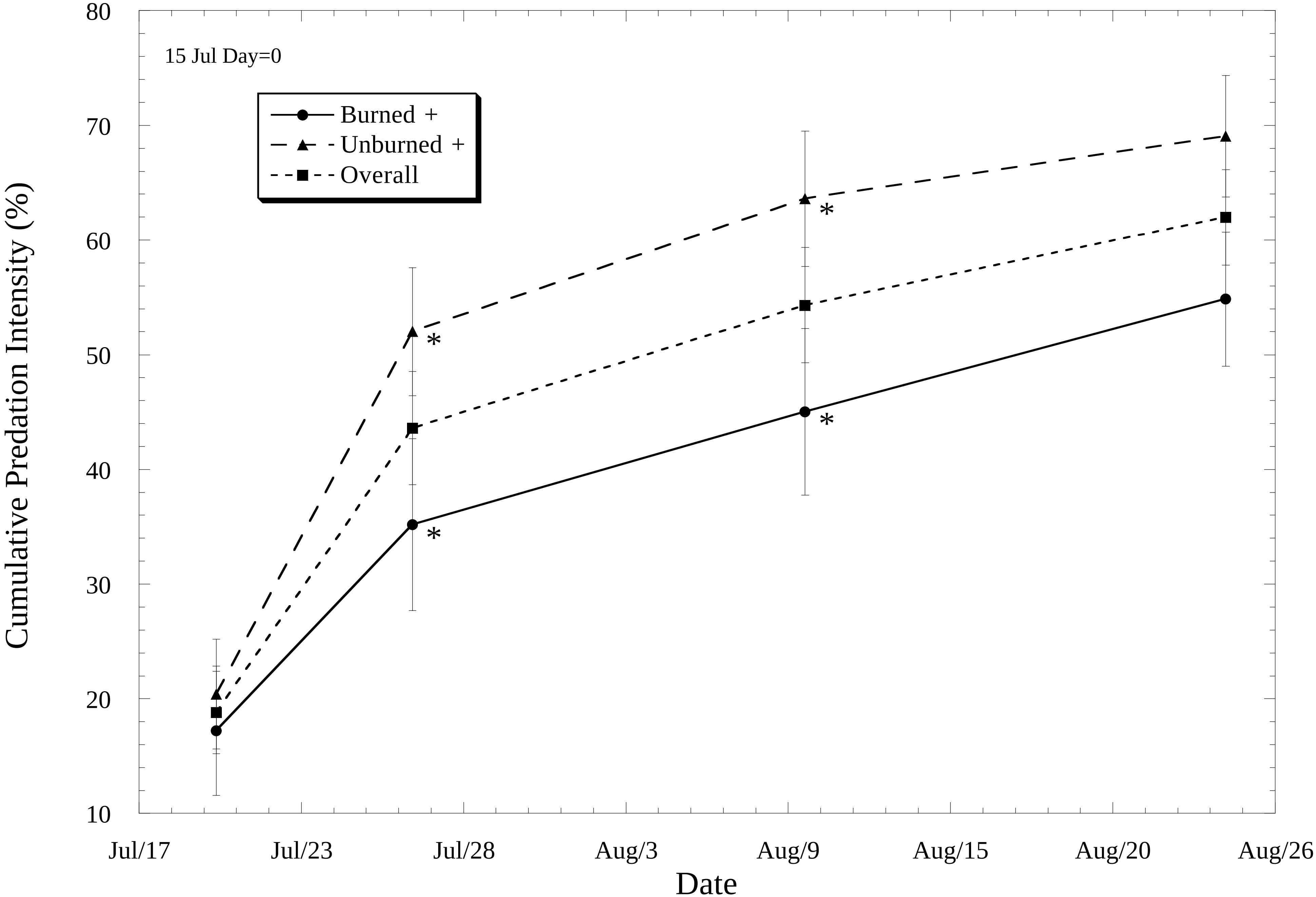


Figure 21. Cumulative predation intensity (% nutlets removed from total nutlet stock) by burn status at the Site 300 Drop Tower experimental population, phase 2. Bars represent one standard error, n=10 for burned and unburned values, n=20 for overall values. Data points marked with * are significantly different at $p<0.05$ for that observation date. Treatments marked with + are significantly different at $p<0.05$ overall.

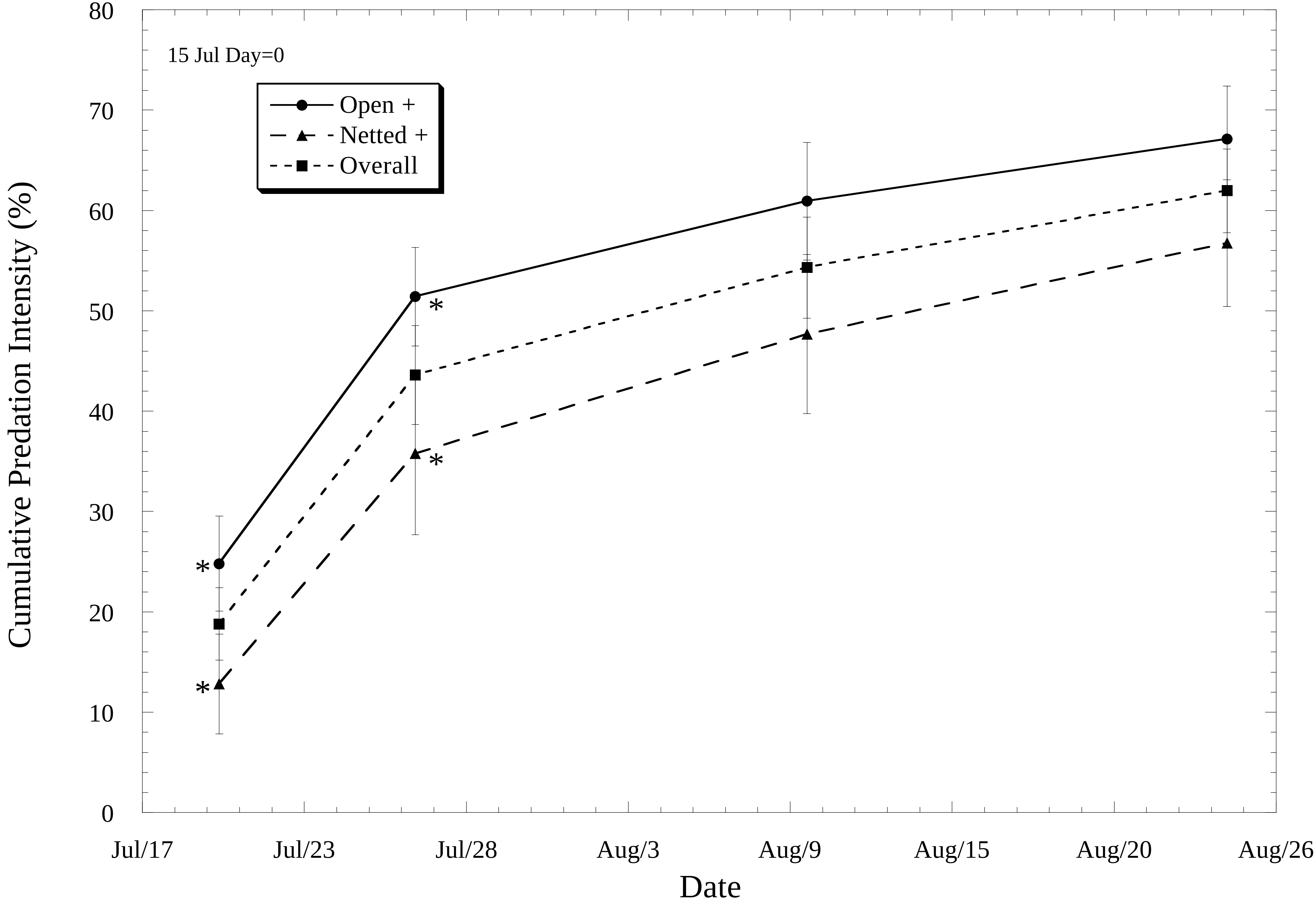


Figure 22. Cumulative predation intensity (% nutlets removed from total nutlet stock) by treatment at the Site 300 Drop Tower experimental population, phase 2. Bars represent one standard error, n=10 for open and netted values, n=20 for overall values. Data points marked with * are significantly different at $p<0.05$ for that observation date. Treatments marked with + are significantly different at $p<0.05$ overall.

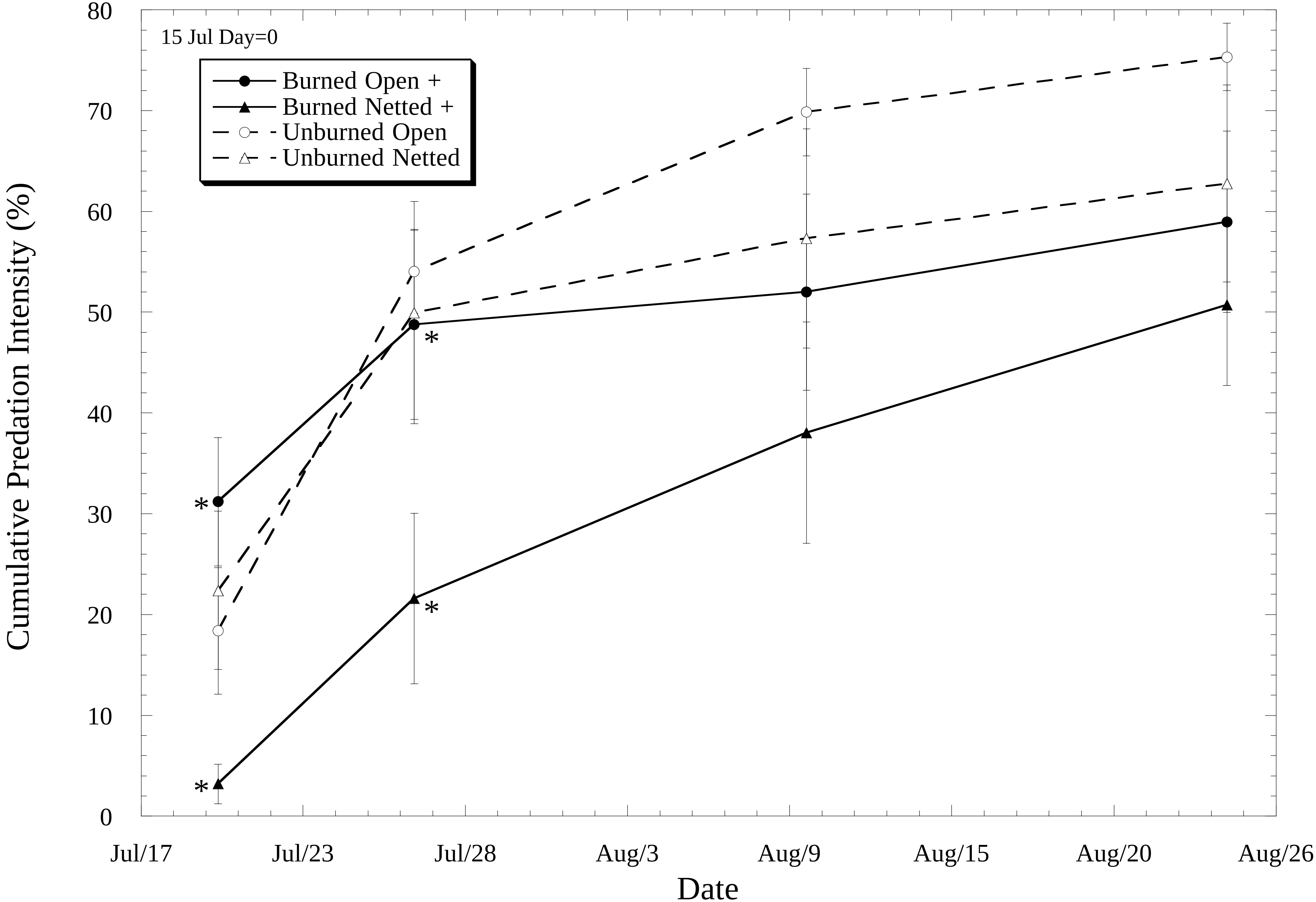


Figure 23. Cumulative predation intensity (% nutlets removed from total nutlet stock) by treatment in the burned versus unburned plots at the Site 300 Drop Tower experimental population, phase 2. Bars represent one standard error, n=5. Data points marked with * are significantly different at $p<0.05$ for that observation date. Treatments marked with + are significantly different a $p<0.05$ overall.

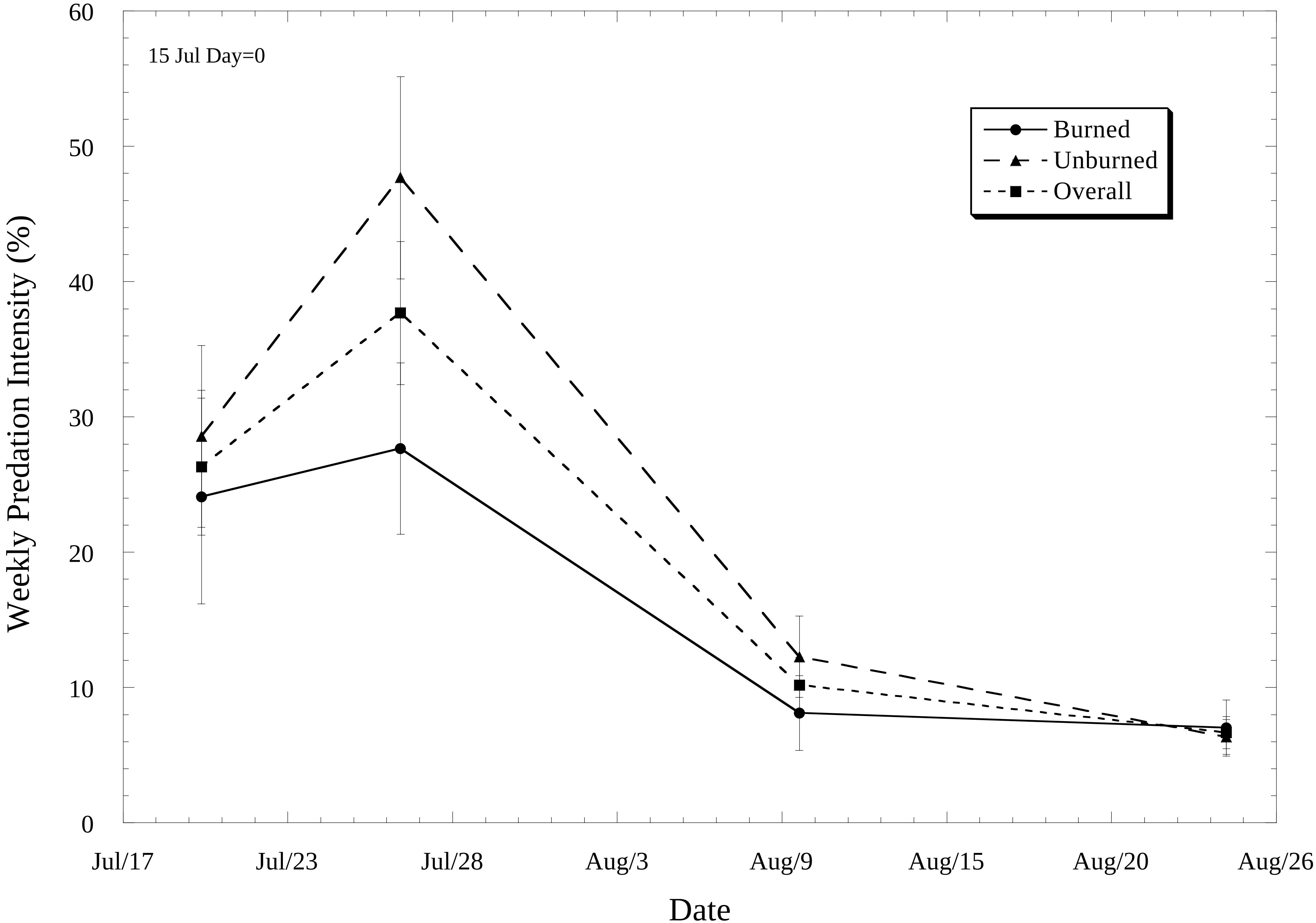


Figure 24. Weekly predation intensity (% nutlets removed per week from remaining nutlet stock) by burn status at the Site 300 Drop Tower experimental population, phase 2. Bars represent one standard error, n=10 for burned and unburned values, n=20 for overall values.

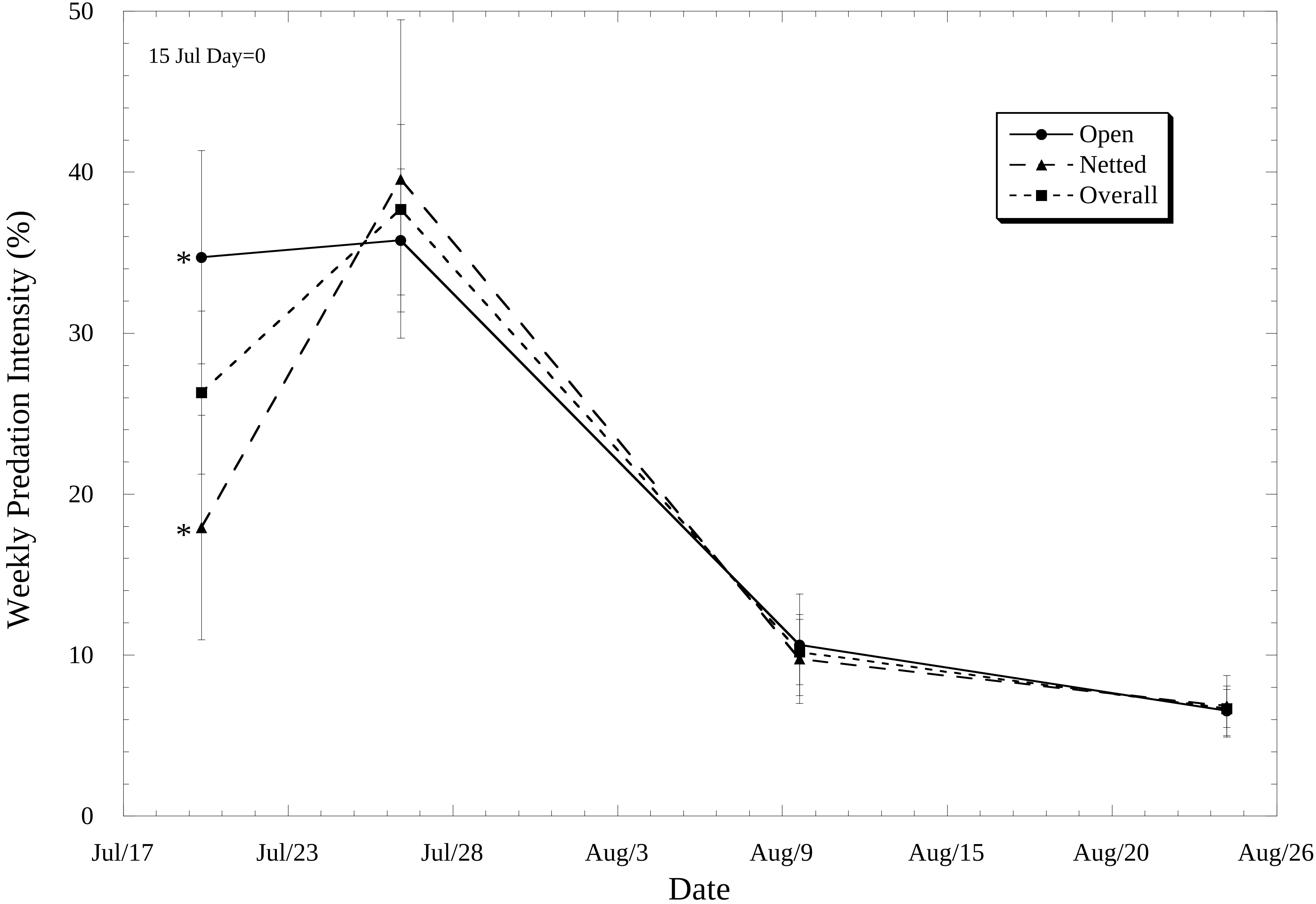


Figure 25. Weekly predation intensity (% nutlets removed per week from remaining nutlet stock) by treatment at the Site 300 Drop Tower experimental population, phase 2. Bars represent one standard error, n=10 for open and netted values, n=20 for overall values. Data points marked with * are significantly different at $p<0.05$ for that observation date.

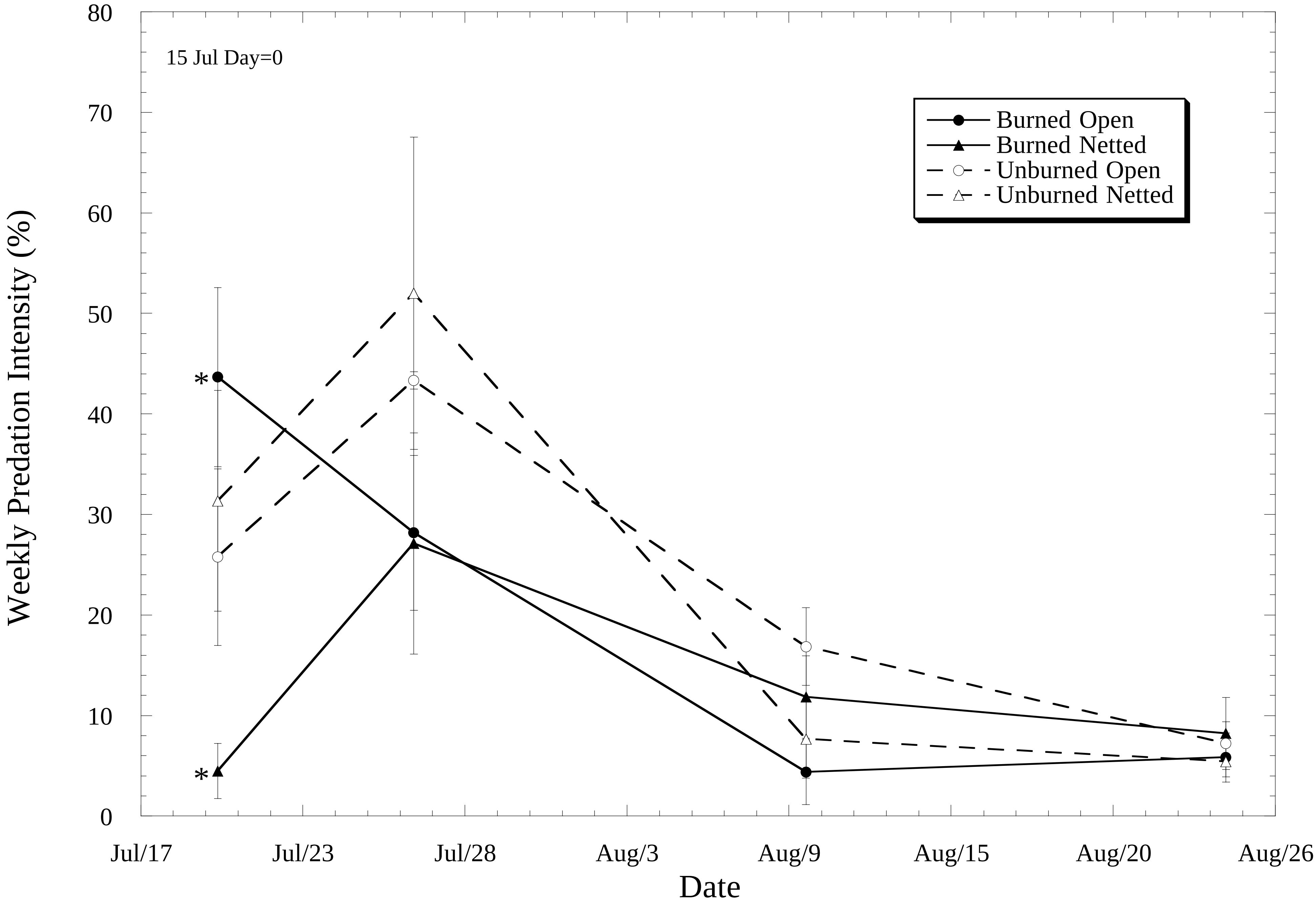


Figure 26. Weekly predation intensity (% nutlets removed per week from remaining nutlet stock) by treatment in the burned versus unburned plots at the Site 300 Drop Tower experimental population, phase 2. Bars represent one standard error, n=5. Data points marked with * are significantly different at $p<0.05$ for that observation date.

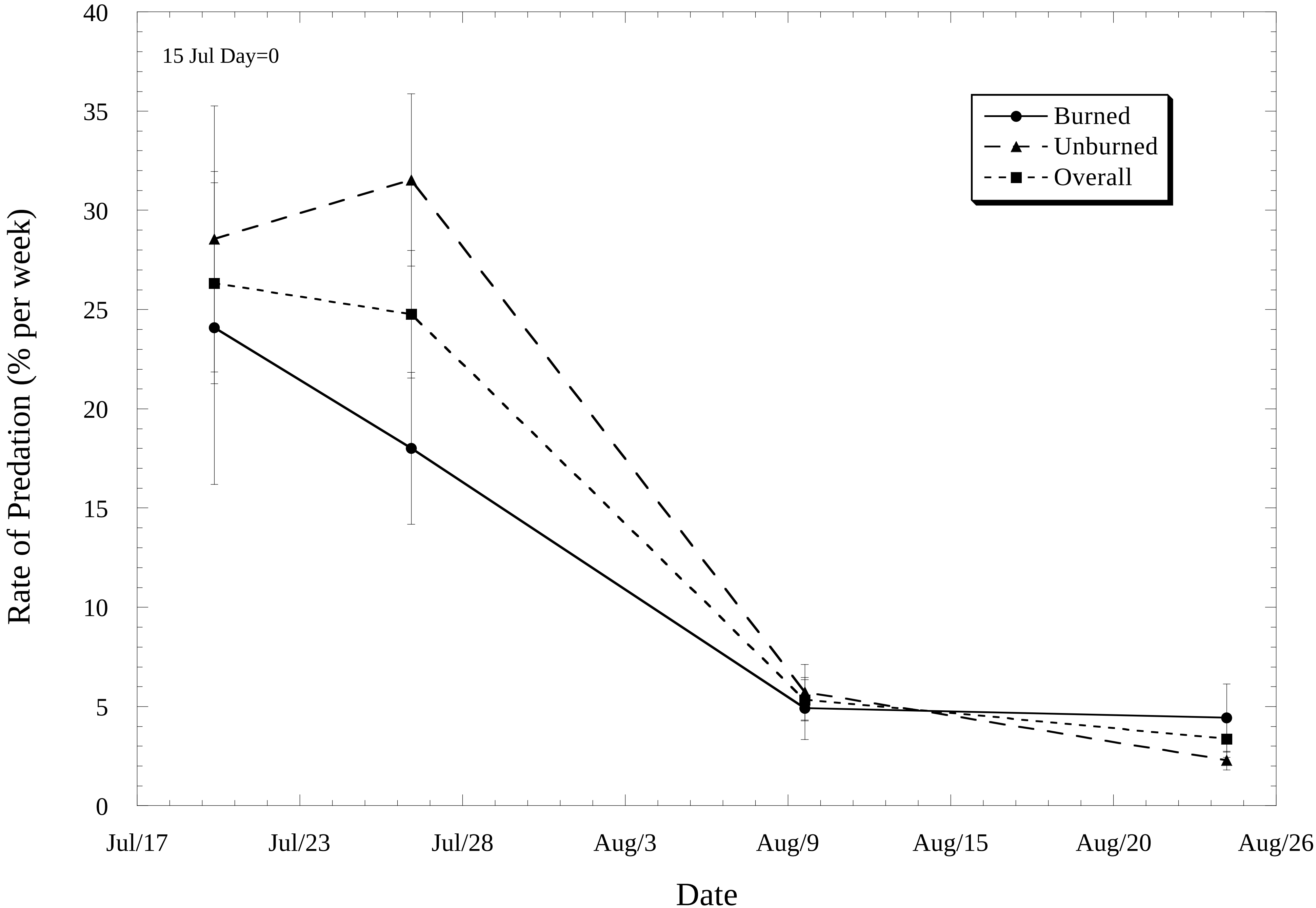


Figure 27. Weekly rate of predation (actual % nutlets removed per week from total nutlet stock) by burn status at the Site 300 Drop Tower experimental population, phase 2. Bars represent one standard error, n=10 for burned and unburned values, n=20 for overall values.

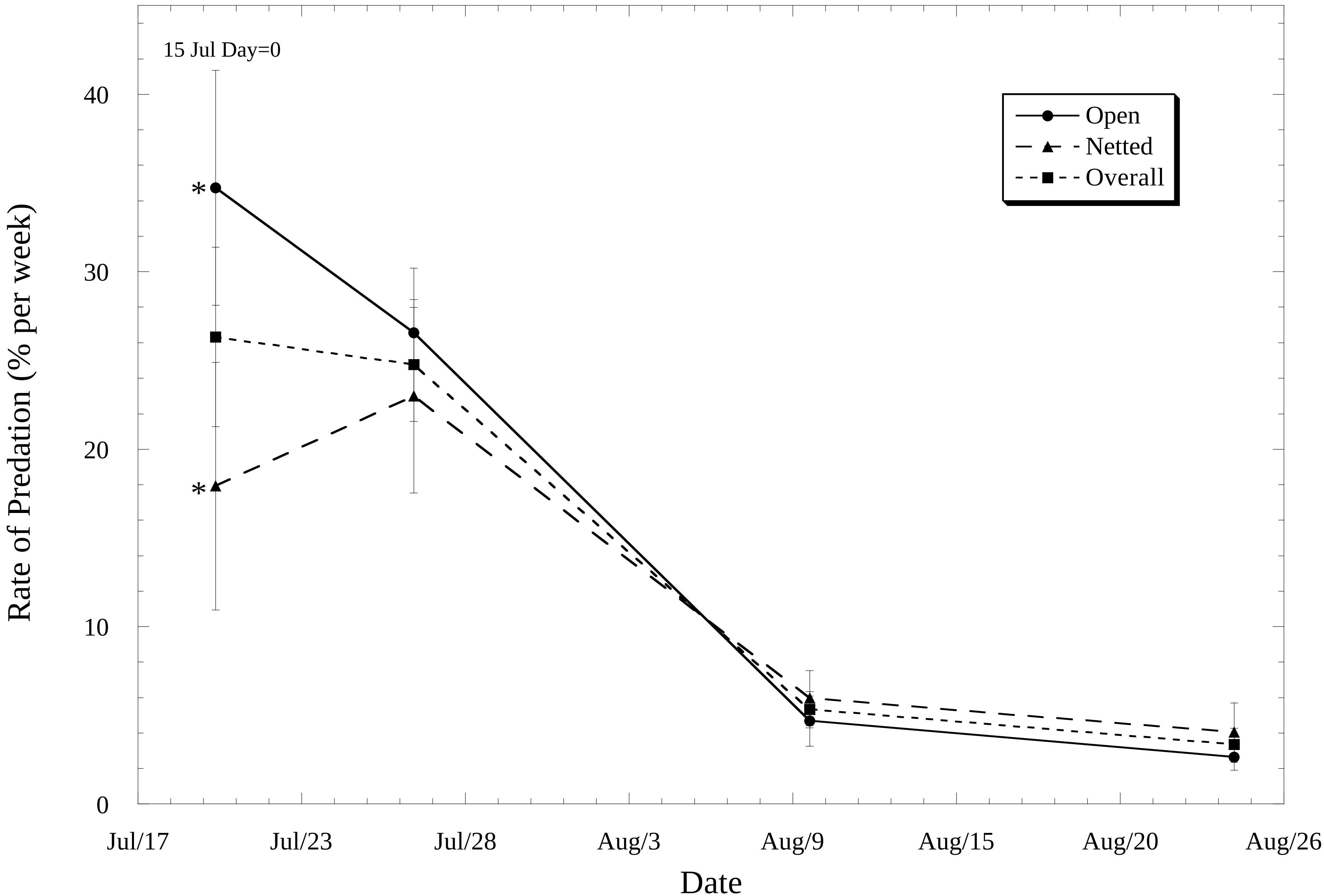


Figure 28. Weekly rate of predation (actual % nutlets removed per week from total nutlet stock) by treatment at the Site 300 Drop Tower experimental population, phase 2. Bars represent one standard error, n=10 for open and netted values, n=20 for overall values. Data points marked with * are significantly different at $p<0.05$ for that observation date.

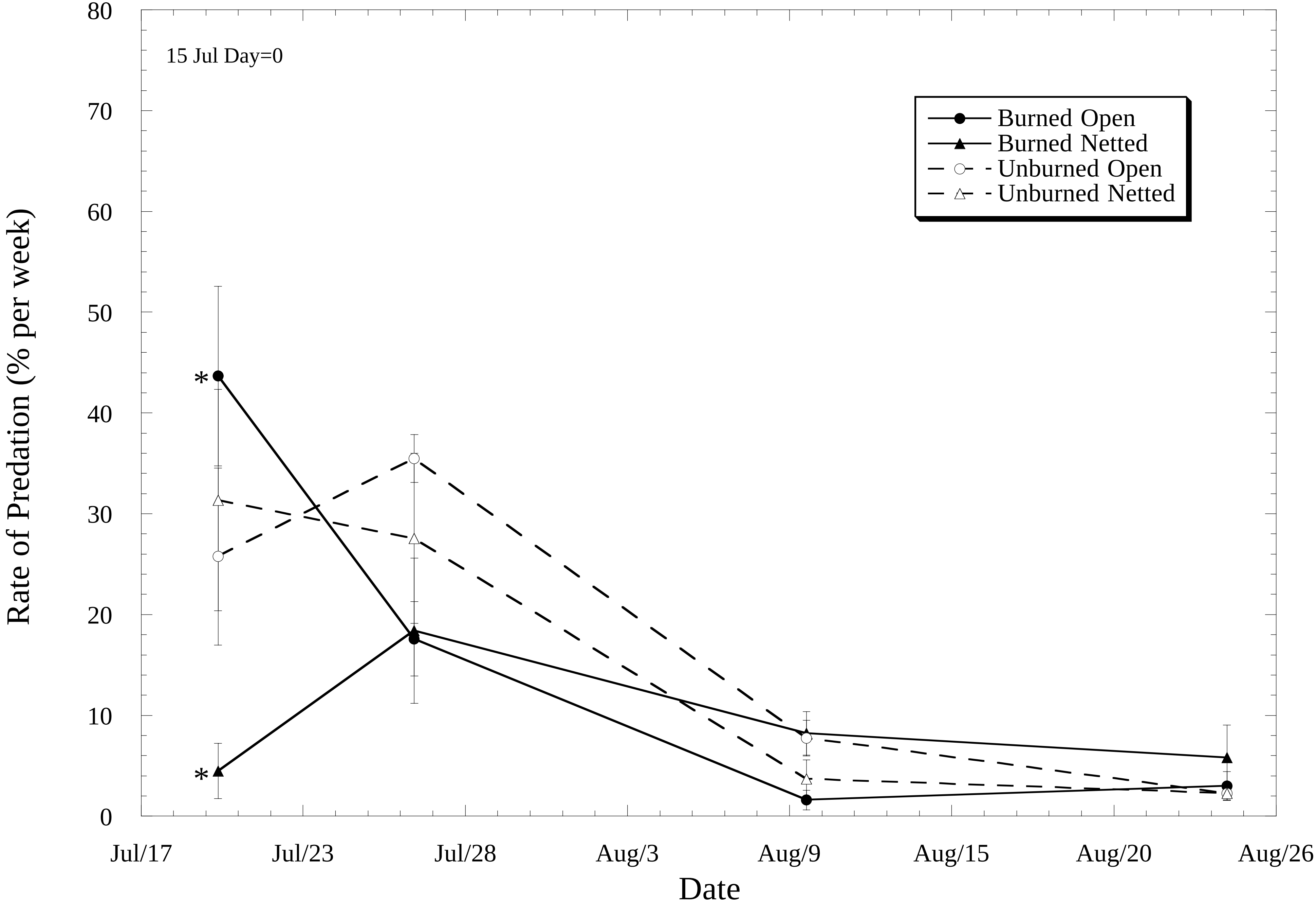


Figure 29. Weekly rate of predation (actual % nutlets removed per week from total nutlet stock) by treatment in the burned versus unburned plots at the Site 300 Drop Tower experimental population, phase 2. Bars represent one standard error, n=5. Data points marked with * are significantly different at $p<0.05$ for that observation date.

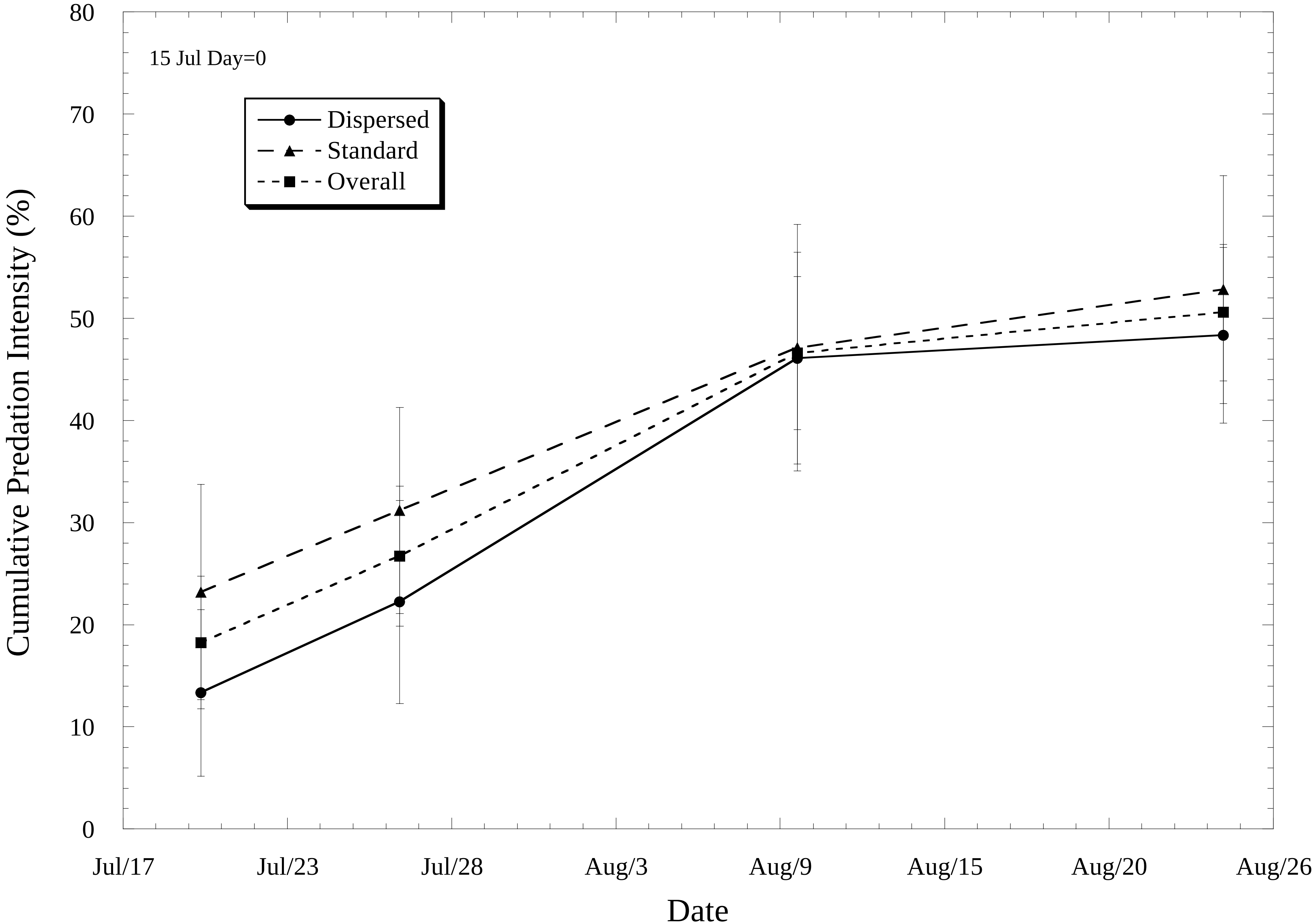


Figure 30. Cumulative predation intensity (% nutlets removed from total nutlet stock) by treatment at the Site 300 Drop Tower native population, phase 2. Bars represent one standard error, n=5 for standard and dispersed values, n=10 for overall values.

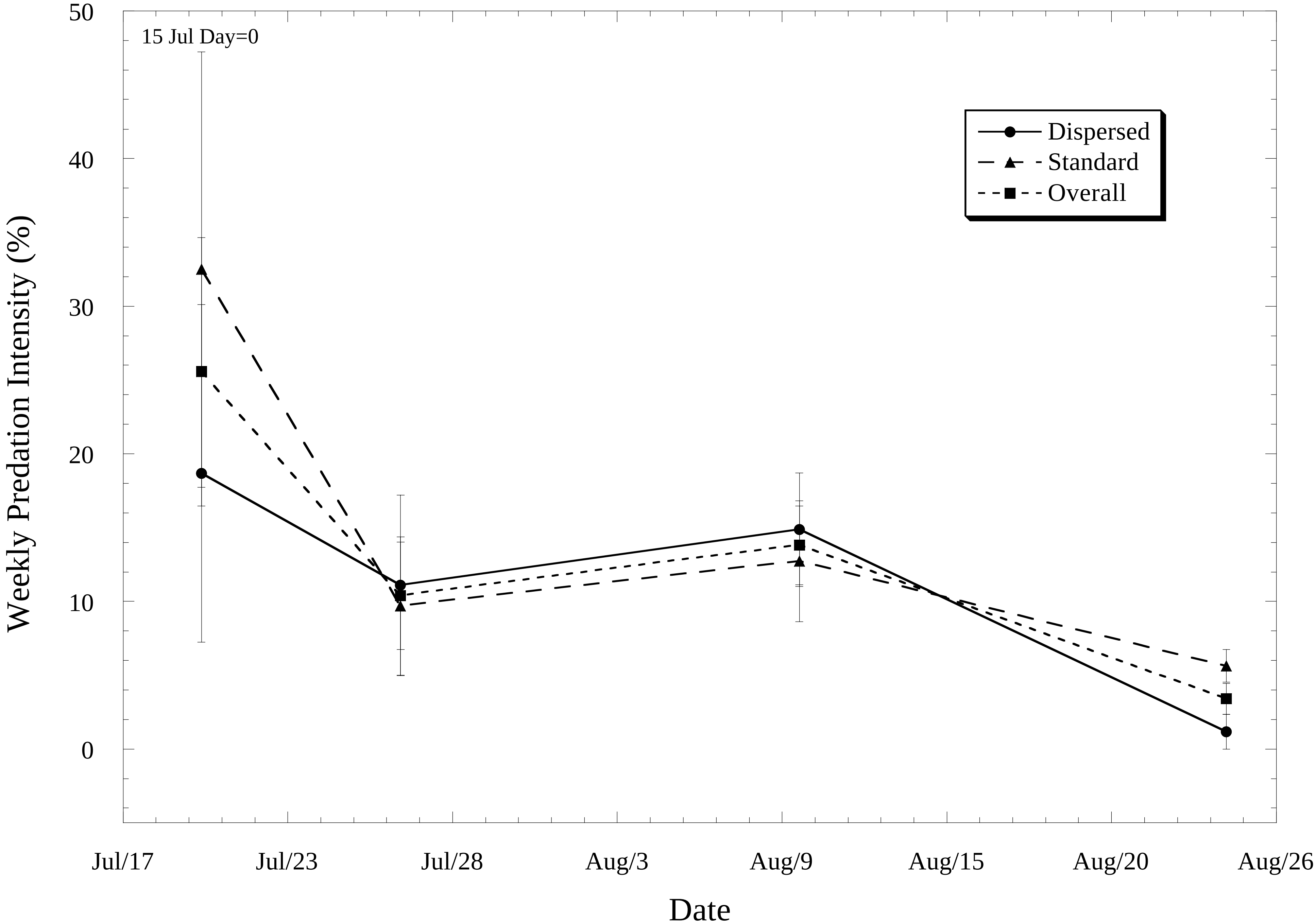


Figure 31. Weekly predation intensity (% nutlets removed per week from remaining nutlet stock) by treatment at the Site 300 Drop Tower native population, phase 2. Bars represent one standard error, n=5 for standard and dispersed values, n=10 for overall values.

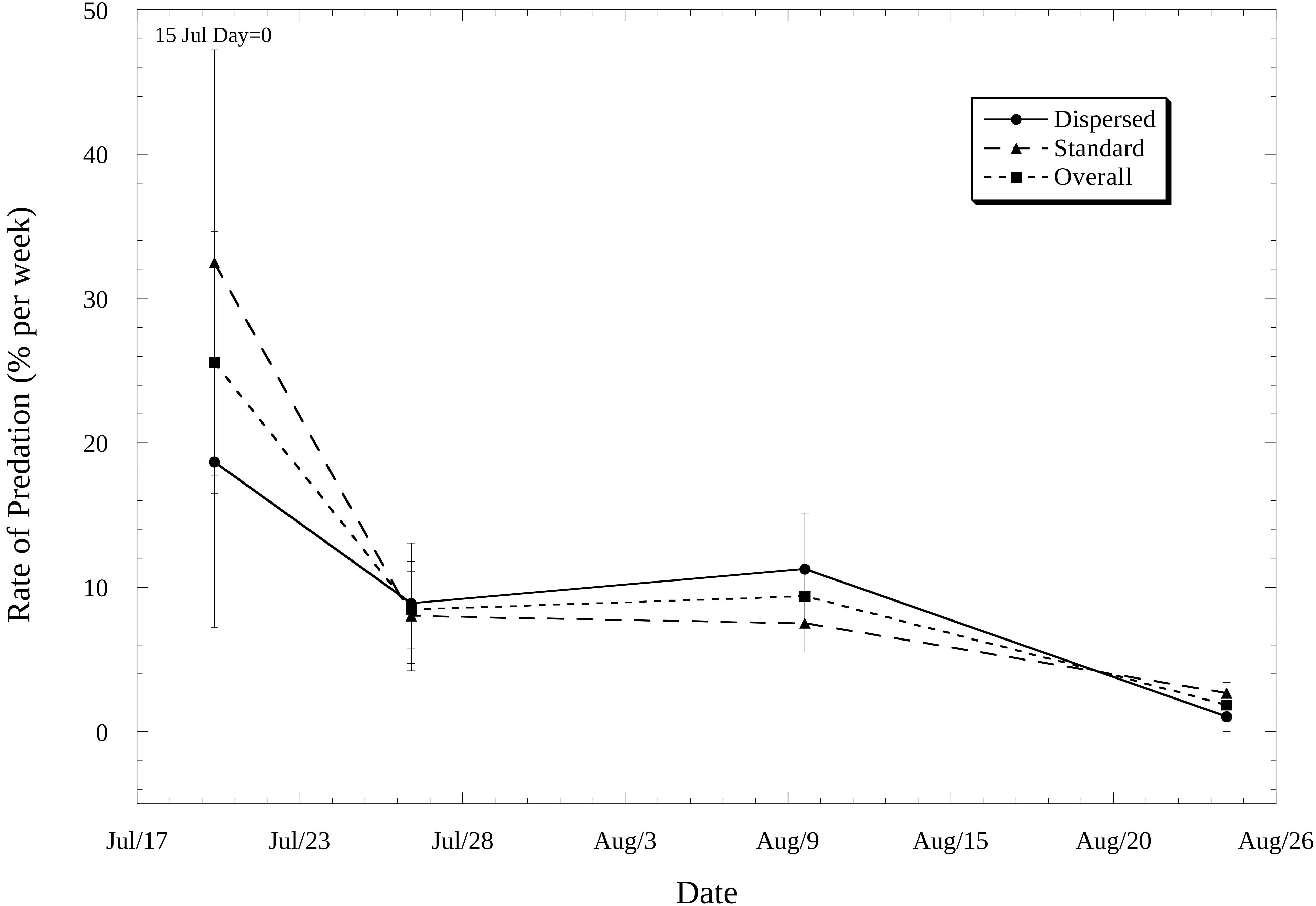


Figure 32. Weekly rate of predation (actual % nutlets removed per week from total nutlet stock) by treatment at the Site 300 Drop Tower native population, phase 2. Bars represent one standard error, n=5 for standard and dispersed values, n=10 for overall values.

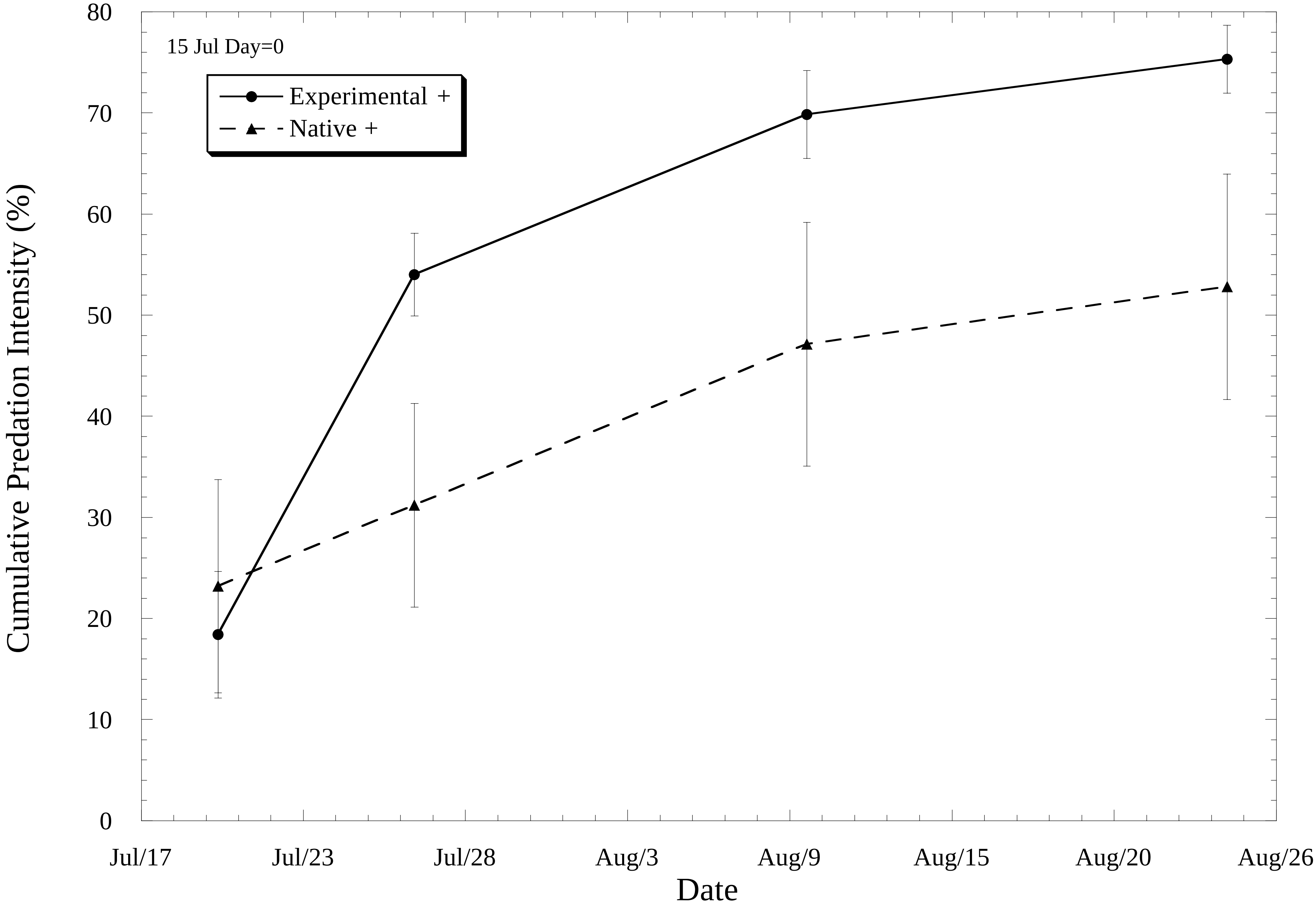


Figure 33. Cumulative predation intensity (% nutlets removed from total nutlet stock) in the unburned, standard plots at the Site 300 Drop Tower experimental and native populations, phase 2. Bars represent one standard error, n=5. Treatments marked with + are significantly different at $p<0.05$ overall.

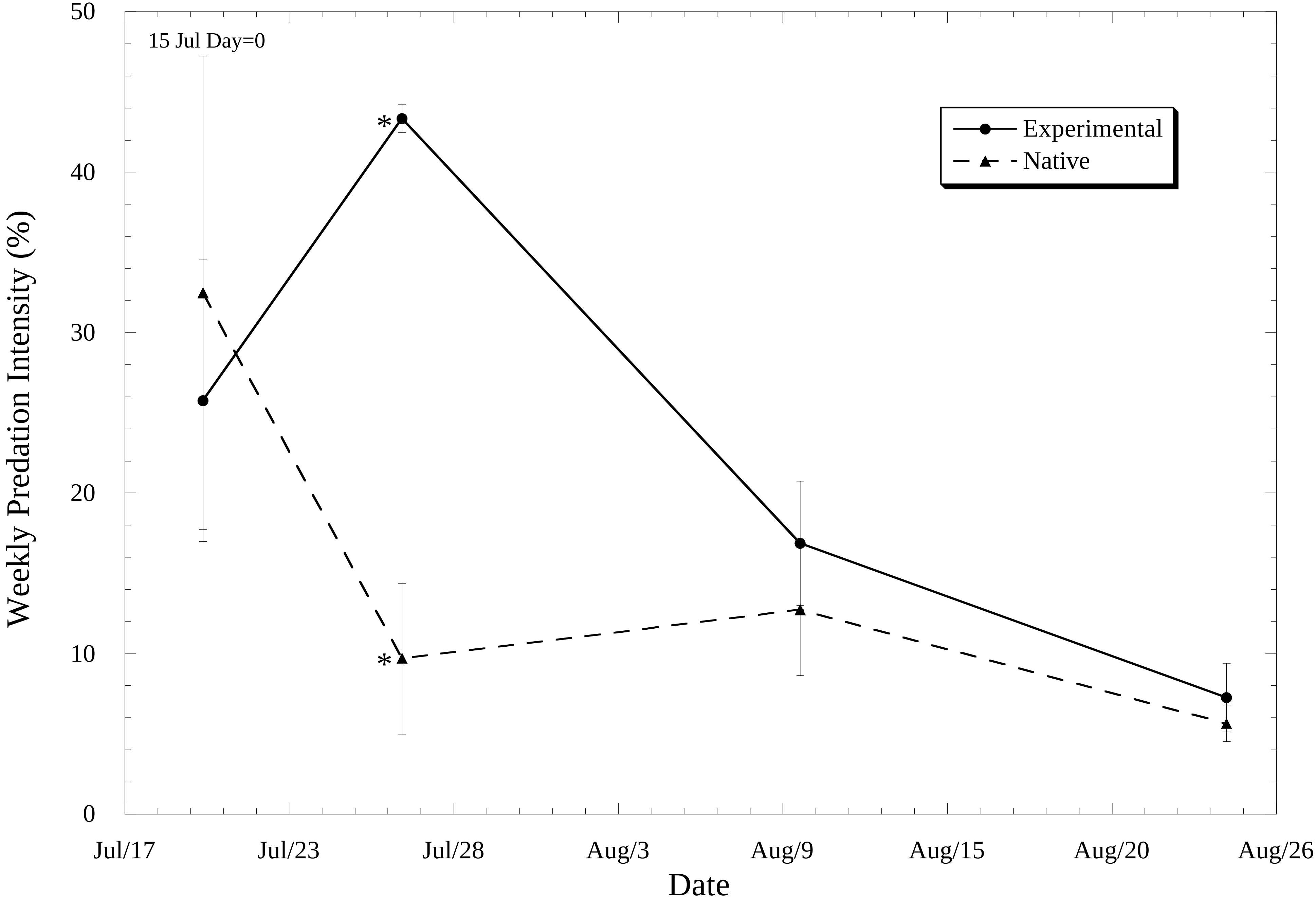


Figure 34. Weekly predation intensity (% nutlets removed per week from remaining nutlet stock) in the unburned, standard plots at the Site 300 Drop Tower experimental and native populations, phase 2. Bars represent one standard error, n=5. Data points marked with * are significantly different at p<0.05 for that observation date.

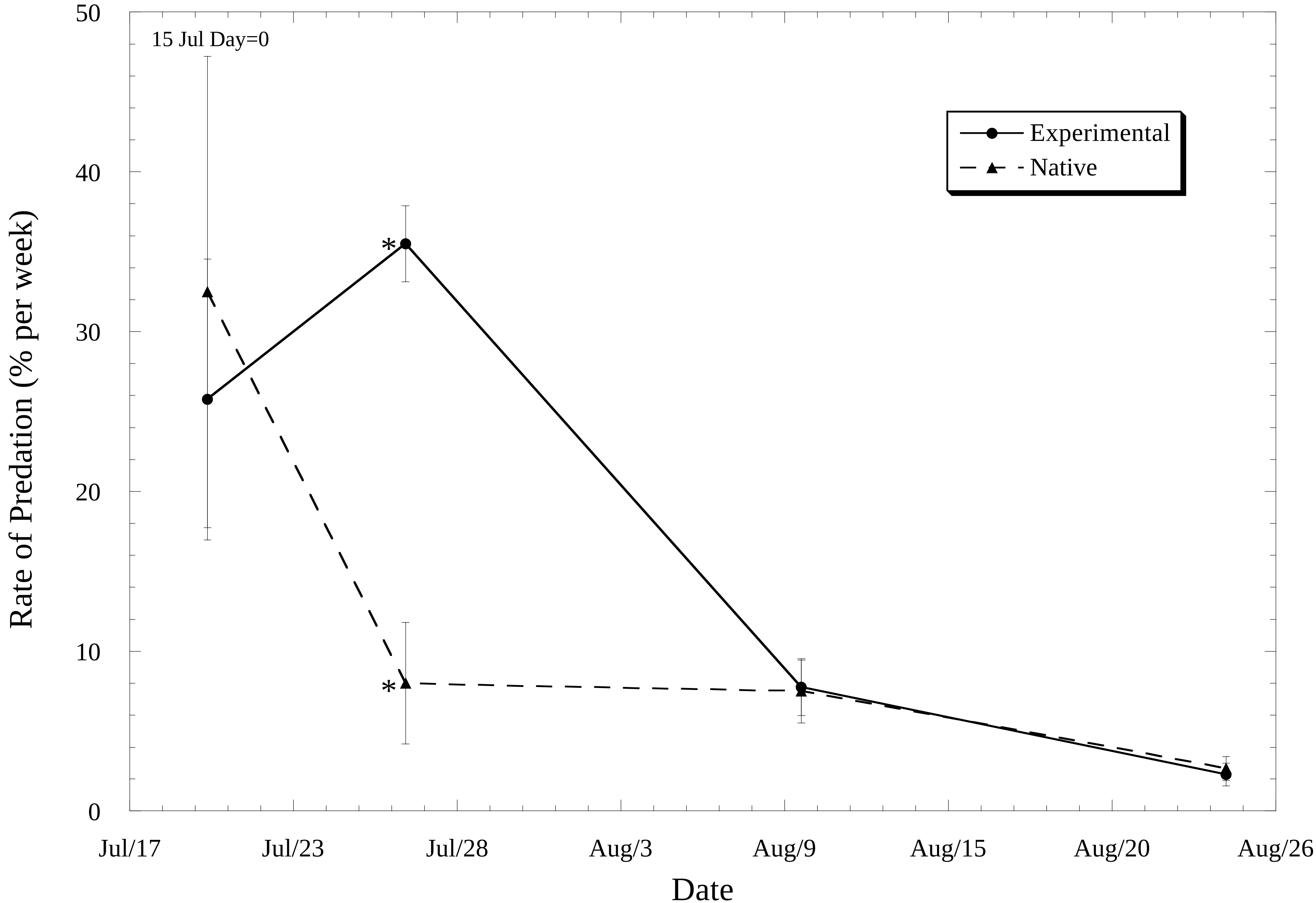


Figure 35. Weekly rate of predation (actual % nutlets removed per week from total nutlet stock) in the unburned, standard plots at the Site 300 Drop Tower experimental and native populations, phase 2. Bars represent one standard error, n=5. Data points marked with * are significantly different at $p<0.05$ for that observation date.

Tables

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

	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
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 and June 1998. 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	218	1.42	30.27 ± 0.67	1.61 ± 0.10[c]	38.39 ± 2.23[e]	8369
Experimental	64	1.73	20.56 ± 0.66	1.03 ± 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. All of the plants in the experimental population were measured (n=64). A sub-sample was measured in the native population (n=140).

[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 statistical analysis of Phase 1 predation study, Drop Tower experimental population.[a]

Round 1

Dependent Variable: Cumulative Predation Intensity					
Source	**DF**	**Type I SS**	**Mean Square**	**F Value**	**Pr > F**
Treatment[b]	1	0.54045	0.54045	12.08	0.0011
Block	4	0.20339	0.05084	1.14	0.3502
Date	2	4.75899	2.37949	53.17	0.0001
Trt*Date[d]	2	0.08851	0.04425	0.99	0.3791
Dependent Variable: Weekly Predation Intensity					
Source	**DF**	**Type I SS**	**Mean Square**	**F Value**	**Pr > F**
Treatment[b]	1	0.22349	0.22349	4.44	0.0401
Block	4	0.05376	0.01344	0.27	0.8977
Date	2	0.45684	0.22842	4.54	0.0154
Trt*Date[d]	2	0.08263	0.04131	0.82	0.4458
Dependent Variable: Weekly Predation Rate					
Source	**DF**	**Type I SS**	**Mean Square**	**F Value**	**Pr > F**
Treatment[b]	1	0.02112	0.02112	1.01	0.3208
Block	4	0.01461	0.00365	0.17	0.9508
Date	2	0.70811	0.35405	16.85	0.0001
Trt*Date[d]	2	0.27968	0.13984	6.66	0.0027
Dependent Variable: Estimated Weekly Predation Rate					
Source	**DF**	**Type I SS**	**Mean Square**	**F Value**	**Pr > F**
Treatment[b]	1	0.00176	0.00176	1.00	0.3343
Block	4	0.00422	0.00105	0.60	0.6705

Round 2

Dependent Variable: Weekly Predation Intensity					
Source	**DF**	**Type I SS**	**Mean Square**	**F Value**	**Pr > F**
Tape[c]	1	0.08257	0.08257	1.26	0.2693
Treatment[b]	1	0.04848	0.04848	0.74	0.3954
Block	4	0.10135	0.02533	0.39	0.8158
Trt*Tape[e]	1	0.06154	0.06154	0.94	0.3391
Dependent Variable: Weekly Predation Rate					
Source	**DF**	**Type I SS**	**Mean Square**	**F Value**	**Pr > F**
Tape[c]	1	0.03775	0.03775	2.47	0.1261
Treatment[b]	1	0.01695	0.01695	1.11	0.3004
Block	4	0.01748	0.00437	0.29	0.8851
Trt*Tape[e]	1	0.02353	0.02353	1.54	0.2239

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

[b] The treatments considered were the open and netted plots. Data from plots containing plates with lids (i.e., the cover treatments), are not included.

[c] Compared plates with double-stick tape to plates not containing the tape.

[d] Treatment by date interaction.

[e] Treatment by tape interaction.

Table 4. Weekly rates of predation at the Site 300 Drop Tower experimental population, phase 1.[a]

	Round 1[b]	Round 2[b]
Average Weekly Rate[c]	18.30 ± 5.43	n/a[e]
Estimated Weekly Rate[d]	18.98 ± 0.14	70.20 ± 0.29

[a] Includes combined results from open and netted treatments.
[b] Results are presented ± one standard error.
[c] Average of the individual weekly rates (shown on Fig. 20), n=3.
[d] Estimated weekly rate is estimated by dividing the final cumulative predation intensity (as shown on Fig. 18) by the total number of weeks, n=20.
[e] Results for round 2 are based on only one week.

Table 5. Summary of statistical analysis of Phase 2 predation study, Drop Tower experimental population.[a]

Dependent Variable: Cumulative Predation Intensity					
Source	DF	Type I SS	Mean Square	F Value	Pr > F
Burn[b]	1	0.47188	0.47188	11.72	0.0011
Treatment[c]	1	0.53769	0.53769	13.35	0.0005
Burn*Trt[d]	1	0.19886	0.19886	4.94	0.0297
Block	4	0.60868	0.15217	3.78	0.0079
Date	3	3.26334	1.08778	27.02	0.0001
Date*Trt[e]	3	0.03402	0.01134	0.28	0.8384
Dependent Variable: Weekly Predation Intensity					
Source	DF	Type I SS	Mean Square	F Value	Pr > F
Burn[b]	1	0.19178	0.19178	3.02	0.0867
Treatment[c]	1	0.07906	0.07906	1.25	0.2682
Burn*Trt[d]	4	0.22246	0.05561	0.88	0.4826
Block	3	2.07849	0.69283	10.92	0.0001
Date	1	0.01826	0.01826	0.29	0.5933
Date*Trt[e]	3	0.26141	0.08713	1.37	0.2584
Dependent Variable: Weekly Predation Rate					
Source	DF	Type I SS	Mean Square	F Value	Pr > F
Burn[b]	1	0.07144	0.07144	1.58	0.2133
Treatment[c]	1	0.09591	0.09591	2.12	0.1501
Burn*Trt[d]	4	0.08745	0.02186	0.48	0.7478
Block	3	1.88002	0.62667	13.86	0.0001
Date	1	0.00650	0.00650	0.14	0.7057
Date*Trt[e]	3	0.29085	0.09695	2.14	0.1031
Dependent Variable: Estimated Weekly Predation Rate					
Source	DF	Type I SS	Mean Square	F Value	Pr > F
Burn[b]	1	0.00821	0.00821	3.19	0.0993
Treatment[c]	1	0.00461	0.00461	1.79	0.2053
Block	4	0.01191	0.00297	1.16	0.3771
Burn*Trt[d]	1	0.00023	0.00023	0.09	0.7679

[a] All data were arcsine transformed prior to statistical analysis.
[b] Burn differentiates between burned and unburned plots.
[c] The treatments considered the open and netted plots.
[d] Burn by treatment interaction.
[e] Date by treatment interaction.

Table 6. Summary of statistical analysis for burned plots only in Phase 2 of the predation study, Drop Tower experimental population.[a]

Dependent Variable: Cumulative Predation Intensity					
Source	**DF**	**Type I SS**	**Mean Square**	**F Value**	**Pr > F**
Treatment[b]	1	0.69527	0.69527	33.52	0.0001
Block	4	0.95424	0.23856	11.50	0.0001
Date	3	1.33875	0.44625	21.51	0.0001
Trt*Date[c]	3	0.23156	0.07718	3.72	0.0227
Dependent Variable: Weekly Predation Intensity					
Source	**DF**	**Type I SS**	**Mean Square**	**F Value**	**Pr > F**
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
Trt*Date[c]	3	0.87701	0.29233	7.72	0.0007
Dependent Variable: Weekly Predation Rate					
Source	**DF**	**Type I SS**	**Mean Square**	**F Value**	**Pr > F**
Treatment[b]	1	0.07619	0.07619	2.87	0.1016
Block	4	0.16561	0.04140	1.56	0.2132
Date	3	0.59733	0.19911	7.49	0.0008
Trt*Date[c]	3	0.88356	0.29452	11.07	0.0001
Dependent Variable: Estimated Weekly Predation Rate					
Source	**DF**	**Type I SS**	**Mean Square**	**F Value**	**Pr > F**
Treatment[b]	1	0.00138	0.00138	0.76	0.4330
Block	4	0.01754	0.00438	2.40	0.2086

[a] All data were arcsine transformed prior to statistical analysis.
[b] The treatments considered the open and netted plots.
[c] Treatment by date interaction.

Table 7. Summary of statistical analysis for unburned plots only in Phase 2 of the predation study, Drop Tower experimental population.[a]

Dependent Variable: Cumulative Predation Intensity					
Source	**DF**	**Type I SS**	**Mean Square**	**F Value**	**Pr > F**
Treatment[b]	**1**	**0.04128**	**0.04128**	**1.07**	**0.3103**
Block	**4**	**0.33899**	**0.08474**	**2.19**	**0.0957**
Date	**3**	**1.98350**	**0.66116**	**17.10**	**0.0001**
Trt*Date[c]	**3**	**0.05312**	**0.01770**	**0.46**	**0.7137**
Dependent Variable: Weekly Predation Intensity					
Source	**DF**	**Type I SS**	**Mean Square**	**F Value**	**Pr > F**
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**
Trt*Date[c]	**3**	**0.10496**	**0.03498**	**0.48**	**0.6976**
Dependent Variable: Weekly Predation Rate					
Source	**DF**	**Type I SS**	**Mean Square**	**F Value**	**Pr > F**
Treatment[b]	**1**	**0.02622**	**0.02622**	**0.54**	**0.4700**
Block	**4**	**0.02769**	**0.00692**	**0.14**	**0.9652**
Date	**3**	**1.38376**	**0.46125**	**9.43**	**0.0002**
Trt*Date[c]	**3**	**0.07189**	**0.02396**	**0.49**	**0.6920**
Dependent Variable: Estimated Weekly Predation Rate					
Source	**DF**	**Type I SS**	**Mean Square**	**F Value**	**Pr > F**
Treatment[b]	**1**	**0.00346**	**0.00346**	**1.13**	**0.3473**
Block	**4**	**0.00570**	**0.00142**	**0.47**	**0.7615**

[a] **All data were arcsine transformed prior to statistical analysis.**
[b] **The treatments considered the open and netted plots.**
[c] **Treatment by date interaction.**

Table 8. Weekly rates of predation in burned versus unburned plots at the Site 300 Drop Tower experimental population, phase 2.

	Burned Plots[a]		Unburned Plots[a]	
	Open	Netted	Open	Netted
Average Weekly Rate[b]	16.47 ± 9.76	9.23 ± 3.15	17.82 ± 7.74	16.22 ± 7.69
Estimated Weekly Rate[c]	10.07 ± 1.53	8.66 ± 1.37	12.86 ± 0.57	10.72 ± 1.67

[a] Results are presented ± one standard error.
[b] Average of the individual weekly rates (shown on Fig. 29), n=4.
[c] Estimated weekly rate is estimated by dividing the final cumulative predation intensity (as shown on Fig. 23) by the total number of weeks, n=5.

Table 9. Summary of statistical analysis of Phase 2 predation study, Drop Tower native population.[a]

Dependent Variable: Cumulative Predation Intensity					
Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment[b]	1	0.11649	0.11649	2.18	0.1506
Block	4	0.98537	0.24634	4.62	0.0055
Date	3	1.27226	0.42408	7.95	0.0005
Trt*Date[c]	3	0.06641	0.02213	0.41	0.7436
Dependent Variable: Weekly Predation Intensity					
Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment[b]	1	0.12840	0.12840	2.06	0.1626
Block	4	0.30751	0.07687	1.23	0.3200
Date	3	0.51492	0.17164	2.75	0.0614
Trt*Date[c]	3	0.16864	0.05621	0.90	0.4533
Dependent Variable: Weekly Predation Rate					
Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment[b]	1	0.08061	0.08061	1.32	0.2597
Block	4	0.15547	0.03886	0.64	0.6396
Date	3	0.60907	0.20302	3.33	0.0336
Trt*Date[c]	3	0.16451	0.05483	0.90	0.4533
Dependent Variable: Estimated Weekly Predation Rate					
Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment[b]	1	0.00035	0.00035	0.14	0.7232
Block	4	0.02798	0.00699	2.87	0.1654

[a] All data were arcsine transformed prior to statistical analysis.
[b] Treatments consisted of dispersed spacing and standard (non-dispersed) spacing of nutlets.
[c] Treatment by date interaction.

Table 10. Summary of statistical analysis of Phase 2 predation study, comparison of Drop Tower experimental and native populations.[a]

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Dependent Variable: Cumulative Predation Intensity					
Site[b]	1	0.26907	0.26907	7.41	0.0110
Block	4	0.52743	0.13185	3.63	0.0166
Date	3	1.52711	0.50903	14.02	0.0001
Site*Date[c]	3	0.19647	0.06549	1.80	0.1694
Dependent Variable: Weekly Predation Intensity					
Source	DF	Type I SS	Mean Square	F Value	Pr > F
Site[b]	1	0.11614	0.11614	2.46	0.1283
Block	4	0.08128	0.02032	0.43	0.7859
Date	3	0.50582	0.16860	3.57	0.0266
Site*Date[c]	3	0.49045	0.16348	3.46	0.0296
Dependent Variable: Weekly Predation Rate					
Source	DF	Type I SS	Mean Square	F Value	Pr > F
Site[b]	1	0.04891	0.04891	1.16	0.2916
Block	4	0.04600	0.01150	0.27	0.8938
Date	3	0.87408	0.29136	6.88	0.0013
Site*Date[c]	3	0.41954	0.13984	3.30	0.0347
Dependent Variable: Estimated Weekly Predation Rate					
Source	DF	Type I SS	Mean Square	F Value	Pr > F
Site[b]	1	0.01155	0.01155	2.82	0.1686
Block	4	0.00751	0.00187	0.46	0.7658

[a] All data were arcsine transformed prior to statistical analysis.
[b] Site compared unburned open plots of standard spacing.
[c] Site by date interaction.

Table 11. Weekly rates of predation at the Site 300 Drop Tower experimental and native populations, phase 2.[a]

	Experimental Site[a]	Native Site[a]
Average Weekly Rate[b]	17.82 ± 7.74	12.66 ± 4.42
Estimated Weekly Rate[c]	12.86 ± 0.57	9.02 ± 1.90

[a] Data are from open, unburned, standard spacing plots.
[b] Results are presented ± one standard error.
[c] Average of the individual weekly rates (Fig. 29 for the open unburned plots in the experimental site, and Fig. 32 for the standard spacing plots for the native site), n=4.
[d] Estimated weekly rate is obtained by dividing the final cumulative predation intensity (Fig. 23 for open unburned plots in the experimental site, and Fig. 30 for the standard spacing plots for the native site) by the total number of weeks, n=5.

Table 12. Comparison of predation of *A. grandiflora* nutlets in 1995 and 1998.

Time Interval	Estimated Weekly Predation Rate[b]	Predation Eveness[c]	Predation Localization[d]	Estimated Weekly Predation Rate[b]	Predation Eveness[c]	Predation Localization[d]
Predation observed in 1995[e]						
	Drop Tower experimental site			**CDFG experimental site**		
Apr 3– Apr 10	**20.0 ± 22.1 n=5 plates**	**60**	**0**	**39.0 ± 33 n=5 plates**	**100**	**40**
Jul 20– Sep 22	**3.8 ± 3.7 n=10 plates**	**60**	**20**	**7.2 ± 3.7 n=8 plates**	**100**	**62.5**
Predation observed in 1998						
	Drop Tower experimental site			**Drop Tower native site**		
Apr 29– May 8[f] (week 1 of Phase 1)	**36.2 ± 12.5 n=10 plots**	**92 ± 10**	**44 ± 28**	**No data collected**	**No data collected**	**No data collected**
Apr 29– Jun 1[g] (Phase 1, Round 1)	**19.6 ± 1.5 n=10 plots**	**100**	**100**	**No data collected**	**No data collected**	**No data collected**
Jul 15– Aug 25[h] (Phase 2)	**12.86 ± 1.3 n=5 plots**	**100**	**0**	**9.02 ± 4.3 n=5 plots**	**100**	**0**

[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] Predation eveness is the percentage of plates missing nutlets. For the 1998 Phase 1 Round 1 data, this represents the average percentage of plates within each plot with missing nutlets. For the 1998 Phase 2 data, this represents the average number of plots with missing nutlets.

[d] Predation localization is the % of plates with <5 nutlets. For the 1998 Phase 1 Round 1 data, this represents the average number of plates within each plot containing less than 5 nutlets. For the 1998 Phase 2 data, this represents the average number of plots with less than 5 nutlets.

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

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

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

[h] These are data from Phase 2, standard spaced, unburned, open plots.