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Rare Plant Restoration and Monitoring at Lawrence Livermore National Laboratory Site 300

Project Progress Report
Fiscal Years 2003 & 2004
October 2002–October 2004

Authors

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Erin Espeland
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September 2005

Environmental Protection Department
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Executive Summary

Site 300 occupies approximately 7,000 acres in California Coast Range in Alameda and San Joaquin Counties (Figure Summ1). Three extremely rare native plant species occur at Site 300: (1) *Amsinckia grandiflora*, a federally-listed endangered borage, (2) *Blepharizonia plumosa*, a late-flowering tarplant that is extremely rare throughout its range, (3) *Eschscholzia rhombipetala,* the diamond-petaled poppy which was not seen from 1950 to 1993 and presumed extinct. A fourth rare species, *California macrophylla*, the round-leaved filaree, is endangered throughout its range, but is not state- or federally- listed at this time. Four more uncommon native plant species occur at Site 300. These species are on the California Native Plant Society's watch list indicating a degree of rarity, but each has a wide enough distribution so as not to be threatened at this time: (1) *Androsace elongata* subsp. *acuta,* California rock jasmine, (2) *Delphinium gypsophilum* ssp. *gypsophilum,* the gypsum-loving larkspur, (3) *Fritillaria agrestis,* stinkbells, and (4) *Hesperevax caulescens*, hogwallow starfish. This report summarizes the detailed work performed on the four rarest species occurring at Site 300 for the 2003 and 2004 fiscal years. Due to manpower limitations and the relative lack of statewide rarity for *A. e. acuta, F. agrestis, H. caulescens,* and *D. g. gypsophilum,* no population mapping or monitoring was done for this species in FY2003 or FY2004.

Amsinckia grandiflora, *Blepharizonia plumosa* and *Eschscholzia rhombipetala* all have varying levels of statewide rarity and abundance at Site 300, hence research and management of each species is different. *Amsinckia grandiflora* currently occurs in two populations at Site 300: one native population (an additional native population has been extirpated for five years) and one experimental population. The goal of our research and management of *A. grandiflora* populations is to control the cover of exotic annual grasses while developing techniques to restore native perennial grasslands and to preserve *A. grandiflora* numbers. *Blepharizonia plumosa* occurs in large numbers throughout Site 300, and thus occurs in areas of active Site 300 operations. However, its close relative, *B. laxa* is not common at Site 300. Efforts are focused on determining the effects of fire on the distribution of both species and identifying possible metapopulation dynamics controlling the Site 300 *B. plumosa* populations. *Eschscholzia rhombipetala* is found in three small populations. Site 1 is in the southwestern corner of Site 300 on a small landslide, site 2 occurs in a steeply sloping grassland north of Building 854, and site 3 is found in a small valley near the western edge of Site 300 known as Round Valley. Because these populations are extremely small and one occurs at a geologically unstable location, low-impact population demographic and community association data are all that are being collected at this time. *California macrophylla* occurs in six locations in the northwest corner of Site 300. Four of these six populations are found in the annually graded portions of fire trails. The remaining two populations are located in grasslands near fire trail populations.

Amsinckia grandiflora Work

Activity Summary

Because populations of *Amsinckia grandiflora* have been very small at the native and experimental sites in recent years, seed bank enhancements were conducted at the Site 300 flashing (FL) experimental population and the Lougher Ridge experimental population in Black

Diamond Regional Park. The Lougher Ridge work was supported by the US Bureau of Reclamation and conducted by BMP Associates under the direction of LLNL. The seed bank enhancements were conducted in fall of 2002 and repeated in 2003. In 2002, a total of 3,750 seeds were planted in the Lougher Ridge population and 2,380 seeds were planted in the FL portion of the Drop Tower population. The 2002 seed bank enhancement was designed to compare the success of seeds from seven different sources that ranged from 4 years old to 8 years old. A common garden experiment was also conducted in the fall of 2002 and the winter of 2003 to further compare the differences in germination for these seven seed sources. Plants from this common garden experiment were grown to maturity, and the seed produced was collected to boost the LLNL seed stores.

In 2003, 4,500 seeds were planted at Lougher Ridge and 2,624 seeds were planted in the FL portion of the Drop Tower experimental population. These seeds were from two sources: the 2002 common garden experiment and a combination of the seven older seed sources used in 2002. A subset of the Site 300 plots were netted to exclude herbivores and granivores after the 2003 seeding to examine the changes in rates of herbivory as a result of the netting.

Annual spring censuses were conducted in 2003 and 2004 at the Drop Tower experimental and native populations and at the Lougher Ridge experimental population. These censuses also measured the success of the seed bank enhancements from the previous fall at the FL subpopulation and the Lougher Ridge experimental population. The abundance of the native perennial grass *Poa secunda* was also recorded for each plot in the Drop Tower experimental population. *Poa secunda* abundance is an indication of the "healthiness" of the plant community here and its ability to support *A. grandiflora*. Biomass was monitored at the time of the seed bank enhancement in the Drop Tower experimental population and at the Lougher Ridge site. In previous years, *Poa secunda* persistence, biomass and predation were monitored in the Site 300 *A. grandiflora* populations to determine differences between burned and unburned plots. In 2003 and 2004, we began monitoring *Poa secunda* persistence, biomass, and predation for the purpose of tracking changes between years instead of between burned and unburned groups.

A long-term experiment to measure the effects of fire frequency (FF) on *A. grandiflora* success began in 2001 at the Drop Tower experimental population. The plots in the FF subpopulation are burned at one of three frequencies or are control plots that will not be burned after plot establishment. The third and fourth treatment burns were conducted in the FF subpopulation in 2003 and 2004.

Results Summary

- Populations continue to be very small. The native Drop Tower population had only five plants in 2003 and three plants in 2004.
- The overall germination seed bank enhancements at the Lougher Ridge Population was 18.1% in 2002 and 22.5% in 2003.
- The germination rate for the seed bank enhancements was higher at Site 300 than Lougher Ridge in 2002 and 2003. At the Site 300 experimental population, the germination rate for the 2002 seeding was 37.6% and 62.2% for 2003.
- Germination (2002) varied by seed source with the oldest source having the lowest germination rate.

- The netted plots (2003) produced more *A. grandiflora* seedlings that were larger and showed less signs of herbivory than the unnetted plots.
- Although germination rates were lower at Lougher Ridge then Site 300, survivorship from germination to flowering was higher at Lougher Ridge than Site 300. Survivorship was estimated to be 29.8% for the 2002 seeding and 91% for the 2003 seeding at Lougher Ridge, and 4.2% for 2002 and 39.4% for 2003 at Site 300.
- In the spring of 2003 (after the fall 2002 seeding), the FL subpopulation had 69 flowering individuals that were too small to be expected to produce any seeds. Lougher Ridge had 206 flowering individuals that were projected to produce 1,592 seeds.
- Overall, the 2003 seed bank enhancement was more successful than 2002 efforts. In the spring of 2004 (after the fall 2003 seeding), there was 753 *A. grandiflora* in the FL subpopulation that were very small and therefore expected to produce only 14 seeds. In the Lougher Ridge population, there were 865 *A. grandiflora* at flowering that were expected to produce 8,739 seeds.
- Preliminary results from the FF experiment show that *P. secunda* is most abundant in plots that were annually burned while *A. grandiflora* is more abundant in the control plots that have not been burned since 2001.
- Predation rates in 2003 were relatively low and were similar to those observed in 2000, 2001, and 2002. In contrast, the 2004 predation was at the highest rate observed since predation monitoring began in 1998, and similar to the high rates observed in 1998 and 1999.

Blepharizonia plumosa Work

All populations at Site 300 were mapped when plants were flowering in fall 2002, 2003, and 2004. Mapping was completed using a handheld Trimble GeoXT GPS. Seedling recruitment was also compared in burned and unburned patches in the summer of 2003.

Results Summary

- The average seedling recruitment was higher in burned patches compared to unburned patches, but this difference was largely due to an extremely high number of seedlings in one burned location. The seedlings were significantly larger in burned patches compared to unburned patches.
- Site wide *Blepharizonia* mapping shows that populations re-emerge during years of limited burning, but they appear to shrink after several years without burning.
- Site wide mapping also shows that *Blepharizonia* thrives in areas where unburned patches occur within burned areas or in areas where artificial or natural firebreaks provide shelter from the burn.

Eschscholzia rhombipetala Work

A new population of *Eschscholzia rhombipetala* was discovered in the western portion of Site 300 in the spring of 2004. This new population is only 0.4 km southwest of the previously known site 2 and 1.7 km north of site 1. All three *Eschscholzia rhombipetala* populations (site 1, site 2, and site 3) were censused at flowering. Plant height and number of flowers were recorded. Location (slump, scarp or grassland) was recorded for the site 1 population. Regressions to predict reproductive output from plant height data were developed. Community composition data were collected from plots located within the populations and in the areas surrounding them.

Results Summary

- *Eschscholzia rhombipetala* populations at sites 1 and 2 were quite small in 2003 and 2004. Site 2 contained two plants in 2003 and one plant in 2004, and site 1 had 10 *E. rhombipetala* in 2003 and 19 in 2004.
- Site 3 was large in 2004 containing 398 *E. rhombipetala*.
- The new population differs from the two previously known populations in that it is found at the bottom of a small stable bowl shaped valley, while sites 1 and 2 are located on steep northwest facing hillsides. *Eschscholzia rhombipetala* at sites 1 and 2 is also found in association with the native perennial grass, *P. secunda,* while *P. secunda* was not found at site 3.
- The presence of *E. rhombipetala* continues to be linked to the percent of bare ground and thatch.

California macrophylla Work

One population (site 1) of *C. macrophylla* was discovered at Site 300 during site wide botanical surveys conducted in 2002. Five additional *C. macrophylla* populations (sites 2 through 6) were discovered at Site 300 in 2003 and 2004 during wildlife surveys. In 2004, we began conducting spring censuses of these populations. Censuses included mapping the distribution of each population using a handheld GPS, estimating the number of *C. macrophylla* in each population. The community composition was also recorded for randomly located quadrats within each population, and the number of floral units was recorded for *C. macrophylla* within these quadrats. Survivorship was recorded for *C. macrophylla* and the closely related species *Erodium cicutarium* at site 1 in the winter of 2002 and the spring of 2003.

Results Summary

- In 2004, the six *C. macrophylla* populations were estimated to have a total of 5,875 plants.
- All six *C. macrophylla* populations were rich in native forbs. The populations occurring on dirt fire trails were particularly diverse.
- As expected, the fire trail populations had more bare ground and less thatch and exotic grass cover than grassland populations.
- We did not find a significant difference between the survivorship or persistence of *C. macrophylla* and *E. cicutarium.*

Section A
Amsinckia grandiflora
Monitoring and Research

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Amsinckia grandiflora
Monitoring and Research

A-1. Introduction

The large-flowered fiddleneck, *Amsinckia grandiflora* (Gray) Kleeb. ex Greene (Boraginaceae), is a rare annual forb native to the California winter annual grasslands. *Amsinckia grandiflora* germinates with the onset of fall or early winter rain, grows vegetatively throughout the winter, flowers in the early spring, and sets seeds and dies prior to the summer drought, a pattern observed in most of the herbaceous species of 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 likely ancestors of the weedy, widespread, and homostylous congeners (Ray and Chisaki, 1957a and 1957b; Shoen 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 an exerted stigma and anthers within the corolla tube. Thrum flowers have the opposing morphology, with the stigma within the corolla tube and exerted anthers (Figure A1). Characteristic of the genus, each flower morph 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.

Amsinckia 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 at Lawrence Livermore National Laboratory (LLNL) Site 300, a high-explosive testing facility operated by the University of California for the U.S. Department of Energy (DOE). The two natural 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. 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 privately owned Connolly Ranch. An experimental population at this site was attempted, but failed, possibly due to extremely high rodent activity

(Pavlik, 1994). Figure A2 shows the approximate locations of the *A. grandiflora* populations at or near Site 300.

Amsinckia grandiflora was federally listed as endangered in 1985. On May 8, 1985, one hundred and sixty acres of LLNL surrounding the native Drop Tower *A. grandiflora* population was designated critical habitat by the U.S. Fish and Wildlife Service (USFWS). In 1997, the USFWS published the final recovery plan for the species (USFWS, 1997). On April 28, 2000, the Secretary of the U.S. DOE established the *A. grandiflora* reserve on the 160 acres of critical habitat and signed a memorandum of agreement with the U.S. FWS describing technical services, management and access to the reserve (U.S. DOE, 2000).

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 native 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 A3). This population is known as the Drop Tower experimental population. The Drop Tower experimental population is divided into two portions. The original experimental population is referred to as the flashing (FL) subpopulation because it is surrounded by metal flashing in an attempt to exclude rodents from the population. The Drop Tower experimental population was later expanded in 1999 to include 20 additional plots to be used in an ongoing experiment on the effects of prescribed burns on *A. grandiflora* and *Poa secunda*. This newer portion of the Site 300 experimental population is referred to as the fire frequency (FF) subpopulation.

Research on the Drop Tower experimental population, the Lougher Ridge experimental population, and data from management of the Drop Tower natural population indicates that competition from exotic annual grasses contributes 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 is necessary to ensure the persistence of this species (Pavlik et al., 1993; Pavlik, 1994; Carlsen et al., 2000). Long-term financial support is being provided through LLNL Site 300 management. The USFWS and the U.S. Bureau of Reclamation have provided additional funding.

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. The use of controlled burning is being investigated as a tool for developing and maintaining perennial grasslands. The impact of seed predation is also being investigated to determine its impact on the population dynamics of *A. grandiflora*. This report details progress made during the 2003 and 2004 federal fiscal years (October 2002 through October 2004).

A-2. Methods and Materials

A-2.1. Rapid Seed Bank Enhancement

In October 2002, the U.S. Bureau of Reclamation entered into an Interagency Agreement with LLNL/U.S. DOE and provided funding to LLNL to conduct rapid seed bank enhancement of experimental *A. grandiflora* population (the Site 300 Drop Tower experimental population and the Lougher Ridge experimental population). LLNL entered into a contract with BMP Ecosciences to support work at Lougher Ridge for both the monitoring and the seed bank enhancement portions of the project. Funding from LLNL Site 300 management was also used to support the seed bank enhancement activities at Site 300.

A-2.1.1. 2002 Seed Sowing at the Experimental Sites

An inventory of seed available for sowing into the experimental populations was completed in November 2002. Seed from seven different sources was available in the LLNL seed collections. The oldest source was harvested as part of a common garden experiment conducted at U.C. Davis in 1989. The remaining seeds were collected from pot or greenhouse experiments conducted by LLNL and U.C. Davis between 1993 and 1998. Table A1 shows the seed sources selected for sowing into the two populations, and the number of seeds sown at each site.

A randomized complete block design was used at both sites. Five blocks were established at each site. At Lougher Ridge, five rows of nine plots each were established. Forty-five existing FL plots (in five rows) were used for the seed bank enhancement at Site 300. At least one plot for each of the seven seed sources was located in each block. Two plots were established in each block for seed source D and G because of the large quantity of seed available from these two sources. One hundred seeds were sown into full Lougher Ridge plots, and 64 seeds were sown into full Site 300 plots, but due to limitations in seed availability, half the number of seeds were used for plots containing seed sources H, K, and M. This resulted in a total of nine plots (including three "half" plots) per block. Plots at Lougher Ridge are 1 m^2. The previously established FL plots at the Drop Tower experimental population measure 0.36 m^2.

Precision planting of seeds was conducted at both experimental populations on December 4 and 5, 2002 using previously developed methods (Pavlik et al., 1993). At both sites, planting frames constructed of 0.48-cm-thick ply board were used. A grid of holes nominally measuring 3.8 cm and separated by 2.5 cm (i.e., arranged on 8 cm centers) was cut into the frames. Planting frames used at Lougher Ridge consisted of a 10 × 10 grid of holes, and frames used at Site 300 consisted of an 8 × 8 grid of holes. This resulted in 100 seeds being sown into each Lougher Ridge plot, and 64 being sown into each Site 300 plot. For plots sown with half the number of seeds, only the center rows of the grid were used to achieve the same effective density as the full plots. Two 0.48 cm holes were also cut into the front edge of the frame. These holes were used to anchor the frames to the plots using either a 30 or 60 cm length of rebar.

Planting was conducted by first anchoring the planting frame in place in the plot. Once the planting frames were anchored, each hole was excavated to a depth of about 0.5 cm into the mineral soil. A single seed was placed into each hole. Each seed was then lightly covered with mineral soil and lightly tapped down. When planting was complete, the frames were lifted off the plots, leaving the rebar in place. This allowed for accurate replacement of the planting frames for use in conducting the monthly census.

Due to the very high amount of existing biomass at Lougher Ridge, biomass was clipped to within about 12 cm of the ground surface for each plot at this site before planting. Biomass removed from five of the plots was collected for subsequent weight determination.

All sowing was completed at both sites within two days. Because of the obvious difference in existing biomass between the two sites, five 0.1 m^2 biomass samples were collected from locations adjacent to, but outside, the plots at both sites on the same dates that sowing was conducted. These samples were dried and weighed and compared between sites. Biomass was collected again at Lougher Ridge and Site 300 in June 2003.

Germination and seedling establishment was recorded for each site during the first week of January 2003 (establishment recorded on January 3, 2003 at Lougher Ridge and January 7, 2003 at Site 300). Establishment and survivorship was monitored at Site 300 again on February 5, 2003. Planting frames were carefully placed over each plot using the rebar left in place from the initial sowing to guide placement of frames. Data sheets consisting of a graphical representation of the grid used in each plot were used to record the presence of *A. grandiflora* seedlings. A separate sheet was completed for each plot, with the location of each hole containing an *A. grandiflora* seedling recorded. At Site 300, the size of each seedling was recorded using the number of leaves present as a measure of size (cotyledon, 2-leaved, 4-leaved, 6-leaved). At Lougher Ridge only the number and location of seedlings in each plot was recorded.

The FL subpopulation was censused on March 25 and April 10, 2003 as described below (Section A-2.2). Although survivorship of individuals was not tracked, the number of plants present at the time of the census was used as an estimate of the number of plants surviving to flowering.

A-2.1.2. Common Garden Experiment

To estimate the maximum possible germination for each seed source, a common garden was established at LLNL's Livermore site. Methods used for germination and transplantation were similar to those used in Carlsen et al., 2002. On January 2, 2003, seeds were placed into Petri plates containing filter paper moistened with distilled water. Four Petri plates containing between 14 and 32 seeds were prepared for each seed source. The plates were placed into a cooler to maintain darkness. The cooler was placed outside the evening of January 2, 2003 to allow for cold scarification of the seeds. The cooler was returned to room temperature the morning of January 3, 2003.

Petri plates were checked for germination on January 6, 2003. Germinules were transplanted into 10-inch plastic nursery pots filled with potting soil. Up to fifteen germinules from a single seed source were transplanted into one pot, at which point a new pot was used. Germination occurred over the span of about 14 days, with the majority occurring within the first 6 days. This produced between 1 and 7 pots for each seed source. All pots were placed outdoors on two tables in a blocked design in a protected, north facing area of the LLNL Livermore site. Pots were manually watered as needed until they had finished flowering. Survivorship of the seedlings was tracked, and all seeds produced were collected.

As the plants in the common garden began to mature, bird predation on the seeds became a problem. Because of this, PVC frames were built around the tables that the pots were placed on and covered with Bird-X™ birdnet to prevent access to the seeds by birds.

A-2.1.3. 2003 Seed Sowing at the Experimental Sites

Precision planting of seeds was repeated on October 13, 2003 at both the Lougher Ridge and Site 300 experimental populations using the same methods and plot locations described above. Forty-five plots were seeded at Lougher Ridge and 41 plots were seeded at Site 300. Seeding was completed using two seed sources: old seeds and new seeds. The old seed source used a combination of the seed sources used in the 2002 planting. The new seed source consisted entirely of seeds collected from the 2002 common garden experiment. The old seed source was used in 21 plots at Site 300 and Lougher Ridge and the new seed source was used in 20 plots at Site 300 and 24 plots at Lougher Ridge. All Site 300 plots were planted with 64 seeds and all Lougher Ridge plots were planted with 100 seeds.

Because many seedlings appeared to have been lost to herbivory in the 2002 planting, all plots that were planting during 2003 at the Site 300 experimental site were covered with Bird-X™ birdnet to limit access to the seeds and seedlings by birds and rodents. Bird-X™ birdnet is a 3/4-inch plastic mesh netting commonly used for pest control. The birdnet was spread over the plots at a height of approximately six to ten inches from the soil by attaching the netting to wooden dowels. The edges of the netting were secured to the ground using metal pins and small pin flags. The resulting netting prevented access to the plots by birds. Although it hindered rodent access to the plots, rodents could potentially access the netted plots through underground burrows or gaps/holes in the netting. The plastic mesh was removed from seven of the forty-one Site 300 plots on November 17, 2003 after the first establishment check (netting removed plots). During the November and December 2003 establishment checks at Site 300, the number of plants in each plot that showed signs of herbivory was recorded. Missing leaves or portions of leaves were recorded as herbivory.

Germination and seedling establishment was again recorded for each site. Establishment was recorded on January 7 and February 5, 2004 at Lougher Ridge and November 21 and December 17, 2003 at Site 300. Establishment and survivorship was monitored using the same methods described above for the 2002 seeding.

The Site 300 population was censused on March 26 and 29, 2004 as is described below (Section A-2.2). As in 2003, although the survivorship of individual plants was not tracked, the number of plants present at the time of the census was used as an estimate of the number of plants surviving to flowering.

A census of the Lougher Ridge population was conducted on April 17, 2004. The methods used at the Lougher Ridge population were similar to those used during the annual spring census at Site 300 (A-2.2). Location, morph, plant height, branch number, and nearest neighbor were recorded for each plant. Species cover was also recorded from a 60 cm × 60 cm quadrats placed at the center of each of the established Lougher Ridge plots. Unlike the Site 300 census, at Lougher Ridge, cover was recorded so that the sum of the percent cover for all species present, bare ground, and thatch equaled 100%.

A-2.1.4. Data Analysis

Statistical analysis of the Site 300 germination data for the 2003 seeding was conducted to determine if there was an effect on the number and size of seedlings in plots that were netted from October through December compared to plots from which the netting was removed one month earlier (netted October through November). Netting was removed early (in November) from only seven of the plots seeded at Site 300 in 2003 (netting removed plots). The remaining 34 plots were netted through December. To balance the design and control for minor changes in microhabitats across the FL subpopulation, the seven netting removed plots were compared to the seven netted plots nearest to each netting removed plot (netted neighbors).

The mean percent of seedlings showing signs of herbivory in netted versus unnetted plots was compared using a one-tailed t-test function. The distribution of seedlings in five size classes (stem only, cotyledon, 2-leaved, 4-leaved, and 6-leaved) was compared for unnetted versus netted neighbor plots using a Chi-squared test (Devore, 1991).

To determine if there was a difference in germination rates between the "old" and "new" seed sources for the 2003 seeding, the mean number of seedlings present per plot, as a percentage of the total number of seeds planted, was compared for plots planted with the "old seed source" versus the "new seed source" using a one-tailed t-test with Welch's correction for unequal variances. Data collected at Lougher Ridge on January 17, 2004 and at Site 300 on December 17, 2003 were used for this test.

A-2.2. Spring Census

The census of the FF and FL populations took place on March 24 and April 10, 2003 and on March 26 and 29, 2004. The native Drop Tower population census was also conducted on March 24, 2003 and on March 29, 2004. Location, 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 and is equivalent to inflorescence number. Nearest neighbor data were also collected for all *A. grandiflora* observed in the experimental and native populations in 2003 and 2004 (including those in the Carlsen-Gregory subpopulation).

Specific cover estimates were recorded by placing a 60 cm × 60 cm quadrat centered in existing plots (experimental populations), haphazard (native population 2003), or random locations (native population 2004) at the time of the spring census. In the experimental and native populations, absolute cover was estimated for each species present, bare ground and thatch.

In the experimental Drop Tower population in 2003, cover estimates were taken for all 55 original 60 cm × 60 cm plots within the FL subpopulation and two additional 60 cm × 60 cm plots (named red flag north and red flag south) in the southeastern corner of the subpopulation that were included in the precision sowing conducted in December 2002. In 2004, cover estimates were taken from the 41 FL plots in which precision sowing was conducted in October 2003 and four additional plots. This included 43 original FL plots and the new plots in the southeastern corner of the FL subpopulation (these plots were called red flag north and red flag south). In 2003 and 2004, cover estimates were also taken from an area in the center of each of the 20 FF plots.

In the native Drop Tower population in 2003, specific plant cover estimates were only taken from two quadrats centered on the location of *A. grandiflora* found in 2003. In 2004, specific plant cover estimates were recorded from five quadrats randomly placed within the historic *A. grandiflora* population and one quadrat placed around the only area containing *A. grandiflora*. In 2004, cover estimates were also recorded from one quadrat centered on the location where *A. grandiflora* was found in the Carlsen-Gregory subpopulation of the native Drop Tower population and two additional locations not containing *A. grandiflora* in the Carlsen-Gregory subpopulation.

A-2.2.1. Estimate of Nutlet Production

The number of nutlets produced by the native populations and the FL and FF experimental subpopulations were estimated using previously developed regression equations. 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, 1991). 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.

A-2.2.2. Analysis of Nearest Neighbor Data

The frequency of nearest neighbor species and Shannon's Index (H') were calculated for the Native population and the FL and FF subpopulations using the formula H' = - Σ (of i = 1 to S) $(n_i/n) * \ln(n_i/n)$, where S is number of different species observed as nearest neighbors, n is the number of individuals observed, and n_i is the number of individuals in the ith species (Shannon and Weaver, 1949). This diversity index is an expression of the likelihood that two plants picked at random will be of two different species. It not only reflects the number of species present in the sample, but also gives an idea of the evenness of distribution for these species (Ludwig and Reynolds, 1988). The higher the number of species and the more evenly they are distributed, the higher the diversity index.

A-2.2.3. Analysis of the Cover Estimates

Cover data were analyzed by calculating constancy, mean cover and Importance Value for each species and for thatch and bare ground. Constancy was calculated by dividing the number of times any one species was observed in a plot or area (referred to as the count) by the total number of plots for that year. Mean cover was calculated by averaging the cover over all plots where each species was found. Importance Values (I.V.) for each species were calculated by summing the constancy and mean cover value by species.

A-2.3. *Poa secunda* Persistence

The number of the perennial bunch grasses *Poa secunda* were counted in both the FF and FL subpopulations during the 2003 and 2004 spring censuses to monitor long-term establishment of *Poa secunda*. For the FL subpopulation, differences in *Poa* densities over burn treatments and 1993 planting regimes were analyzed using the general linear model. PROC GLM in SAS (SAS,

1990) was used for data to 2001; lm in R (version 1.9.0) was used for 2002, 2003, and 2004 data. Analysis of the FF *Poa* counts is described in Section A-2.4.1.

A-2.4. Fire Frequency (FF) Experiment

The FF subpopulation consists of twenty plots: five control plots that will not be burned after the initial burn (1998), five low frequency plots that will be burned once every five years, five medium frequency plots that will be burned once every three years, and five high frequency plots that will be burned each year. Figure A4 shows the layout of these plots. The population was established by initially burning the entire area of the FF subpopulation in 1998. Perennial bunch grasses *(Poa secunda)* were planted in the center portion of each FF plot in 1999 (Carlsen et al., 2001) and allowed to establish in 1999–2000, as were *A. grandiflora* that were transplanted into the plots. Perennial bunch grasses were planted at the same density in each plot. In 2001, plot burn treatments were selected using a randomized block design. Because of the nature of the burns, it was important that no two plots of the same treatment be adjacent to each other. This extra stipulation for plot selection prevented areas from acting ecologically as larger 2.5 m × 1 m blocks, rather than the intended 1 m × 1 m areas. Burn treatments began in the summer of 2001. All FF plots, except the control plots, were burned on July 18, 2001, and on June 20, 2002, the high frequency FF plots were burned. Again in June 30, 2003 only the high frequency plots were burned. On June 6, 2004, the high frequency plots were burned again, and the medium frequency plots received their first treatment burn.

A-2.4.1. Analysis of FF Data

All statistical tests of these data were performed using R version 1.9.0. R’s analysis of variance model (`aov`) was used to determine if burn frequency affected the abundance of *Poa*. Tukey’s Honest Significant Differences (`TukeyHSD`) was used for subsequent post hoc tests. Because the first treatment burn in the medium frequency plots was not conducted until the summer of 2004 (after the spring census), there were only three burn frequency groups at the time of the 2003 and 2004 censuses: (1) the 5 control plots that had never been burned, (2) the 10 low and medium frequency plots which were burned once during the initial burn in 2001, and (3) the five high frequency plots that had been burned once a year since 2001.

Because *A. grandiflora* frequencies were not normally distributed, a nonparametric Kruskal-Wallis test was used to examine differences in *A. grandiflora* abundance in the three different burn frequency groups present in 2003 and 2004 (control, low + medium, and high).

Because only two burn frequencies, five control plots (not burned), and 15 low, medium, and high frequency plots (burned once) were present in 2002, a nonparametric Wilcoxon test was used to compare the abundances of *A. grandiflora* and *P. secunda* in the control versus treatment plots during this year.

A-2.5. Flashing Biomass

Biomass sampling began in 1998 to measure the differences in biomass between burned and unburned plots. Baseline biomass data was collected in 1998, and a prescribed burn was conducted in the southern half of the FL subpopulation later that spring. The southern half of this population was burned again in the spring of 1999, and no burns occurred in the population between 1999 and 2003. On June 6, 2003, the entire FL subpopulation was burned in an effort to increase the success of *A. grandiflora* and *P. secunda* in that area.

In 1999 through 2002, five biomass samples were taken within the 1999 burn areas and five samples were taken outside of the 1999 burn area. Starting in 2003, five samples were taken each year throughout the FL subpopulation and these samples were not evenly distributed in the 1999 burn and unburned areas.

Biomass samples ($0.1m^2$) were collected from the center of five FL plots on May 18, 2003 and additional five plots on May 18, 2004. These plots were selected using a randomized block design with the additional requirement that biomass samples were not taken plot where the biomass had been sampled during the previous two years. Biomass samples were separated into *Poa,* other grass, forbs, and thatch. These plots are shown on Figure A5 as "B03" and "B04".

A-2.5.1. Analysis of Biomass Data

In 2002 and previous years, differences in biomass amounts over burn treatments were analyzed using the general linear model: lm in R version 1.9.0. In 2003 and 2004, sample sizes were too small to measure differences between burned and unburned plots.

A-2.6. Predation Monitoring

Starting in 1998, *A. grandiflora* nutlets were set out each year to monitor levels of seed predation within the experimental population. As in the biomass and *Poa secunda* persistence experiments described above, prior to 2003 the predation experiment was designed to measure differences between burned and unburned groups. Starting in 2003, the goal of the predation experiment shifting to monitoring annual changes in predation in the FF and FL subpopulations instead of differences between burned and unburned groups. In 1999 through 2002, predation monitoring was conducted in two rounds. Round one was conducted before the prescribed burn in the FF subpopulation and round two was conducted after the FF burn. A single round of predation monitoring was conducted in 2003 and 2004.

For each plot included in the predation experiment, a single nutlet was adhered with double-stick tape to each of 25 3.5-inch galvanized nails spaced 10 cm apart in five rows of five nails placed in the center of the existing FF or FL plot. Each nail was pressed into the soil so the nail head is flush with the soil surface.

In 2003, a total of five grids of nutlet/nails were placed using a randomized block design in the FF plots (Figure A4). Nutlet/nails were placed into the plots on May 16, 2003. Nails were checked on May 23, June 5, July 3, and October 17. On October 17, all nutlet/nails were removed.

In 2004, a total of ten grids of nutlet/nails were placed using a randomized block design. Five grids were located in the FL plots and five were located in the FF plots (Figure A4). Nutlet/nails were placed into the plots on May 25, 2004. Nails were checked on June 1, June 11, and September 17. On September 17, all nutlet/nails were removed.

A-2.7. Analysis of Predation Data

Since rounds of the experiment conducted between 1998 and 2004 were of variable length, cumulative predation data were truncated at the three-week mark. These cumulative predation percentages were not normally distributed and were compared among treatments using Kruskal-Wallis, a non-parametric ANOVA, in the NPAR1WAY procedure in SAS (SAS, 1990). Alpha for interyear comparisons was adjusted for multiple comparisons by the Bonferroni correction, resulting in an overall alpha of 0.005. Differences in cumulative predation in 2004 between the FF and FL plots (at three weeks and at the end of the summer) were also compared using the Mann-Whitney U test. Noncumulative predation intensity is defined as the percent of seeds removed within each time period.

Predation intensity was also calculated. Predation intensity is a measure of the level of predation at a specific time. Predation intensity was calculated by dividing the number of nutlets newly missing during a given site check (the number of nutlets missing at a given check minus the number of nutlets missing during the previous check) divided by the total number of nutlets originally placed at the site.

A-2.8. Lupine Study

The lupine study was initiated in the fall of 1999 to investigate the potential effects of *Lupinus albifrons* expansion on the biomass accumulation of *A. grandiflora* competitors. In previous years, *L. albifrons* and dying *L. albifrons* in the native population were mapped and presented graphically (Carlsen et al., 2003). In 2001 through 2004, the extent of *Lupinus albifrons* invasion of the native population was recorded with a photograph.

In 2004, we attempted to boost *A. grandiflora* success at the native Drop Tower population by manually removing *L. albifrons* from the entire native population and reducing grass and thatch build-up in selected plots. The vegetation removal treatment was conducted in approximately one half of the existing native population to allow future comparison of areas receiving the vegetation removal treatment and areas were the vegetation has not been altered.

Treatment areas for reducing grass and thatch build-up were chosen by first dividing the native population into a 3 × 4 grid using existing fence posts that mark the perimeter of the population. Of the 12 cells, six were chosen for the vegetation removal treatment based on the historic presence of *A. grandiflora* in the cells; the goal was to apply the vegetation removal treatment to half of the areas that historically contained the majority of *A. grandiflora* plants while leaving the other half of these population centers as controls. Figure A6 shows the historic distribution of *A. grandiflora* at the native population with the treatment locations.

All vegetation removal treatments were conducted on September 29, 2004 well after *A. grandiflora* had senesced, and when the soil was dry and stable, so the site could be accessed without the threat of increased erosion due to foot traffic. In the treatment cells, *L. albifrons* was removed by cutting it at its base. The entire treatment cell was also trimmed using a weed whacker to a height of approximately 10 to 12 inches and lightly raked.

A-3. Results and Discussion

A-3.1. Rapid Seed Bank Enhancement of Experimental *Amsinckia grandiflora* Populations

A-3.1.1. 2002 Seed Sowing at the Experimental Sites

Germination (averaged over all seed sources: germination = number germinated/total number of seeds) was high in the common garden (65.4%) and lower at the two field locations: 37.6% at Site 300 and 18.1% at Lougher Ridge (Table A2).

Germination varied by seed source, with the H source having the lowest germination. This seed was collected from a common garden at U.C. Davis in 1989. Sources D, G, and I had the highest germination (Figure A7). Source D seed was collected from a greenhouse pollination experiment in 1995, source G seed was collected from a common garden experiment in 1998, and source I was collected from a 1994 common garden. Intermediate germination rates were found for source C (1994 field experiment), K (1993 field experiment) and M (1994 greenhouse pollination experiment).

Although Lougher Ridge had low germination rates, average post-germination survivorship per plot at this location was high (29.8 ± 25.2%, number plants at flowering per plot/total number germinated seeds per plot, all values are Means ± 1 SD) compared to Site 300 (4.2 ± 5.9%, Table A2). The common garden had very high overall survivorship (98.2%).

At the end of the growing season, the Site 300 location had 69 flowering individuals that were too small to be expected to produce any seeds (average height 7.4 ± 4.0 cm). Lougher Ridge had 206 flowering individuals that were projected to have produced 1,592 seeds. The average height at this location was 23.5 ± 9.7 cm. (These estimates were calculated using a regression previously developed from the Site 300 experimental population: # nutlets/plant = 16.81* (# of inflorescences) -36.76, r = 0.96, $p < 0.0001$.) The common garden produced 433 plants from which 19,752 seeds were collected. Average height at flowering is unavailable for this population.

The mean dry biomass of samples collected from areas adjacent to Lougher Ridge plots at the time of seed sowing (December 2002), 133 ± 45.7 g/0.1 m^2, was over ten times higher than the mean biomass collected from areas adjacent to Site 300 plots at the same time, 11.3 ± 4.6 g/0.1 m^2 (Table A3). Lougher Ridge plots were thinned at the time of seeding because of the large amount of biomass present. An average of 25.6 ± 7.5 g/0.1 m^2 was removed from the plots. Biomass samples were again taken after thinning. The biomass remaining after thinning was 47.2 ± 18.1 g/0.1 m^2. Unfortunately, this method of estimation does not appear to be accurate because the total of thinned biomass plus remaining biomass is only 72.8 ± 22.6 g/0.1 m^2, which is approximately half the biomass recorded in adjacent areas. Biomass samples taken inside plots were much higher in June of 2003 at Lougher Ridge, 130.0 ± 43.4 g/0.1 m^2, than at Site 300, 13.7 ± 2.6 g/0.1 m^2.

A-3.1.2. 2003 Seed Sowing at the Experimental Sites

Overall germination was considerably higher in 2003 than 2002 at Site 300 (62.2% in 2003 compared to 37.6% in 2002, Tables A2 and A4). Alternatively, at Lougher Ridge, overall germination rates for 2003 (22.5%) were similar to germination rates in 2002 (18.1%). In both 2002 and 2003, the germination rates were higher at Site 300 than Lougher Ridge.

Although germination rates were lower at Lougher Ridge, survivorship to flowering at Lougher Ridge was much higher than at Site 300, repeating the pattern seen in the 2002 seeding (Table A4). Germination at Lougher Ridge was recorded on January 17, 2003 one month later than the Site 300 germination check on December 17, 2003. Because of this, survivorship is not totally comparable, but it gives a general idea of the rate of survivorship at each site. Average survivorship per plot at Lougher Ridge from January 17, 2003 to March 28, 2004 (flowering) was 91.4 ± 19.73% compared to the average Site 300 survivorship per plot from December 17, 2003 to March 26, 2004 which was 39.42 ± 20.07%.

The new seed source was more successful than the old seed source when comparing the mean percent germination and average number of flowering plants (as a ratio of number of flowering plant/number of seeds planted) for Site 300 and Lougher Ridge combined (Table A5). The percent of seeds that germinated was significantly greater for the new seed source than the old seed source (t = 1.76, df = 82.2, $p = 0.04$), and the mean of the ratio of number of plants present at flowering to the number of seeds planted was significantly greater for the new seed source than the old seed source (t = 3.27, df = 75.5, $p = 0.00081$).

The primary difference between the community compositions of two sites in 2003 was the average percent cover of bare ground (Table A6 and Table A11). At Site 300, there was more bare ground (47.0% ± 19.7%: Mean ± SD) compared to Lougher Ridge (1.4% ± 3.3). The dominant species also differ between the two sites. *Bromus diandrus, Lolium multiflorum* and *Carduus pycnocephalus* were the dominant species at Lougher ridge, and no native bunch grasses were observed in the plots. At Site 300, *Avena* sp., *Erodium cicutarium, Vulpia myuros* and *Poa secunda* are the dominant species.

Netting the plots also had a significant effect on the success of the seeding at Site 300 (Table A7). More plants in the netting removed plots showed signs of herbivory (77.9 ± 23.5%) compared to the netted neighbor plots (36.0 ± 31.3%: t = -3.66, df = 12, $p = 00016$). Plants were also larger in the netted neighbor plots ($X^2 = 132.28$, df = 4, $p < 0.001$). The mean percent of the larger 4-leaved (63.6 ± 10.1%) and 6-leaved (6.8 ± 7.1%) seedlings in netted plots was greater than the mean percent in 4-leaved (39.9 ± 13.8%) and 6-leaved seedlings (0.5 ± 1.4%) in unnetted plots. Alternatively, for the smaller size classes, the mean percent of seedlings per plot was greater in the unnetted plots than in netted plots.

A-3.2. Spring Census

Population sizes continued to be very small in the Drop Tower Native population in 2003 and 2004. A total of five *A. grandiflora* were observed in 2003; one at the original Drop Tower native site and four in the Carlsen-Gregory subpopulation. In 2004, only three *A. grandiflora* were observed in the native Drop Tower population: one in the original site and two at the Carlsen-Gregory subpopulation (Table A8, Figure A8).

Population numbers were higher in the experimental subpopulations in 2003 and 2004 compared to the native population as a result of the success of rapid seed bank enhancement efforts in 2003 compared to 2002 (Table A8).

Figure A9 shows the general locations of *A. grandiflora* plants observed in the native Drop Tower population in 1998–2004. The Native population has contained less than fifty plants each year for the last six years (Figure A8). As can be seen in Figures A10 and A11, numbers of individuals observed in the FL and FF subpopulations have also remained low in recent years. Although the 2003 seed bank enhancement project was successful in increasing the population size in the FL subpopulation, these plants were very small. Plants in the FL subpopulation in 2003 were 7.3 ± 4.0 cm tall (Mean ± SD) and unbranched and 13.7 ± 5.3 cm tall with very few plants having more than one branch in 2004. As result of the small plant size, the FL subpopulation was estimated to produce no seeds in 2003 and fewer than 30 seeds in 2004. Although there were many fewer plants in the native population compared to the experimental populations, the plants in the native population were much larger (18 ± 3.7 cm height in 2003 and 20.7 ± 11.11 cm height in 2004) and therefore were estimated to produce more seeds than the experimental populations.

When examining population sizes from Draney Canyon, the Drop Tower native population, and the Drop Tower experimental population (Figure A12), it appears that numbers remained stable or increased in the years 1986 to 1996. After 1996, the numbers of all three populations dropped. Draney Canyon had no plants in 1998–2000 and was not surveyed in 2001, 2002, or 2003. The historic Draney Canyon population site and surrounding areas were surveyed in 2004 and no *A. grandiflora* was observed. While it appears that high rainfall years are detrimental to *A. grandiflora* populations, the effect is either delayed or dependent on multiple years of high rainfall in close proximity. The size of all four populations with total annual rainfall is shown in Figure A12.

A-3.2.1. Nearest Neighbor Data

Composition of nearest neighbors overemphasizes the importance of small, understory plants, but since data collection methods have remained the same over the years, these data are useful in making comparisons among subpopulations and years. Table A9a,b shows the percent species composition of *A. grandiflora* nearest neighbors for both native and experimental populations.

Shannon's index (H') of diversity is also shown although this index should be used with caution because the highest possible value of H' is affected by sample size. For example, the highest possible H' for a sample size of three is 1.10 while the highest possible H' for n = 10 is 2.30 and for n = 20 is 3.0.

The exotic species *Erodium cicutarium*, *Avena* spp., *Bromus diandrus,* and *Bromus hordeaceus* have consistently been among the most common nearest neighbors in the native, FF, and FL subpopulations. Another exotic grass, *Vulpia myuros,* did not occur as a nearest neighbor in the native population in 1997–1998 but has periodically been a common nearest neighbor in the native and experimental populations since 1999.

The presence of native forb and grass species, such as *Galium aparine, Collinsia heterophylla*, *Achillea millefolium* and *Poa secunda,* as nearest neighbors in the experimental and native populations, has been much more variable. Other native plants that commonly occur as nearest neighbors are *Claytonia parviflora* and *Lupinus bicolor*.

A-3.2.2. Cover Estimates

Cover estimates have been taken in all three populations since 2001. Cover estimates for 2003 are shown in Table A10. *Erodium cicutarium* has the highest importance value for all three populations in 2003. In the FL subpopulation, two native forbs, *Clarkia* sp. and *Lupinus bicolor* have the 2nd and 3rd highest I.V. Two grasses, *Avena* sp. and *Poa secunda,* ranked 2nd and 3rd in I.V. in the FF subpopulation. In the native population, *Avena* sp. and *Vulpia myuros* had relatively high I.V. The I.V. for *A. grandiflora* is relatively high for the native population because plot locations were chosen in the native population to coincide with the location of *A. grandiflora* plants.

Table A11 shows the cover estimates for 2004 for the native, FL and FF subpopulations. Again in 2004, *Erodium cicutarium* had the highest I.V. for both experimental populations, but *Avena* sp. ranked highest in the native population. In the FL and FF subpopulations, *Avena* sp., *Lupinus bicolor, Poa secunda,* and *Vulpia myuros* also have relatively high I.V. The I.V. for *A. grandiflora* is also the highest in the FL subpopulation because the seed bank enhancement conducted the previous fall in this population resulted in the presence *A. grandiflora* in 84% of the plots that cover estimates were taken from. In the native population, *Bromus hordeaceus* and *Erodium cicutarium* have the 2nd and 3rd highest I.V.

2004 cover estimates were taken 10 months after the prescribed burn of the entire FL subpopulation. As a result, the mean cover of bare ground in the FL subpopulation increased from 12.8% in 2003 to 47.0% in 2004, and the mean cover of thatch decreased from 10.8% to 2.1%. While the cover of bare ground in the native and FF subpopulation remained relatively constant in 2003 (FF mean cover 17.9%, Native mean cover 15.0%) and 2004 (FF mean cover 23.4%, Native mean cover 13.5%), the mean cover of thatch in these populations more than doubled from 2003 (FF mean cover 7.4%, Native mean cover 20%) to 2004 (FF mean cover 15.6%, Native mean cover 55%).

The 2003 and 2004 cover estimates reveal several similarities and differences in the composition of the three Site 300 populations. *Erodium cicutarium* and *Avena* sp. dominate all three populations, although some differences are present that appear to be a result of the treatments applied to the experimental populations more than differences in microhabitats. The FL subpopulation has a high cover of bare ground and low percent cover of thatch relative to the other populations, and native forbs are more important in the FL subpopulation than in the other two populations. In the FF subpopulation, *P. secunda* continues to rank among the highest I.V., but was uncommon in the native population.

A-3.3. Flashing Subpopulation Biomass Collection

Biomass samples have been collected in the FL plots each year since 1998 to measure the difference in four biomass categories (herb, thatch, *Poa,* and total) between burned and unburned plots and in plot types originally established in 1993. Three types of plots were established in 1993, those planted with *Poa secunda* at a specified density, plots with existing *Poa secunda,* and plots cleared of all perennial grasses. The planted *Poa* and existing *Poa* plots were established at three different densities (low, medium, and high). Original 1993 *Poa* densities are shown in Table A13. The original treatment burns were conducted in May of 1998 and 1999.

Changes in total biomass in burned and unburned plots are shown in Figure A13. Total biomass was at its highest in 1998 at around 30 g/0.1m^2 for burned plots and 20 g/0.1m^2 in unburned plots. Not only were these biomass samples taken before the first prescribed burn in the FL plots, the previous winter was unusually wet (19.7 inches rainfall). Although total biomass in the FL subpopulation gradually declined from 1998 to 2001, there was an increase in biomass in 2002. Total biomass decreased again in 2003 and 2004. In 2003, the total average biomass was 13.7 g/0.1m^2, and, in 2004, total average biomass dropped to 6.5 g/0.1m^2. This is the lowest total average biomass since 1998.

From 2001 through 2004, there was little difference in total biomass in burned and unburned plots (Table A12, Figure A14a,b). A significant difference in total average biomass between burned and unburned plots was only observed in 1999 and 2000, the first growing seasons following the treatment burns. Total biomass in 1999 and 2000 was close to 20 g/0.1m^2 in unburned plots and approximately 10 g/0.1m^2 in burned plots.

Biomass samples collected from the FL subpopulation were lower in 2004 than 2003 for all four categories of biomass (annual grasses, herbs, *Poa* and thatch). The largest decrease between 2004 and 2003 was in thatch, which decreased from 0.72 g/0.1m^2 to 0.08 g/0.1m^2. The average biomass of annual grasses and thatch was lower in 2003 compared to 2002; the average biomass of *Poa* and forbs increased slightly in 2003.

There was a significant difference ($p < 0.05$) in herb biomass in burned versus unburned plots in 2002, but not in any of the other biomass categories. "Burned" plots have not been burned since 1999, so it is possible that this lack of difference between the two plot types in 2001 and 2002, particularly for thatch (a variable for which the two areas have traditionally been different in the past), is due to that factor. Comparisons between burned and unburned plots were not done for 2003 and 2004 because of small sample size.

A-3.4. Flashing Subpopulation *Poa secunda* Persistence

In 2003, ten years after the FL plots were established at fixed densities of *Poa secunda* or cleared of perennial bunch grasses, there was a significant difference in *P. secunda* density between the three plot types: *Poa* planted, existing *Poa,* and plots cleared of perennial grasses (F = 3.49, $p = 0.038$; Table A13). After plot establishment in 1993, there had been a significant difference in density by plot type until 2000. In 2001 and 2002, there was not a significant difference due to starting density or plot type. In 2002, there was a significant interaction between starting density and plot type ($p < 0.05$). Once again, in 2004 the difference in *Poa* densities between plot types falls short of significance (F = 2.66, $p = 0.080$). In 2003 and 2004, there was also no significant difference in *Poa* densities based on starting density.

Until 2000, there was no difference in *Poa* densities between burned and unburned plots. In 2000, after two consecutive years of burning, there appeared to be a difference in *P. secunda* densities between burned and unburned plots ($p = 0.017$). In 2001, when two years had passed since the last burn, the effects of the burn were not significant for *P. secunda* density ($p = 0.09$). In 2003 and 2004, there continued to be no effect on *Poa* density from the 1999 burn.

A-3.5. Fire Frequency Experiment

Figure A15 shows the density of *Poa secunda* in the FF plots from 1999 through 2004. The FF plots were originally established in 1999 with 33 *P. secunda* per plot for all fire frequencies. In 2000, the number of *P. secunda* dropped only slightly in all plots (average of 29 *P. secunda* plants per plot), and in 2001, the number of *P. secunda* per plot continued to drop (average of 22 *P. secunda* plants per plot) (Table A14). In the summer of 2001, after *Poa* counts were completed, FF treatment burns began. All plots except the control plots were burned in 2001. In the FF subpopulation, the overall average number of *Poa* plants per plot increased to 27 in 2002. In 2002, only one treatment burn had been conducted so effectively there were only two different burn frequencies in the population: controls and all other plots. In 2002, the density of *Poa* plants in the control plots was significantly less than (Wilcoxon rank sum, W = 13.5, $p = 0.04$) the density in other plots. There was an average of 20.6 ± 6.4 plants/m^2 (Mean ± SD) *Poa* in the control (unburned) plots and 29.1 ± 7.1 plants/m^2 in all other plots (burned).

In 2002, there was also a significant difference in *A. grandiflora* densities in control plots versus all other plots (Wilcoxon rank sum, W = 65, $p = 0.01$; Table A15). The average density of *A. grandiflora,* 1.5 ± 2.5 *A. grandiflora*/m^2, in the burned plots (low, medium, and high frequency) was less than the 5.6 ± 4.8 *A. grandiflora*/m^2 in the control plots.

In 2003, the average *Poa* density for the three different fire frequencies was not significantly different (ANOVA, $F_{2,17} = 0.72$, $p = 0.5$) although the control plots continued to have the lowest *Poa* densities 20.6 ± 9.44 *Poa*/$m^{2,}$ Mean ± SD) followed by the low and medium frequency plots (25.4 ± 6.1 plants/m^2) and the high frequency plots (26.4 ± 11.4 plants/m^2). In 2004, *Poa* densities had the same ranking as in 2003 when divided by fire frequency treatments (control, low & medium, high), although the difference between the groups widened, and there was a significant difference between fire frequency treatments (ANOVA, $F_{2,17} = 17.882$, $p \leq 0.0001$). The average density of *Poa* in the control plots in 2004 (8.0 ± 4.2 plants/m^2) decreased sharply from the 2003 density, and the density increased in the high frequency plots in 2004 (27.2 ± 7.0 plants/m^2) compared to 2003. Post hoc tests show that there is a significant difference in the average *Poa* density between the control plots and the high frequency plots and between control and the combination of low and medium frequency plots (Tukey's HSD, $p < 0.001$) while there was not a significant difference between *Poa* densities in the high frequency plots compared to the low & medium frequency plots (Tukey's HSD, $p = 0.1$). A significant difference in *A. grandiflora* densities in the three burn groups was not seen in 2003 (Kruskal-Wallis rank sum, 1.6, $p = 0.4$), and in 2004 the difference in *A. grandiflora* densities just missed significance (Kruskal-Wallis rank sum, 5.2, $p = 0.08$).

A-3.6. Predation Study

Figure A16 shows the median cumulative predation for 1998 through 2004 for the first three weeks of monitoring. The cumulative predation in 2004 was quite high compared to most other years especially in the FL subpopulation. Although the average cumulative percent predation reached 80.2 ± 8.6% (mean ± SD) in 2003 by the end of the summer, predation was only 32.0 ± 22.1% after three weeks (Figure A17). This is significantly less ($p < 0.0045$) than the 2004 cumulative percent predation of 84.8 ± 22.5% over the same time period. Cumulative predation through the end of the summer in 2003 was also significantly less than ($p < 0.011$) from the cumulative predation through the end of the summer in 2004 (94.6 ± 8.6%).

Predation intensity (Figure 18) was particularly high early during the 2004 monitoring period. In 2004, predation intensity was 58.9 ± 38.5% by day 7, and in 2003, predation intensity had only reached 10.7 ± 6.3%.

The final cumulative predation was significantly higher ($p < 0.014$) in the FL subpopulation (98.4 ± 22.0%) compared to the FF subpopulation (70.6 ± 2.5%) after the first three weeks, and also at the end of the summer ($p < 0.018$; FL 100 ± 0%; FF 89.2 ± 8.8). In the four years where seed predation in burned and unburned areas was compared, predation in the burned plots was always statistically equal to or higher than predation in the unburned plots (Espeland et al., 2005). The FL plots had been burned in June of 2003, and 2004 summer predation monitoring in the FL plots was conducted the following growing season after the burn. By contrast FF predation monitoring in 2004 was conducted in plots that had not been burned since 1998 or 2001.

A-3.7. Lupine Study

Figure A19a,b shows a photograph of the native population in the spring of 2001–2004. The distribution of *L. albifrons* was similar during those three years, although many of the lupines present had begun to die back. Also, many of the lupines removed in the fall of 2004 as part of the vegetation clearing treatment had died prior to removal.

A-4. Recommendations and Future Work

The native Drop Tower population continued to be very small in 2003 and 2004. The native population had only three plants in 2004; the smallest population size recorded since 1980. The number of *A. grandiflora* in the FL and FF experiment populations has also been low recently. In 2003, even after the seed bank enhancement of the previous winter, only 69 *A. grandiflora* were found in the FL subpopulation.

Site 300 seedlings suffered from a great deal of herbivory in the winter of 2003, which caused many of the plant deaths. There was also an unusual rain pattern during the 2002/2003 rainy season. After a wet December (3.55 inches rainfall) in 2002, there was only a total of 2.0 inches of rain in January through March of 2003 (LLNL 2004). This lack of rainfall early in 2003 may have decreased the survivorship of plants, from the 2002 seed sowing, that germinated after the December rains.

In 2004, after two years of seed bank enhancement efforts, there were 753 *A. grandiflora* in the FL experimental subpopulation. Unfortunately, these plants were very small and weren't expected to produce much seed. The Lougher Ridge experimental populations produced 868 *A. grandiflora* in 2004 (also following two years of seed bank enhancement). The Lougher Ridge plants were larger than the Site 300 plants resulting in the estimated production of over 8,700 seeds.

As a result of the 2002 and 2003 seed bank enhancement projects, we were also able to make several conclusions about the methods used to enhance the germination and survival of *A. grandiflora* grown from seed in the experimental populations. Germination in the common garden was high, which indicates that the seed from most seed sources was quite viable. It is likely that seeds had lower germination rates at the two field locations due to two factors: (1) granivory and (2) unsuitable microconditions. Seeds that were not eaten but were unable to germinate due to nonoptimal conditions in the soil should be a continuing source for population of future years.

Amsinckia grandiflora seed stored in the seed collections at LLNL does appear to lose some viability with age. Older seed sources were shown to be less successful in the 2002 and 2003 seed bank enhancement projects. Previous germination studies have also shown that greenhouse and common garden grown *A. grandiflora* seeds have increased germination rates compared to field grown seeds (unpublished data). This increased germination rate may be due to decreased seed dormancy because of an extremely favorable maternal environment rather than due to increased seed viability. Seedlings also grew larger and showed less signs of herbivory when plots were covered in as plastic netting designed for exclude birds.

We are also beginning to see results in the long-term fire frequency experiment begun in 2001. The native perennial grass *Poa secunda* is most abundant in plots that are burned annually. Previous research shows that *A. grandiflora* is more successful in plots dominated by *P. secunda* compared to plots dominated by exotic annual grasses (Carlsen et al., 2000), but early results from the fire frequency experiment show that *A. grandiflora* is more abundant in the unburned control plots dominated by dense annual grasses than the burned plots. Clearly there are a variety of factors affecting the success of *A. grandiflora* populations.

While prescribed burns help to produce a plant community dominated by *P. secunda*, seed predation is also higher in plots that have been burned. Because of the extremely high rates that we have observed in some years, seed predation is very likely a significant factor in determining *A. grandiflora* population sizes. Seed predation across years appears to be biomodally distributed; Some years have lower predation and in some years seed predation almost completely removed all *A. grandiflora* seed. By continuing to monitor seed predation rates we should be able to identify environmental factors that contribute to “good” and “bad” years.

While we have revealed some clues to the successful restoration of *A. grandiflora* populations and continue to work to sustain the existing experimental and native populations, the reasons for the sharp declines in this population in recent years are still unclear. Seed bank enhancement efforts are more successful when plots are netted and seeds from greenhouse or common garden experiments are used, but the resulting plants can be small and produce little seed. We can promote the establishment of a native perennial grassland with prescribed burns, but seed predation is quite high in these burned areas. To help unravel the combination of factors necessary to promote *A. grandiflora* success, we plan to continue our long-term fire frequency and predation experiments, and explore the benefits of the vegetation removal treatment in the native populations. If funding becomes available, we also hope to study the effects of grazing on *A. grandiflora* success.

A-5. References

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Section A
Figures

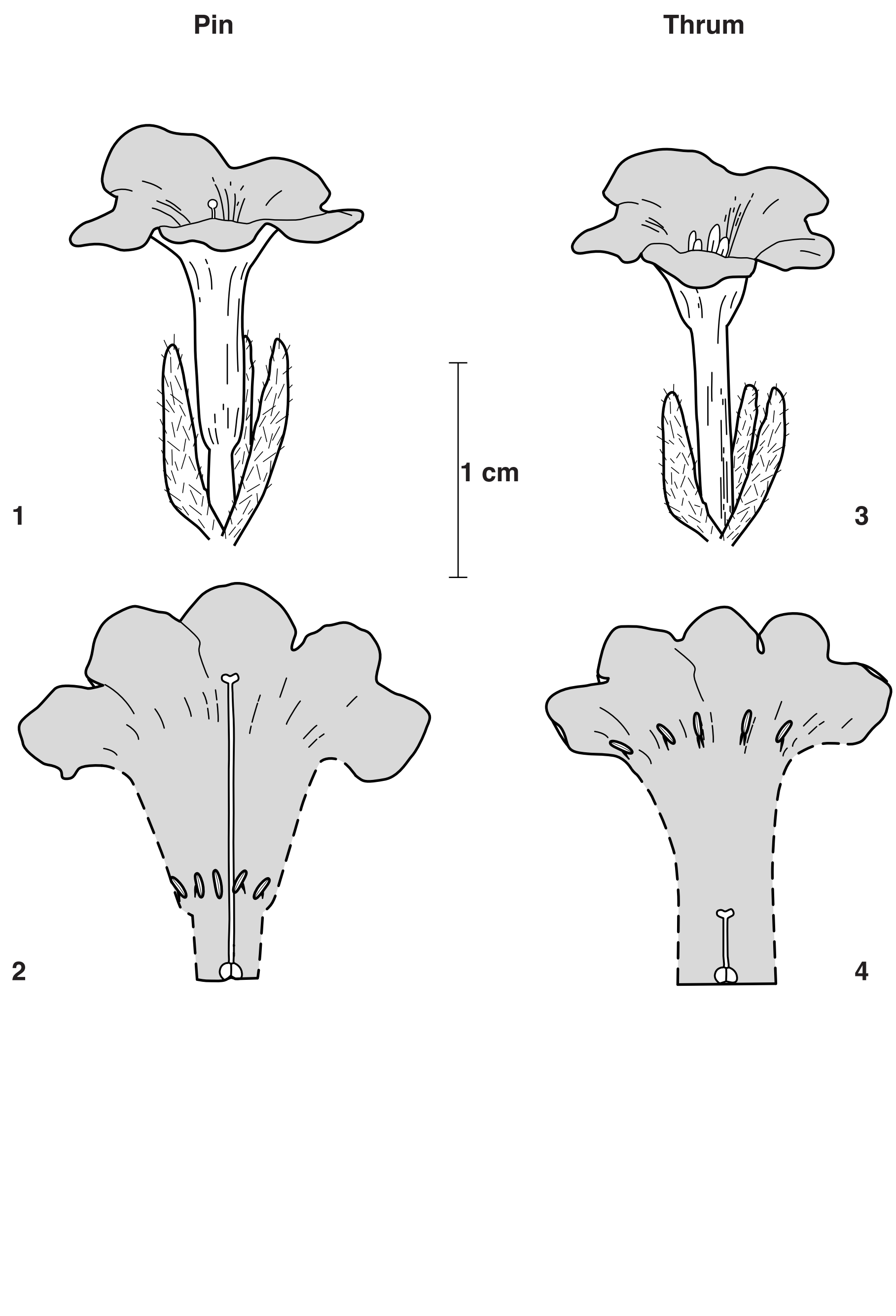

Figure A1. Flowers of *Amsinckia grandiflora.* 1. Intact pin flower. 2. Dissected pin flower. 3. Intact thrum flower. 4. Dissected thrum flower. (from Ornduff, 1976)

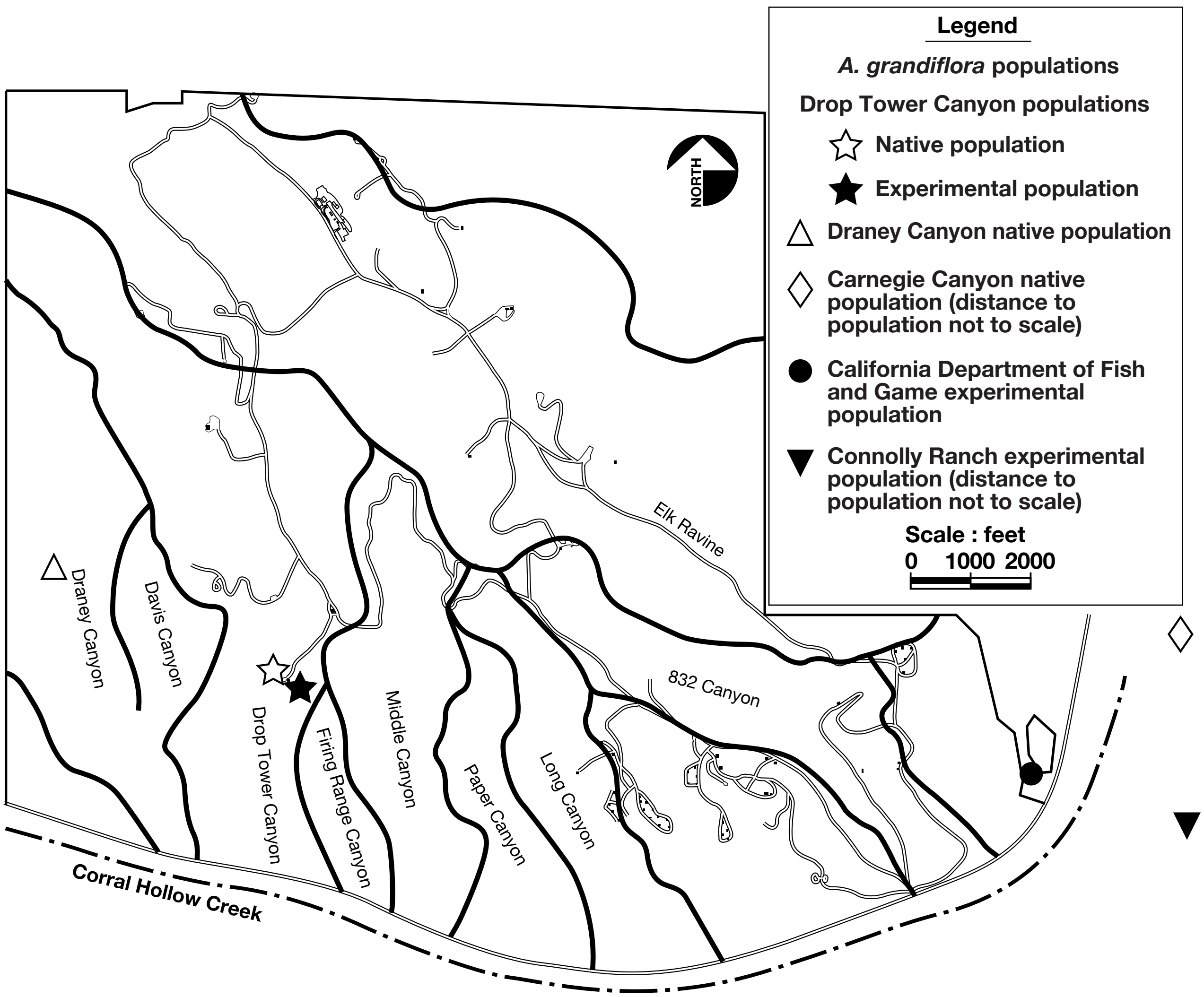

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Figure A2. Locations of *Amsinckia grandiflora* populations at or near Lawrence Livermore National Laboratory (LLNL) Site 300.

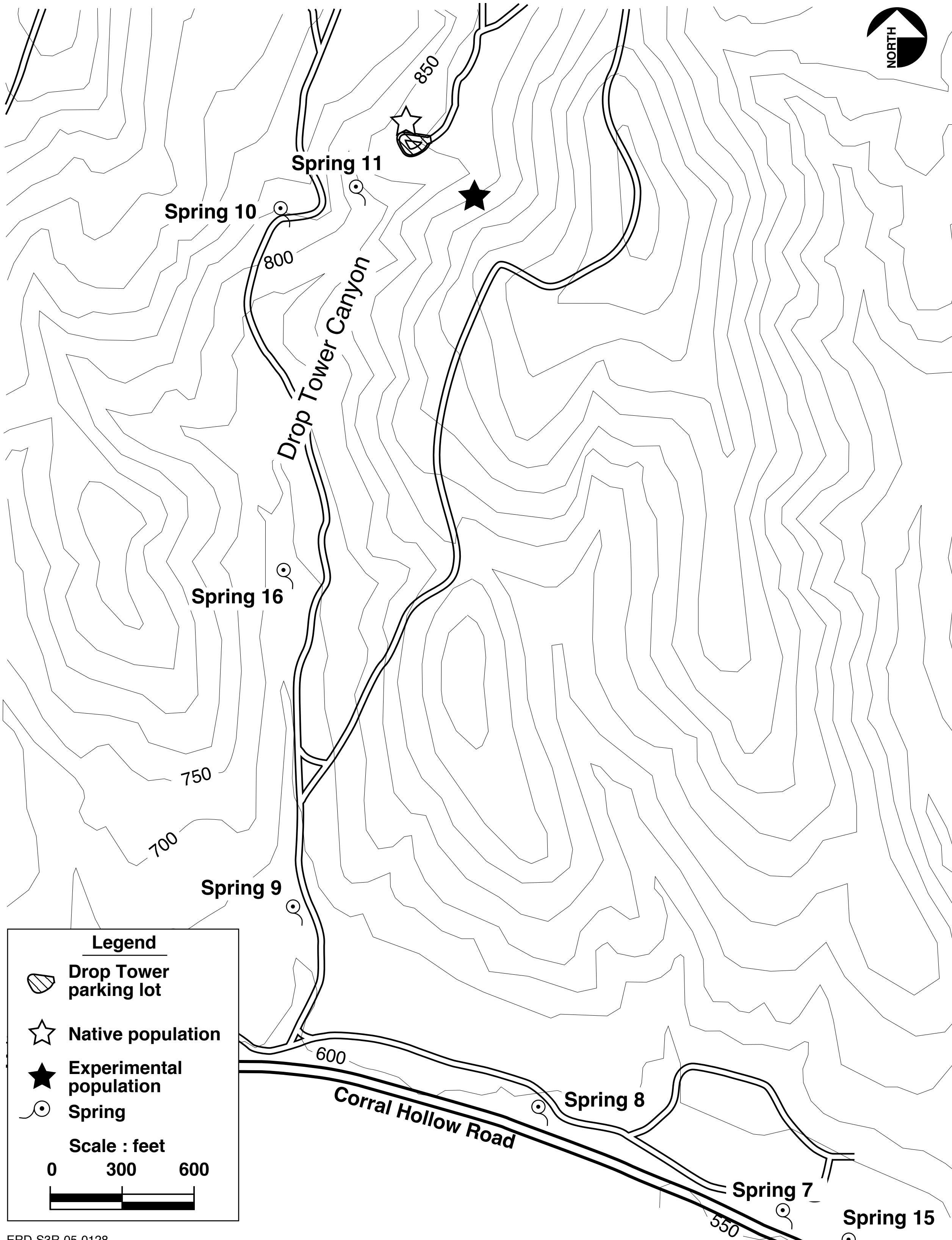

Figure A3. Location of native and experimental *Amsinckia grandiflora* populations in Drop Tower Canyon.

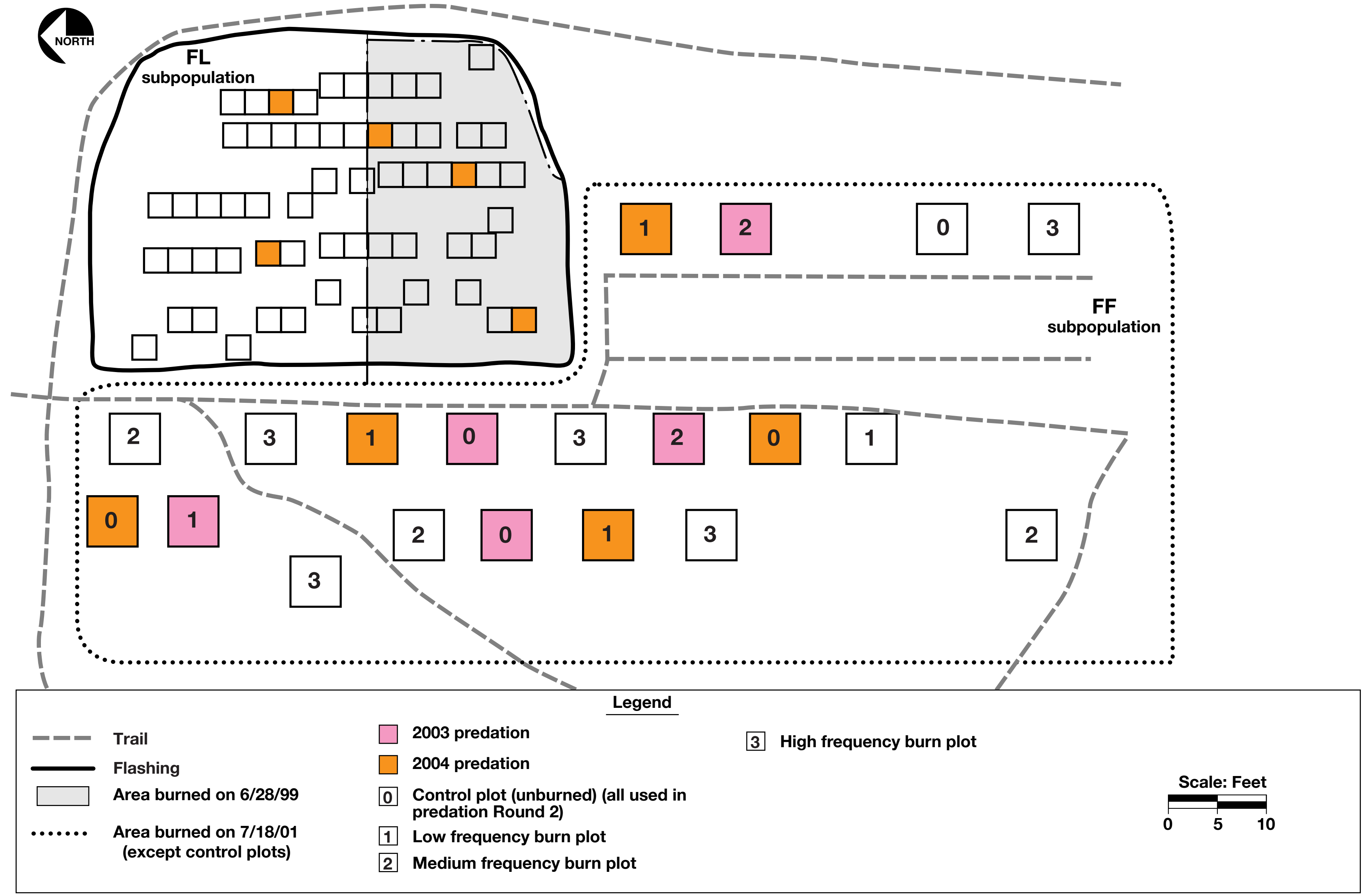

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Figure A4. Summary of experimental treatments at the experimental *Amsinckia grandiflora* populations.

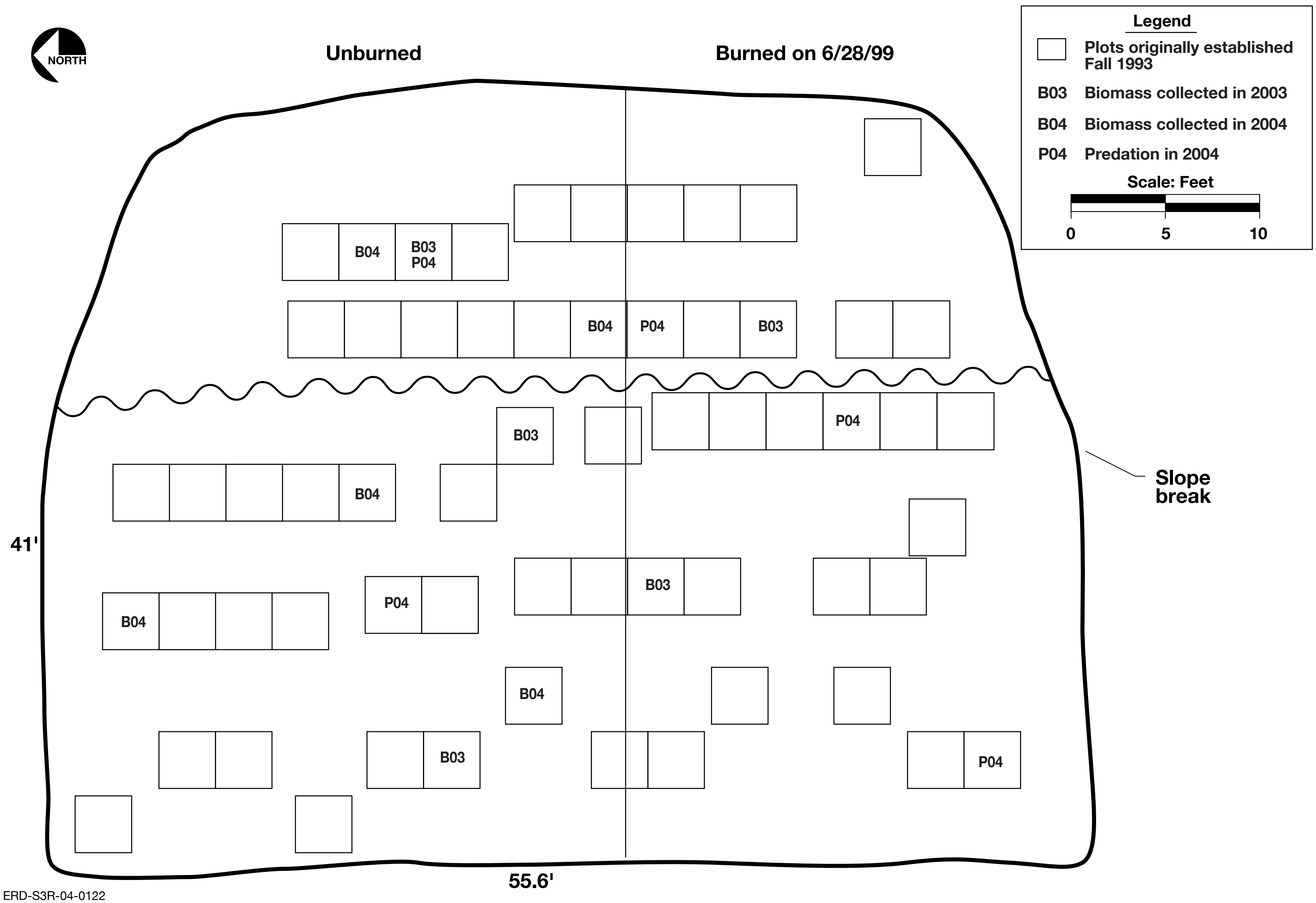

Figure A5. Summary of experimental treatments at the experimental FL subpopulation.

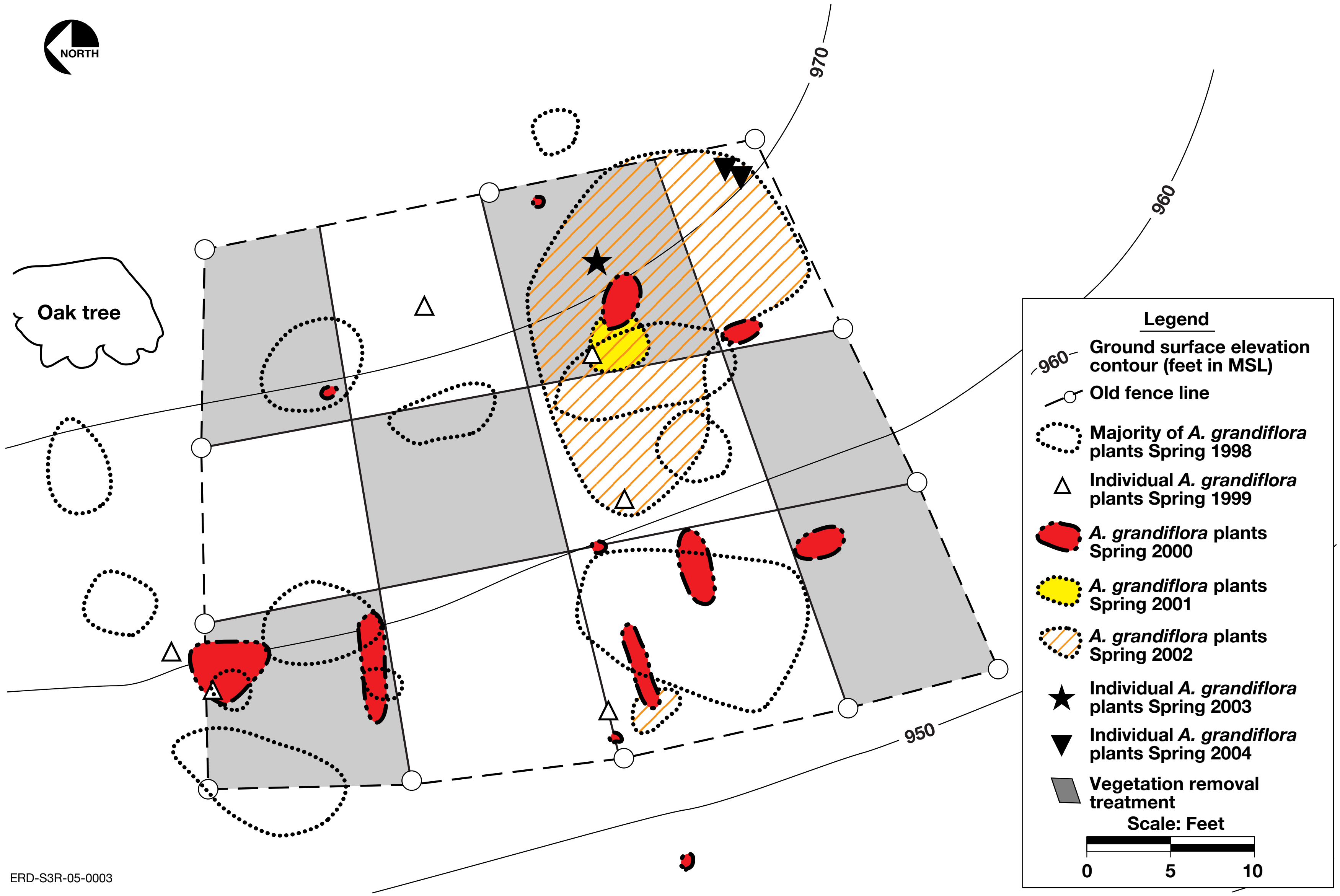

Figure A6. Native population *Amsinckia grandiflora* locations and vegetation removal. Shaded plots were cleared of *Lupinus albifrons* and other vegetation to a height of 8 – 10 inches and lightly raked on September 29, 2004. *Lupinus albifrons* only was removed from unshaded plots.

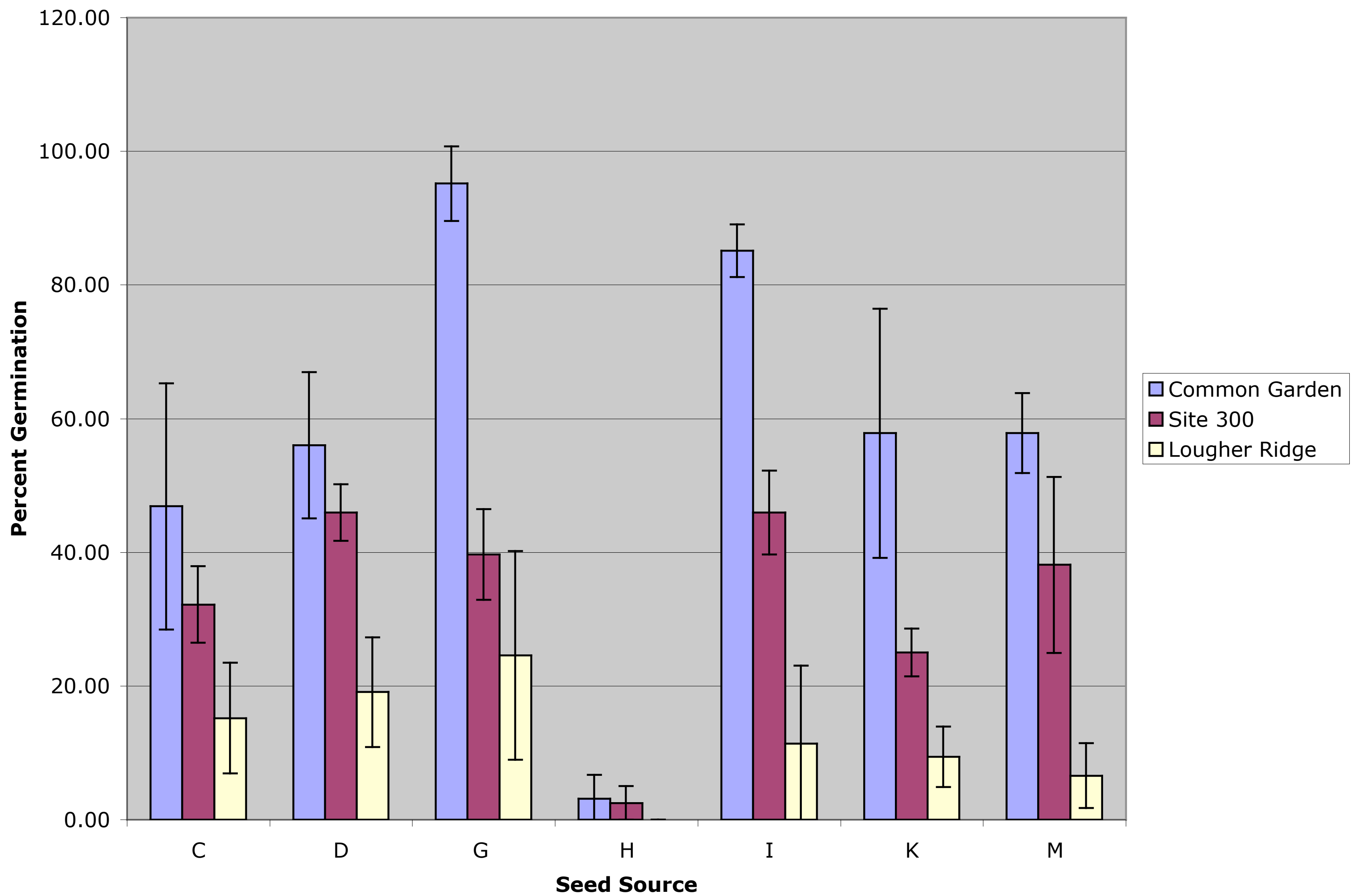

Figure A7. Seed bank enhancement study germination. Percent germination of *Amsinckia grandiflora* seeds sown at Site 300 and Lougher Ridge experimental populations in December 2002, and seeds germinated in Petri plates before transplant to pots for the common garden experiment. (Error bars represent standard deviation)

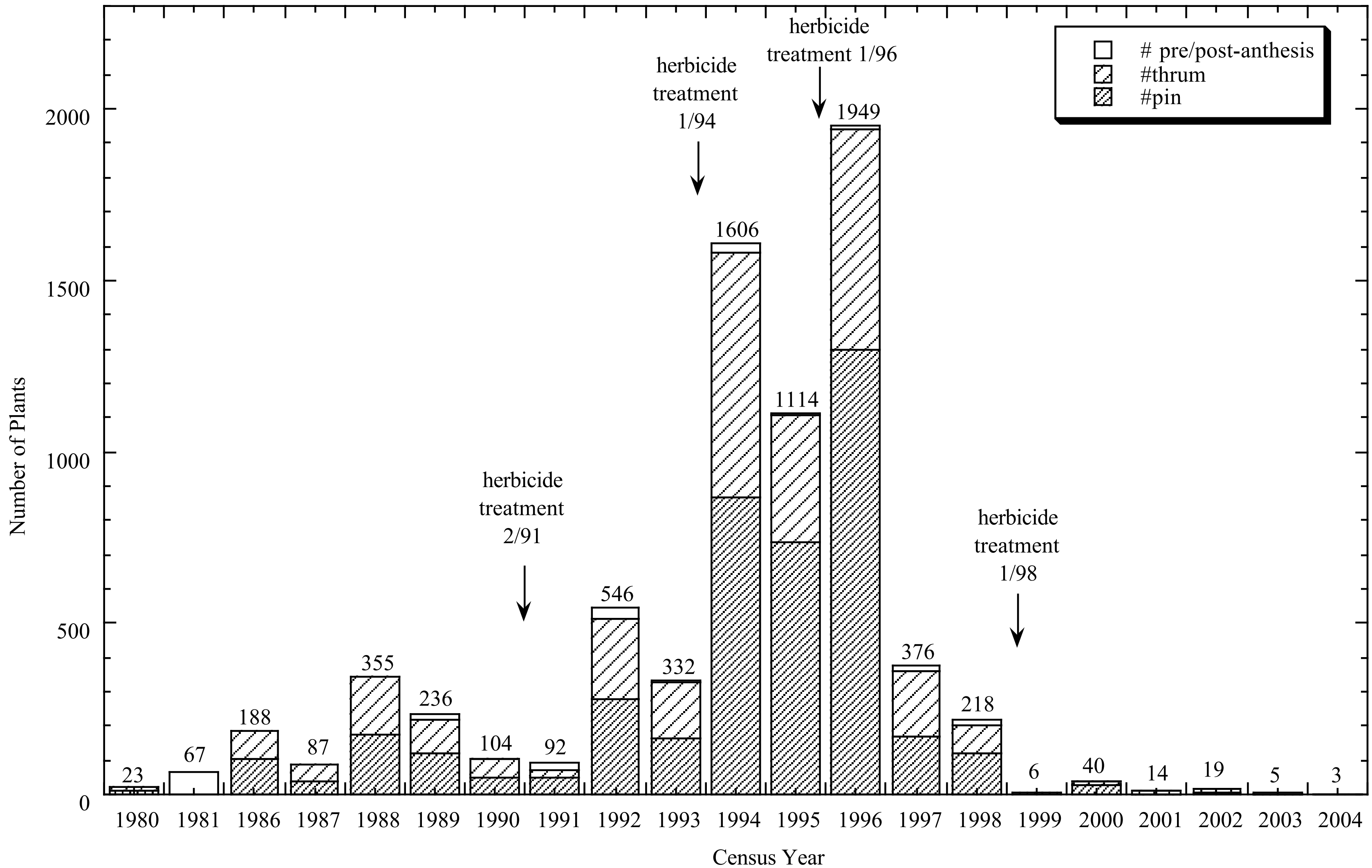

Figure A8. Historical spring census data of the Site 300 Native Drop Tower population. Total population size is given above each bar. Approximate timing of herbicide treatments is shown.

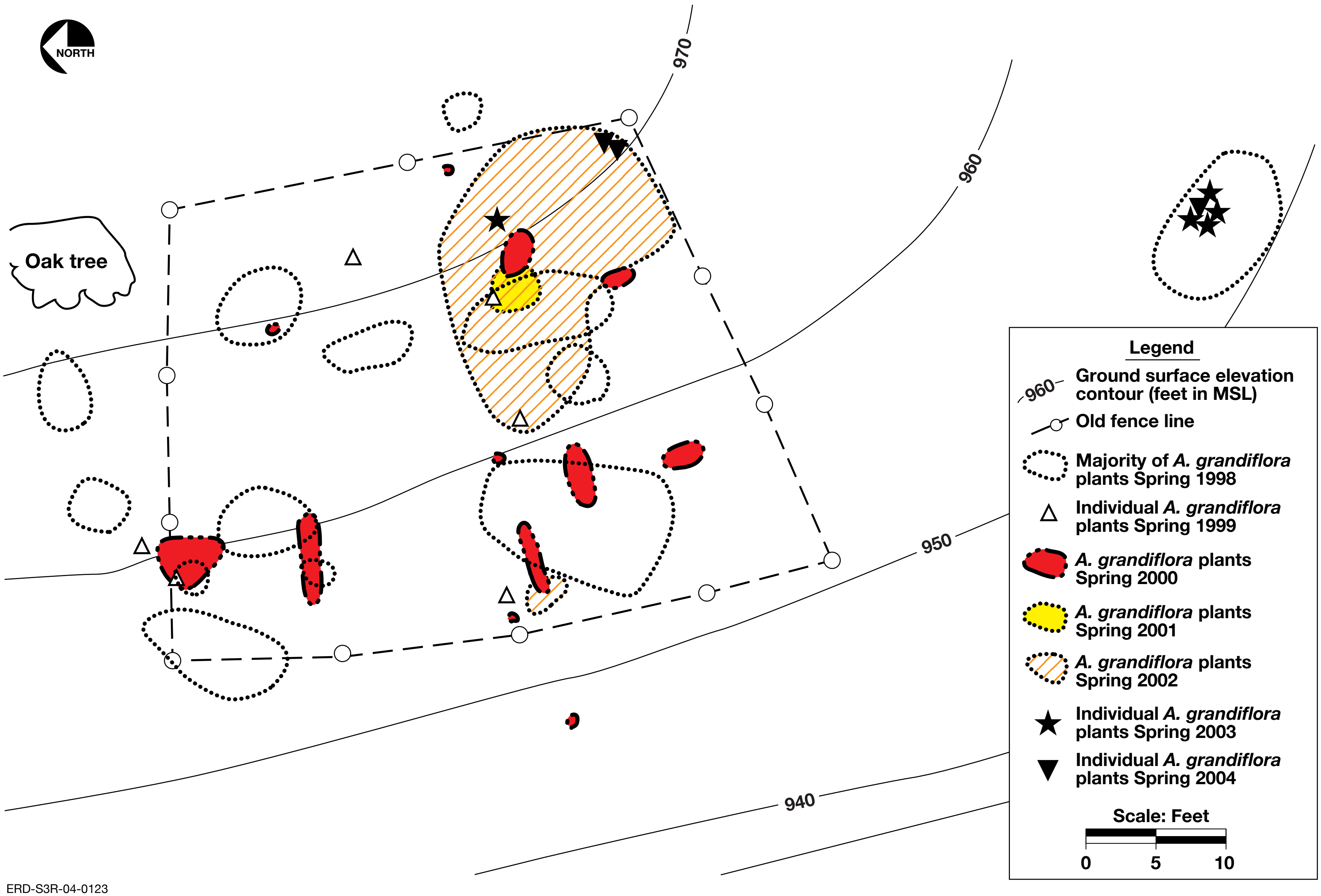

Figure A9. Spring census of the *Amsinckia grandiflora* native Drop Tower population: 1998–2004.

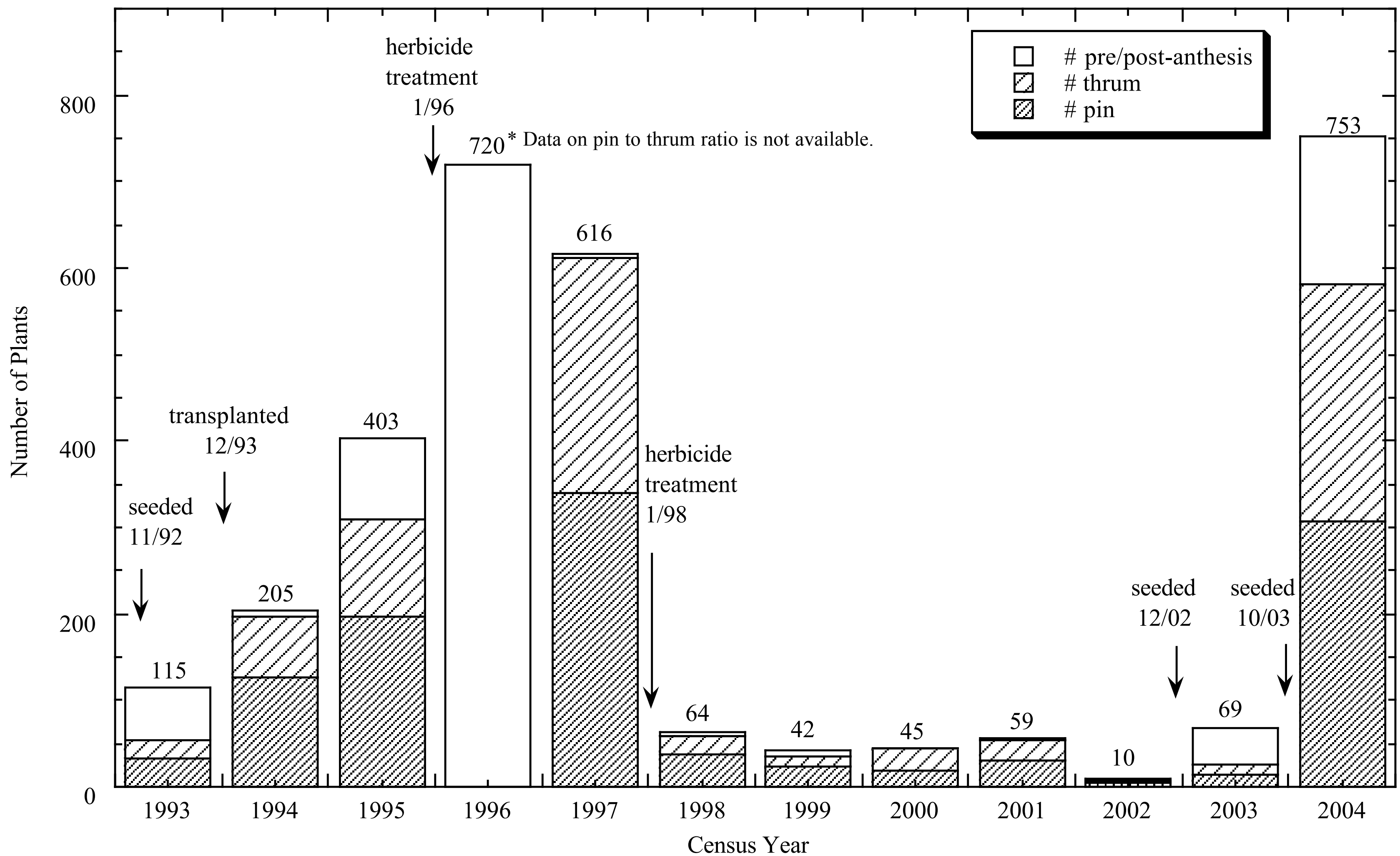

Figure A10. Historical spring census data of the Site 300 experimental FL subpopulation. Total population size is given above each bar. Approximate timing of all treatments is shown.

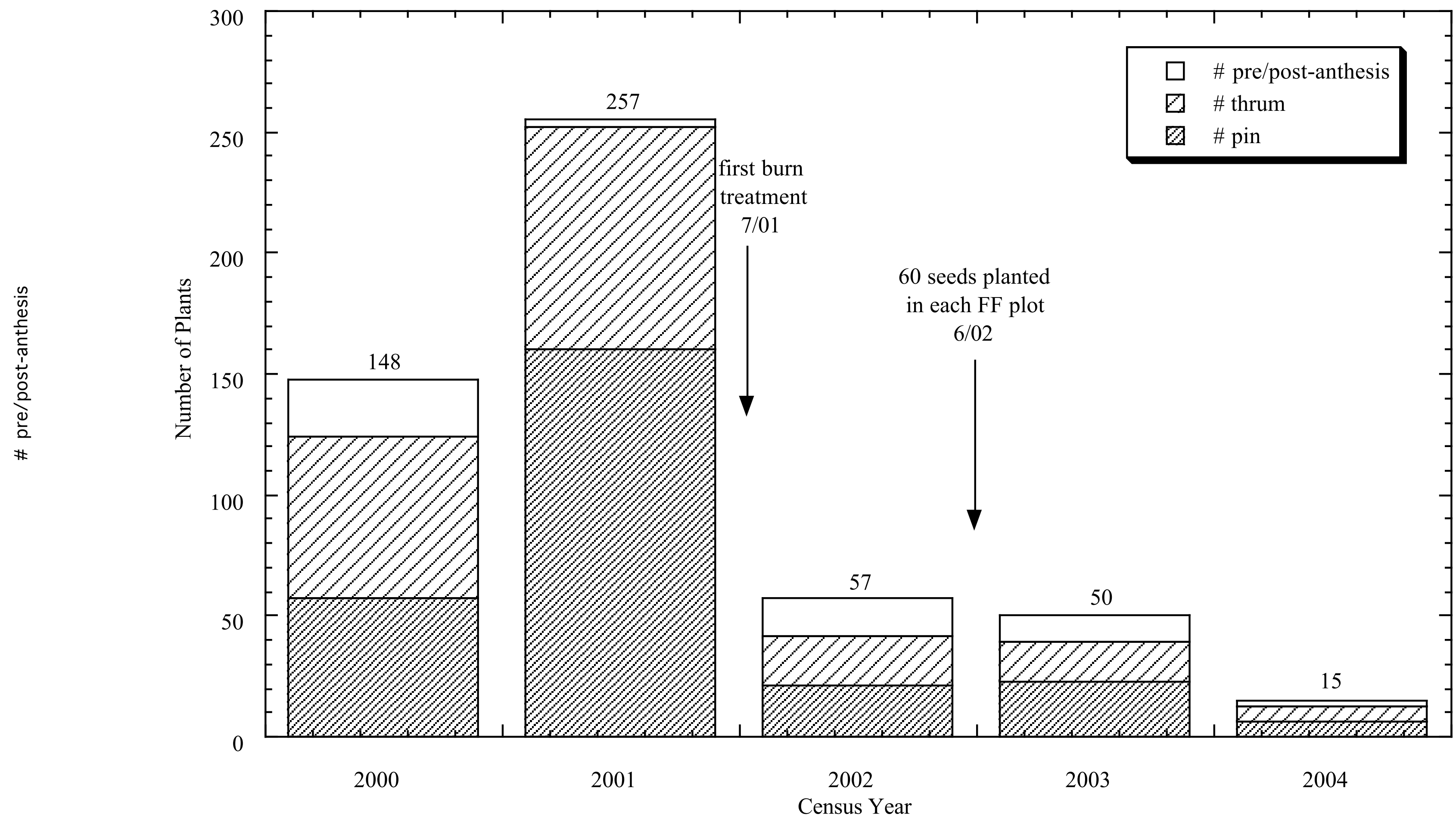

Figure A11. Spring census data of the Site 300 experimental FF subpopulation. Total population size is given above each bar.

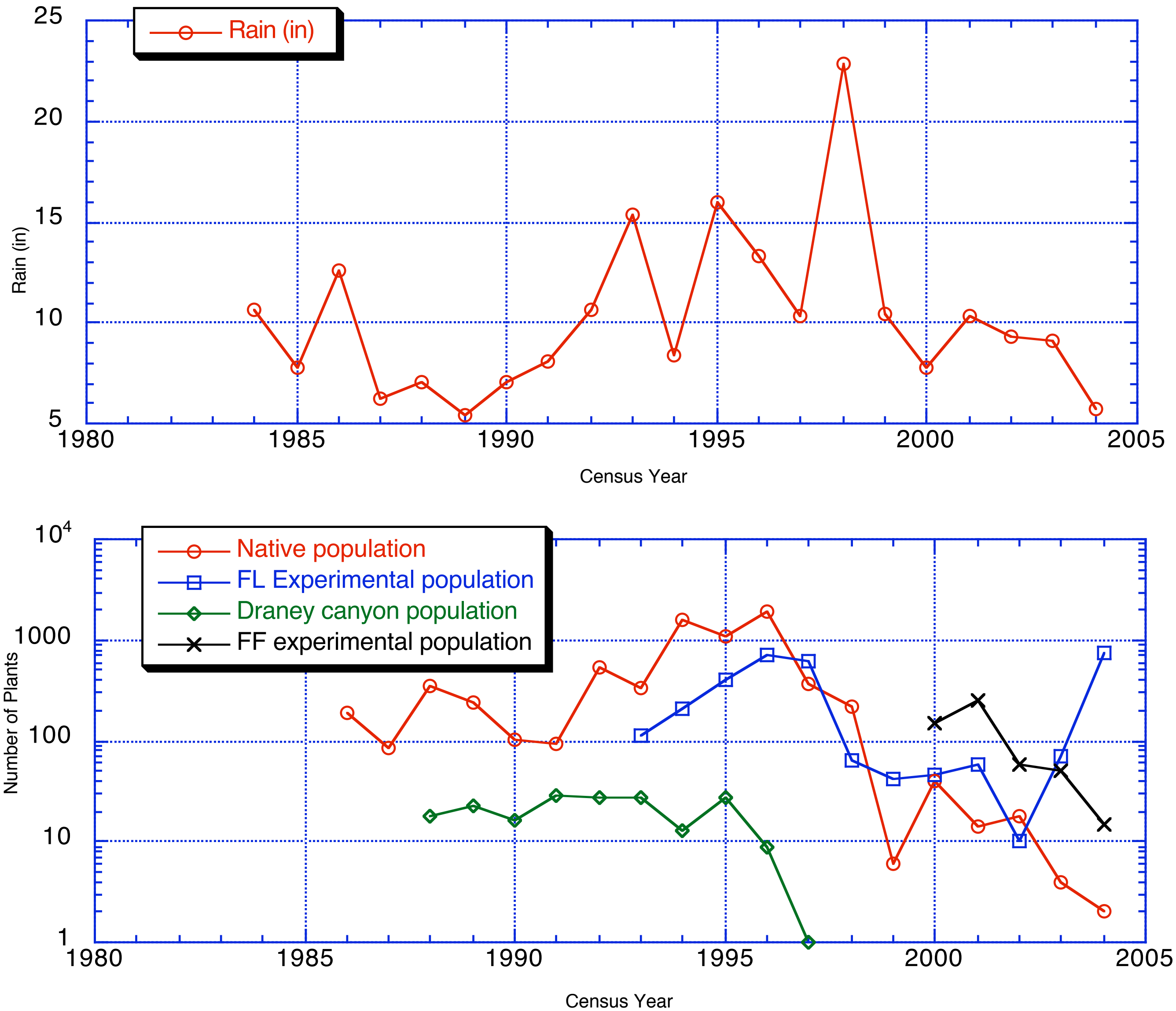

Figure A12. Log plot of population size at time of census, shown with rainfall totals over growing season.

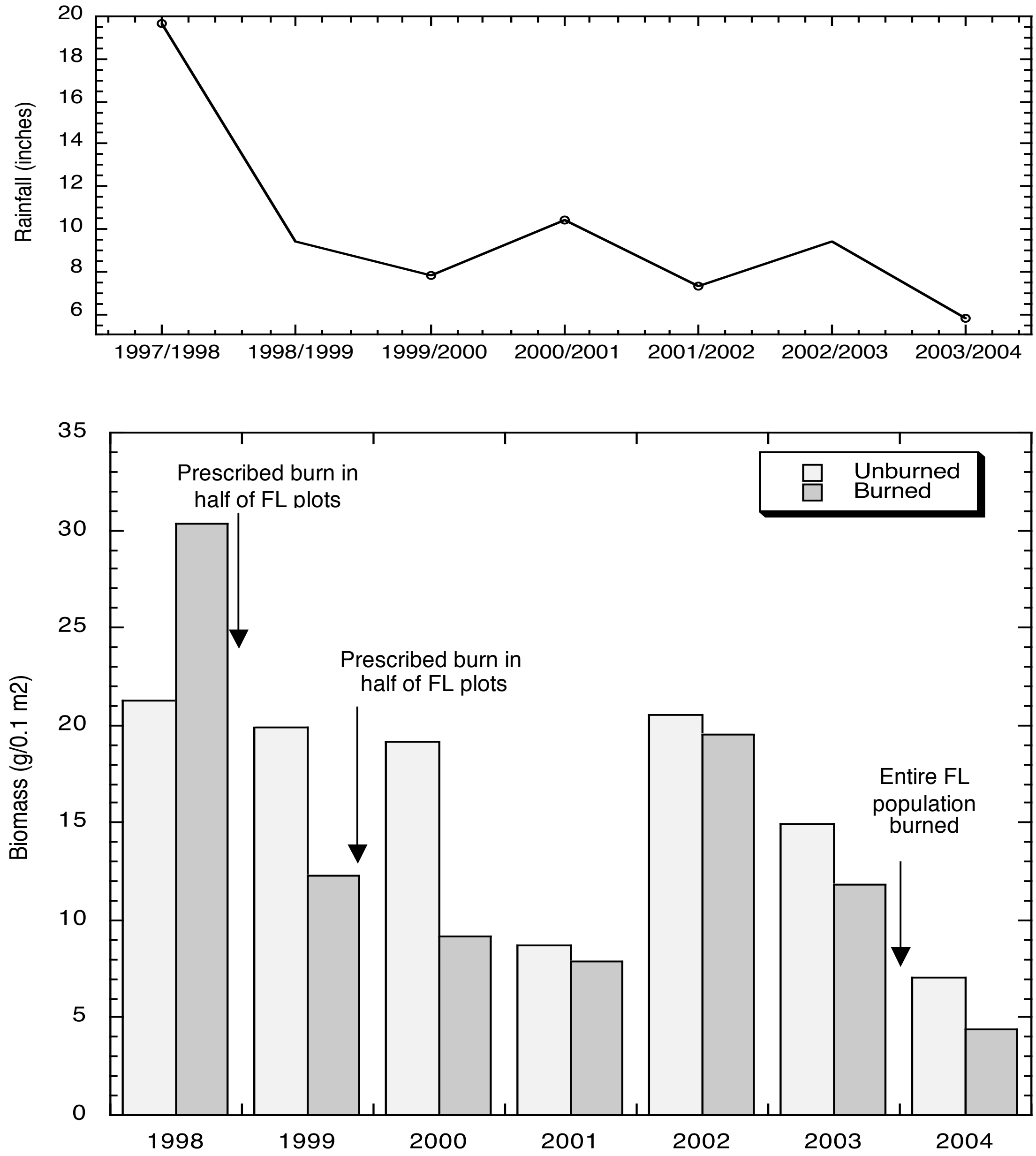

Figure A13. Total average biomass for 1998 through 2004. Burned versus unburned refers to the 1998 and 1999 prescribed burns.

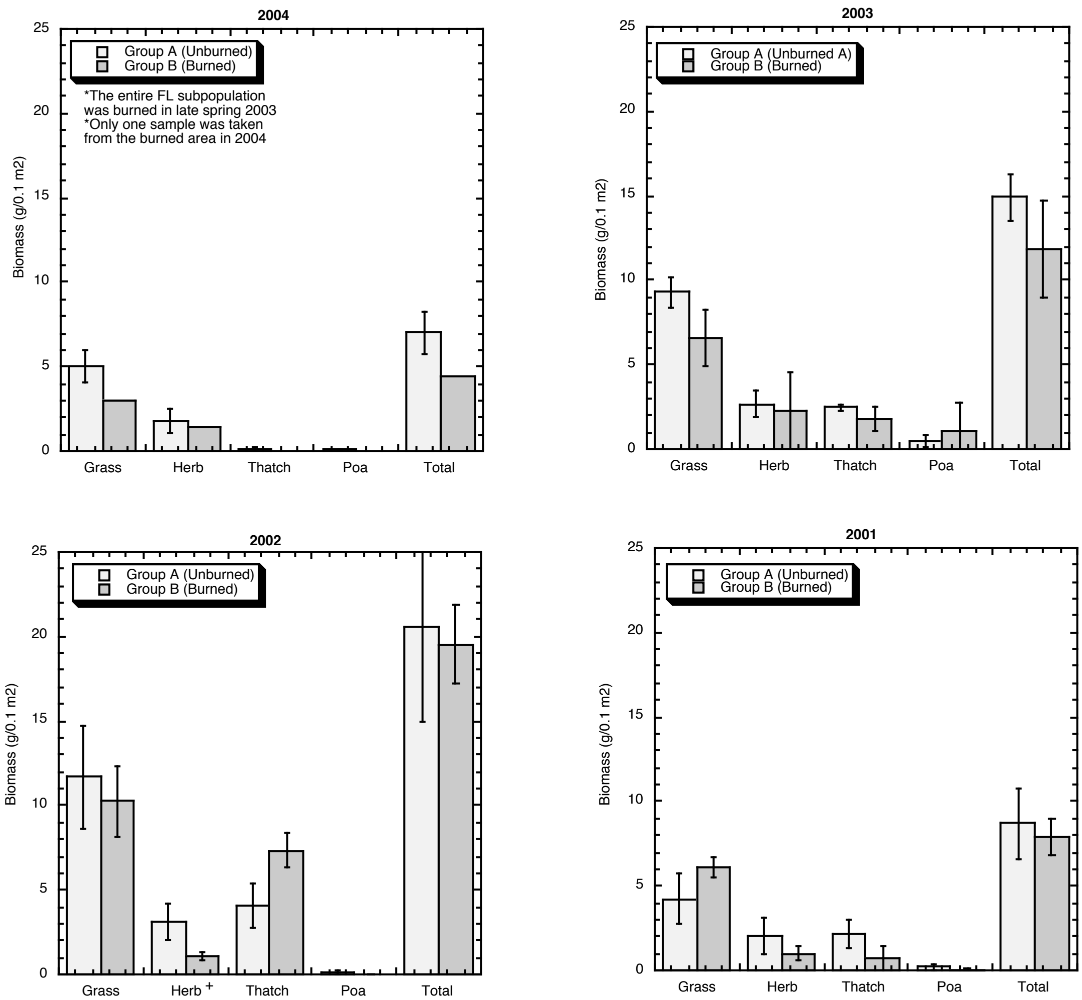

Figure A14a. Biomass of burned vs. unburned FL plots for 2001 through 2004. Bars are one standard error. ++ indicates treatments differ at $p < 0.01$. + indicates treatments differ at $p < 0.05$. N = 5. Burned versus unburned refers to the 1998 and 1999 prescribed burns.

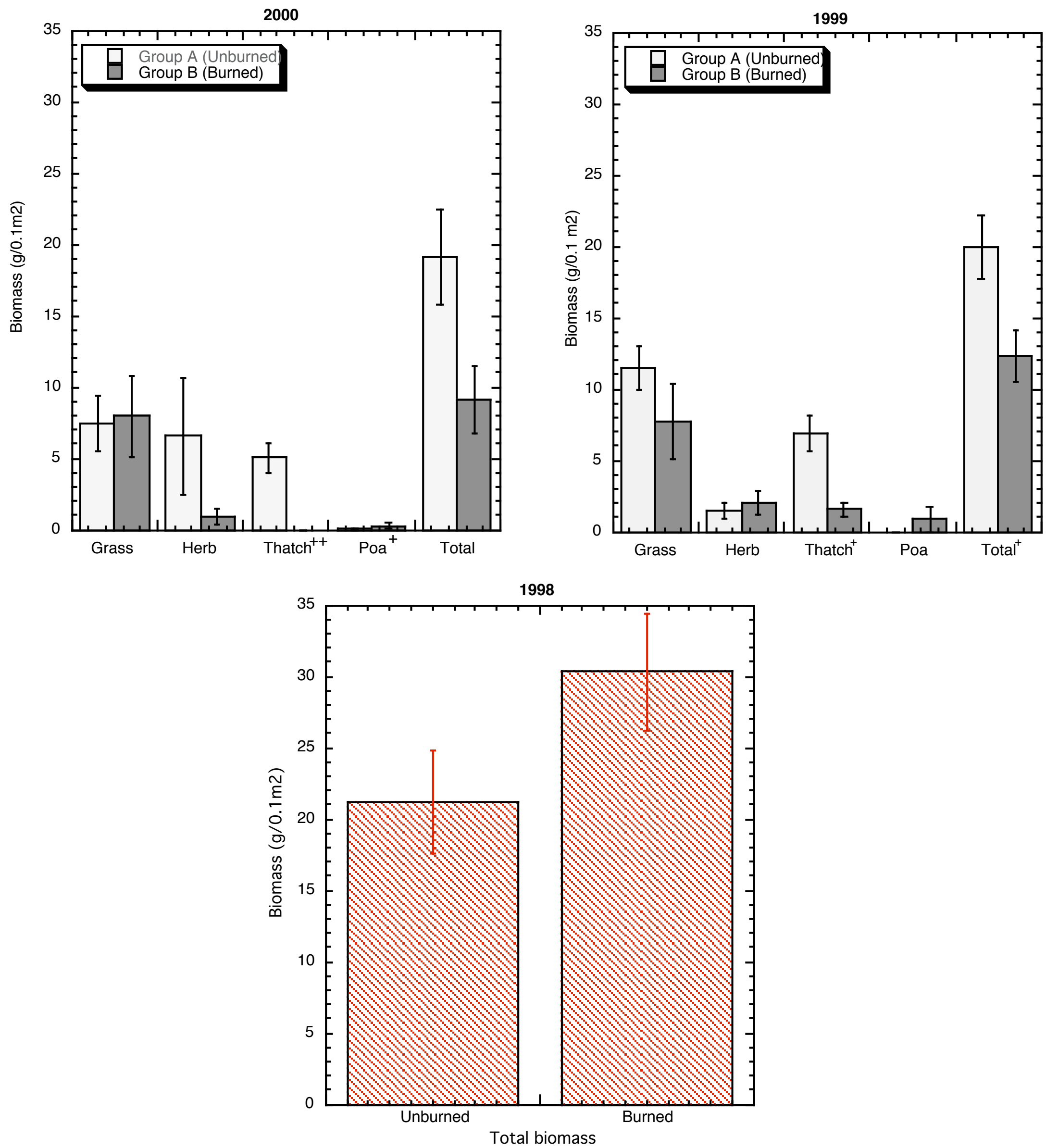

Figure A14b. Biomass of burned vs. unburned FL plots for 1998 through 2000. Bars are one standard error. ++ indicates treatments differ at $p < 0.01$. + indicates treatments differ at $p < 0.05$. N = 5. Burned versus unburned refers to the 1998 and 1999 prescribed burns.

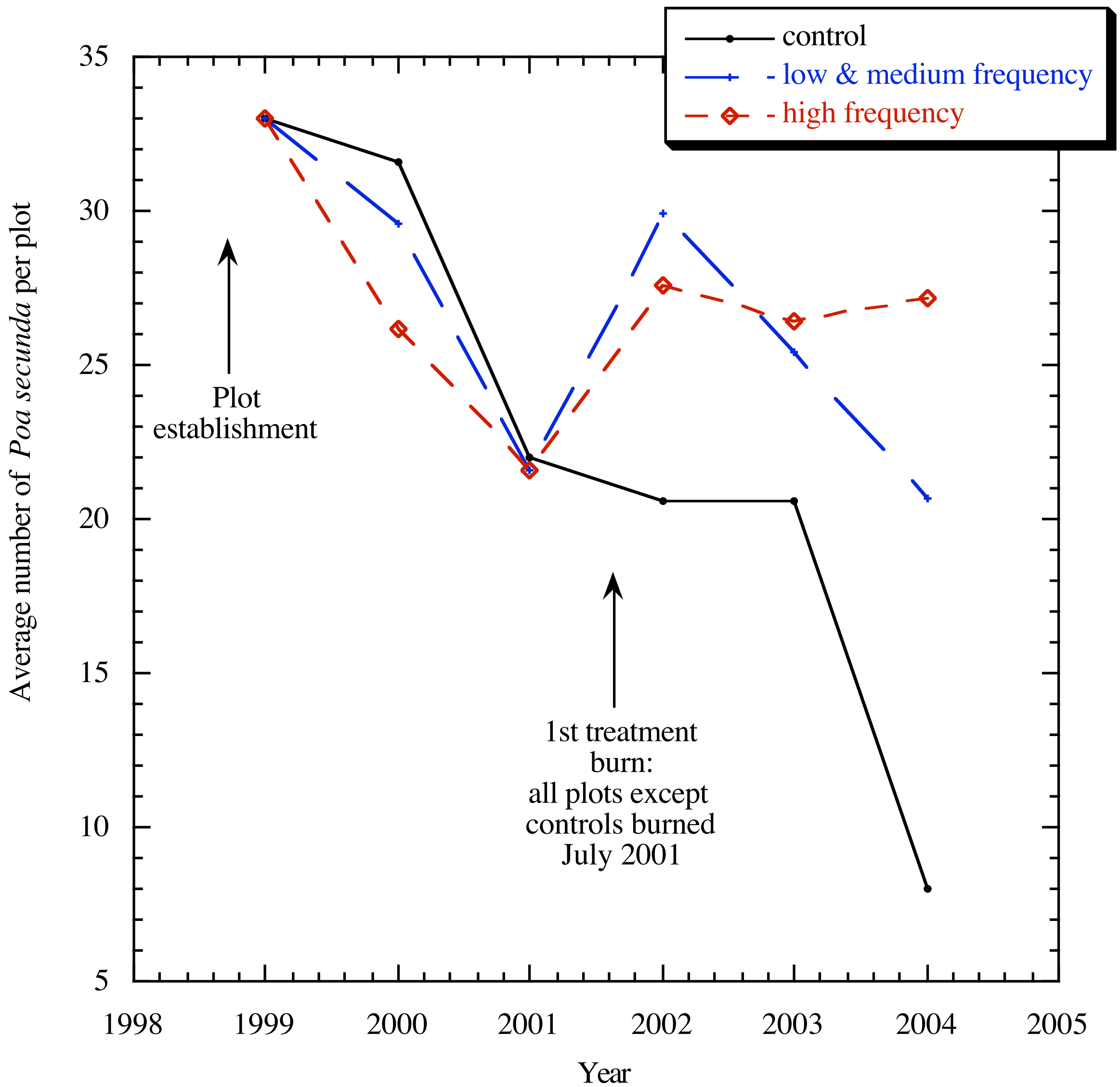

Figure A15. Average number of *Poa secunda* plants per plot for each of three burn frequencies. The low and medium frequency plot are grouped because the medium and low frequency plots were burned at the same rate until summer 2004 when the first medium frequency burn was conducted.

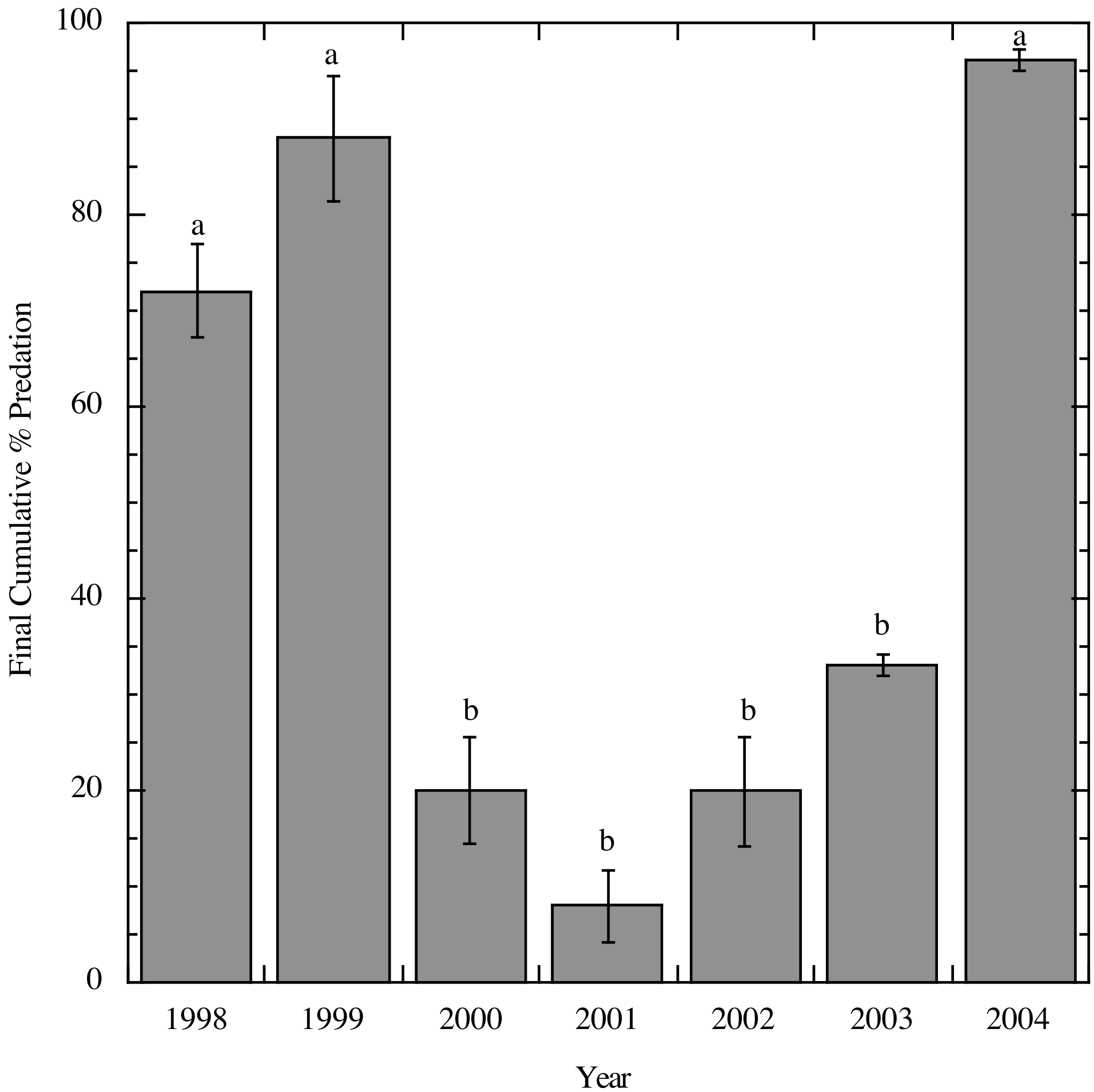

Figure A16. Final cumulative percent predation for the first 21 days of predation monitoring each year: Open unburned plots only: 1998–2002. Values are median ± standard error. Different letters indicate significant differences $p < 0.005$.

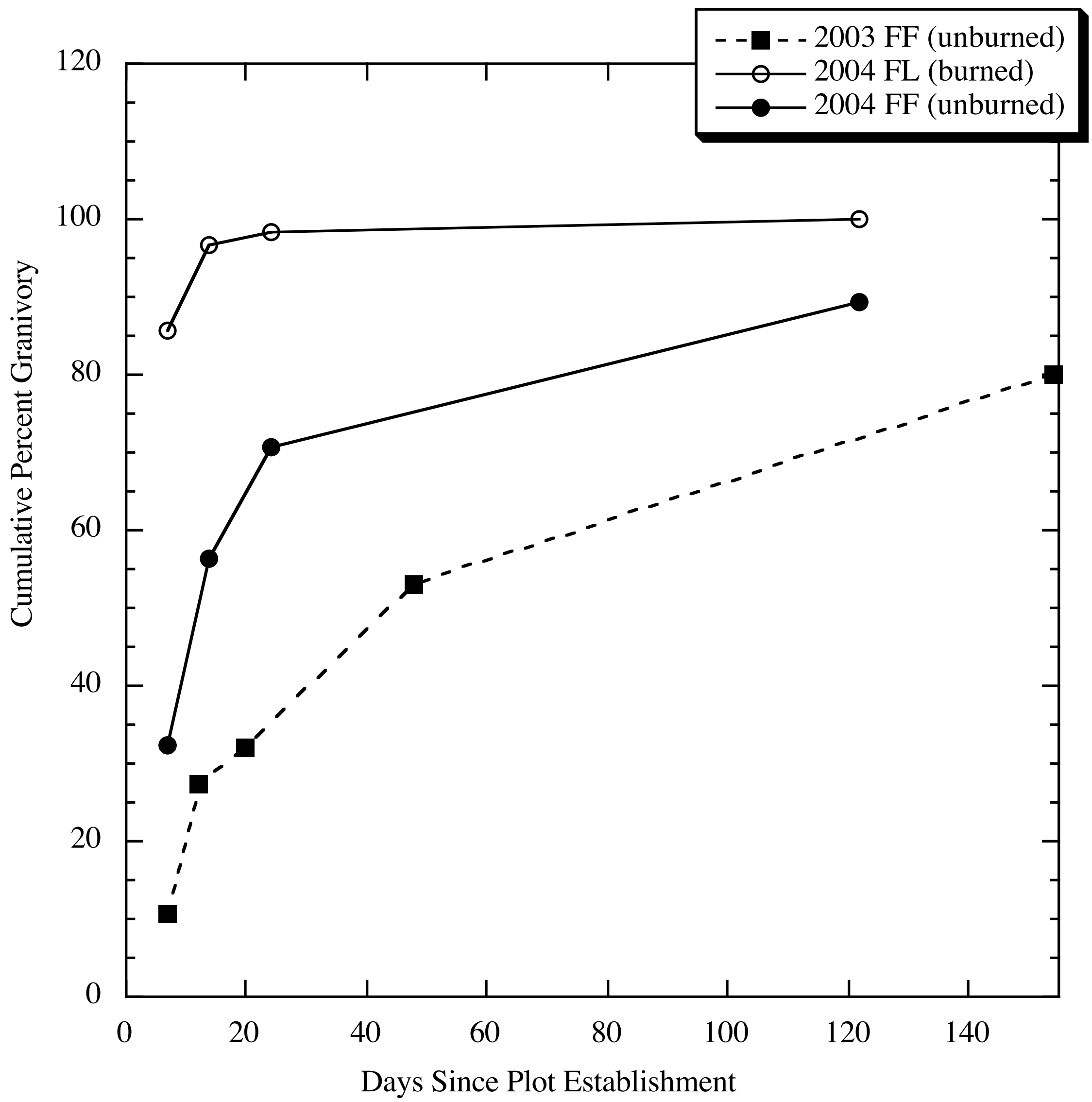

Figure A17. Cumulative percent granivory in 2003 and 2004 by population and burn.

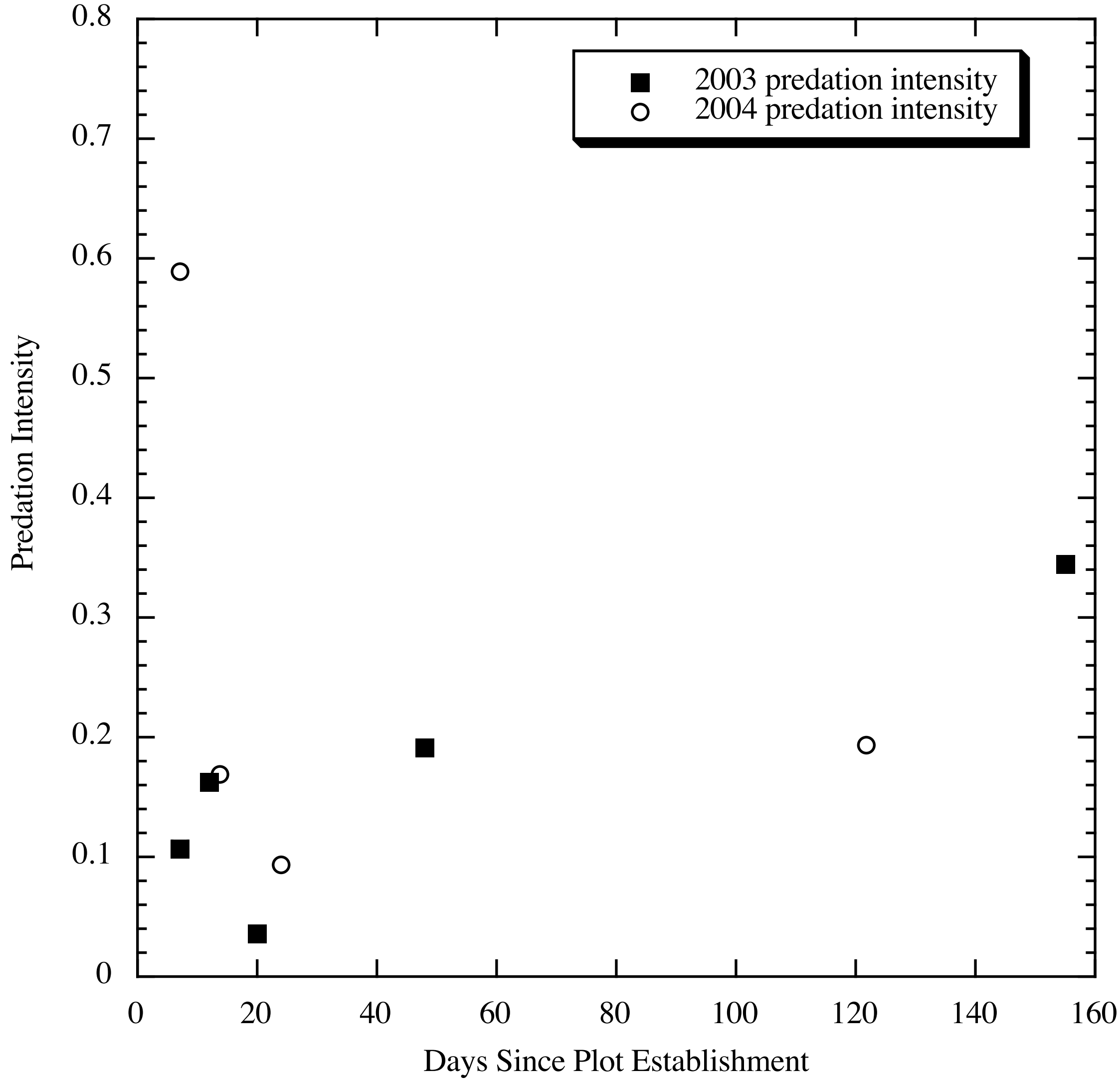

Figure A18. Predation intensity for all 2003 and 2004 locations. (2003 fire frequency only, 2004 flashing and fire frequency)

2001

2002

Figure A19a. Native population in Spring 2001 and 2002. Small shrubs are *Lupinus albifrons.* The native population is outlined in red, and the original *Lupinus albifrons* is outlined in blue.

2003

2004

Figure A19b. Native population in Spring 2003 and 2004. Small shrubs are *Lupinus albifrons.* The native population is outlined in red, and the original *Lupinus albifrons* is outlined in blue.

Section A
Tables

Table A1. Seed sources used in 2002 seed bank enhancement of *Amsinckia grandiflora* experimental populations at Lougher Ridge and Site 300.

			Lougher Ridge		Site 300	
Seed source	**Description**	**No. of plot/ site**	**No. seeds/ plot**	**Total planted**	**No. seeds/ plot**	**Total planted**
Source C 1 plots/block	1994 Site 300 Field	5	100	500	64	320
Source D 2 plots/block	1995 LLNL Greenhouse Pollination Experiment	10	100	1,000	64	640
Source G[a] 2 plots/block	1998 LLNL Common Garden Pot Experiment	10	100	1,000	62	620
Source H 0.5 plot/block	1989 UC Davis Common Garden	5	50	250	32	160
Source I 1 plots/block	1994 LLNL Common Garden Pot Intraspecific Competition	5	100	500	64	320
Source K 0.5 plot/block	1993 Site 300 Field Competition	5	50	250	32	160
Source M 0.5 plot/block	1994 LLNL Greenhouse	5	50	250	32	160
Total Planted				**3,750**		**2,380**

[a] **Sixty-two seeds per plot were used for source G because there was not enough seed available from this source to use 64 per plot.**

Table A2. Germination and survivorship for Lougher Ridge and Site 300 for the 2002 seeding conducted on December 3 and 4, 2002.

Site 300	January 7, 2003 N = 45	February 5, 2003 N = 45	March 27, 2003 N = 45
Average number of plants per plot (Total Number of plants)	19.89 ± 12.49 (895)	17.04 ± 10.92 (767)	1.53 ± 2.61 (69)
Percent of seeds germinated per plot (Overall % germination[a])	35.00 ± 19.61% (37.61%)		
Percent survivorship per plot from January 7		86.75% ± 34.03%	4.21% ± 5.89%
Lougher Ridge	**January 3, 2003 *n* = 45**	**March 11, 2003 *n* = 45**	**April 9, 2003 *n* = 45**
Average number of plants per plot (Total Number of plants)	14.44 ± 12.22 (650)	4.0 ± 5.27 (180)	4.56 ± 5.36 (205)
Percent of seeds germinated per plot (Overall percent germination[a])	14.44% ± 12.22% (18.06%)		
Percent survivorship per plot from January 3		23.87% ± 18.23%	29.77% ± 25.16%[b]

Notes:

A total of 3,750 seeds were planted at the Lougher Ridge Site, and 2,380 seeds were planted at Site 300 in December of 2002. Values are means ± 1 SD.

N = Number of plots.

SD = Standard deviation.

[a] Total number of seedlings divided by the total number of seeds planted.

[b] The increase in the total number of plants observed from March 11 to April 9 most likely resulted from plants that were missed in March but were more easy to observe in April when they were flowering.

Table A3. Biomass (dry biomass g/0.1 m^2) samples collected in December 2002 and June 2003 at Lougher Ridge and Site 300. (Mean ± SD, N = 5).

	December 2002 (samples taken adjacent to plots)	Biomass removed during thinning treatment (samples taken adjacent to plots)	Biomass remaining after thinning treatment (Dec. 2002) (samples taken adjacent to plots)	Thinned + remaining (samples taken adjacent to plots)	June 2003 (samples taken inside plots)
Lougher Ridge	133 ± 45.7	25.6 ± 7.5	47.2 ± 18.1	72.8 ± 22.6	130 ± 43.4
Site 300	11.3 ± 4.6	NA	NA	NA	13.7 ± 2.6

Notes:

N = Number of plots.

NA = Not applicable.

SD = Standard deviation.

Table A4. Germination and survivorship for Lougher Ridge and Site 300 for the 2003 seeding conducted on October 13, 2003.

Site 300	Nov. 21, 2003 N = 41	Dec. 17, 2003 N = 41	Mar. 26 & 29, 2004 N = 40
Plants per plot (Total Number of plants)	37.90 ± 12.51 (1554)	41.66 ± 15.99 (1708)	17.83 ± 12.25 (713)
Percent of seeds germinated (Overall percent germination[a])	59.22% ± 19.54% (56.61%)	61.69% ± 22.32% (62.22%)	
Percent survivorship per plot from December 17			39.42% ± 20.07%

Lougher Ridge	Jan. 17, 2003 N = 45	Mar. 2, 2004 N = 45	Mar. 28 & 29, 2004 N = 45
Number of plants per plot (Total Number of plants)	22.46 ± 12.63 (1,011)	21.98 ± 12.06 (989)	20.74 ± 8.21 (868)
Percent of seeds germinated (Overall percent germination[a])	22.46% ± 12.63% (22.47%)		
Percent survivorship per plot from January 17		91.64% ± 37.76%	91.40% ± 19.73%

Notes:

A total of 4,500 seeds were planted at the Lougher Ridge Site and 2,624 seeds were planted at Site 300 in December of 2002. Values are means ± 1 SD.

N = Number of plots.

SD = Standard deviation.

[a] Total number of seedlings divided by the total number of seeds planted.

Table A5. Comparison of germination rates and number of *Amsinckia grandiflora* at flowering per plot for plots planted with seeds from an old versus new seed sources (2002 seed bank enhancement).

	Old seed source	New seed source
Germination per plot[a]	34.50 ± 23.32%	44.59 ± 29.82%
Percent present at flowering per plot[b]	16.66 ± 11.03%	26.55 ± 16.48%

Notes:

For plots in the Lougher Ridge and Site 300 populations combined (N = 86, Mean ± SD).

- Percent germination per plot = (number of seedlings)/(number of seeds planted per plot).
- Percent present at flowering per plot = (number of flowering plants)/(number of seeds planted per plot).
- Germination was measured at Lougher Ridge on December 17, 2003 and at Site 300 on January 17, 2003. Census of flowering plants was conducted on March 27, 2003 at Site 300 and on April 9, 2003 at Lougher Ridge.
- The old seed source includes seeds from greenhouse and common garden experiments conducted in 1989 and 1998.
- The new seed source includes seeds from a common garden, harvested in the spring of 2003.

N = Number of plots.

SD = Standard deviation.

[a] Significant difference between seed sources, $p = 0.041$.

[b] Significant difference between seed sources, $p = 0.00081$.

Table A6. Constancy, percent mean cover, and I.V. for plots in the Lougher Ridge population in the spring of 2004. (N = 45)

	Mean % cover	SD % cover	Constancy	I.V.
Amsinckia grandiflora	5.43	8.07	97.78	1.03
Amsinckia menziesii	0.54	1.64	22.22	0.23
Avena fatua	3.82	6.42	77.78	0.82
Brassica sp.	2.42	8.78	40.00	0.42
Bromus diandrus	22.61	22.08	100.00	1.23
Bromus hordeaceus	8.66	12.48	97.78	1.06
Bromus madritensis	0.01	0.07	2.22	0.02
Carduus pycnocephalus	14.43	18.67	86.67	1.01
Chorogalum sp.	0.06	0.37	2.22	0.02
Claytonia perfoliata	0.03	0.13	6.67	0.07
Elymus sp.	0.44	2.98	2.22	0.03
Epilobium sp.	0.01	0.07	2.22	0.02
Erodium cicutarium	0.08	0.38	6.67	0.07
Galium sp.	1.52	2.13	77.78	0.79
Geranium sp.	0.18	0.53	17.78	0.18
Hordeum sp.	0.21	0.64	15.56	0.16
Hypocharis glabra	0.02	0.10	4.44	0.04
Lactuca serriola	2.58	4.73	57.78	0.60
Leymus sp.	8.03	9.68	71.11	0.79
Lolium multiflorum	29.73	22.31	100.00	1.30
Lupinus sp.	0.06	0.37	2.22	0.02
Marah sp.	3.06	10.78	13.33	0.16
Medicago sp.	0.14	0.53	11.11	0.11
Melica californica	0.84	3.33	13.33	0.14
Sonchus sp.	0.14	0.41	20.00	0.20
Triteleia laxa	0.81	1.71	40.00	0.41
Vicia sp.	0.10	0.39	11.11	0.11
Unknown Apiaceae	0.07	0.38	4.44	0.05
Total vegetation cover[a]	93.91	4.70	100.00	1.94
Bare ground	1.42	3.25	40.00	0.41
Thatch	4.27	3.85	80.00	0.84

Notes:

Constancy = (Number of times a species occurs/total number of plots) × 100.
I.V. = Importance values (Constancy + mean cover)/100.
N = Number of plots.
SD = Standard deviation.

[a] Total vegetation cover + bare ground + thatch = 100% for each plot.

Table A7. Effects of netting on seedling establishment. Site 300 experimental population, 2003 seed bank enhancement study.

	2003 Planting			
	All netted N = 33	Netted (Neighbors to netting removed plots) N = 7	Netting removed N = 7	All plots N = 40
% seedlings cotyledon	3.35 ± 7.05	1.48 ± 2.0	7.61 ± 6.13	4.10 ± 7.02
% seedlings 2-leaved	29.46 ± 17.60	28.12 ± 13.41	47.59 ± 10.88	32.63 ± 17.92
% seedlings 4-leaved	59.78 ± 16.77	63.58 ± 10.09	39.95 ± 13.80	56.31 ± 17.84
% seedlings 6-leaved	6.97 ± 8.41	6.81 ± 7.05	0.51 ± 1.35	5.84 ± 8.03
% of seeds germinated	66.47 ± 20.34	70.21 ± 12.44	47.33 ± 13.15	63.23 ± 20.28
% with signs of herbivory	25.49 ± 21.67	35.96 ± 31.28	77.89 ± 23.25	34.66 ± 29.58

Notes:

Comparison of plots that were netted from the seeding in October 2003 through the December 2003 with plots only netted from October 2003 to November 2003. Sizes and counts were recorded on December 17, 2003. (Values are means ± 1 SD)

Netted neighbors includes the subset of seven plots immediately adjacent to the netting removed plots.

There is a significant difference in the distribution of seedlings in the four-size classes between netting removed and netted neighbors ($p < 0.001$).

N = Number of plots.

SD = Standard deviation.

Table A8. Summary of demographic data collected from the Site 300 Drop Tower experimental and native populations and the Lougher Ridge experimental population. (Values are means ± 1 SD)

Population	Total no. of plants	P/T ratio[a]	Average height (cm)	Average no. of branches per plant[b]	Estimated average seed production per plant[c]	Estimated total seed production per population
Spring 1999						
Native	6	all P	15.30 ± 7.30	1.0 ± 0	0	0
FL plots (experimental)	42	2.18	13.30 ± 5.41	1.02 ± 0.15	0	0
Spring 2000						
Native	40	2.16	20.13 ± 6.51	1.70 ± 1.16	10.92 ± 14.44	436.98
FL plots (experimental)	45	0.76	16.78 ± 5.52	1.32 ± 0.97	2.70 ± 10.74	121.92
FF plots (experimental)	148	0.85	16.67 ± 5.98	2.33 ± 1.55	10.54 ± 20.58	1560.85
Spring 2001						
Native	14	0.43	17.21 ± 4.09	1.0 ± 0	1.42 ± 2.35	36.40
FL plots (experimental)	59	1.29	13.67 ± 5.09	1.0 ± 0	0	0
FF plots (experimental)	257	1.74	15.74 ± 4.51	1.02 ± 0.20	0.11 ± 1.22	28.27
Spring 2002						
Native	19	1.14	24.69 ± 4.83	1.50 ± 0.56	9.93 ± 11.13	188.7
FL plots (experimental)	10	1.67	15.78 ± 6.39	1.0 ± 0	0	0
FF plots (experimental)	57	1.00	15.15 ± 6.25	1.05 ± 0.26	0	0
Spring 2003						
Native	5	4	18 ± 3.65	1.0 ± 0	3.18 ± 4.61	12.72
FL plots (experimental)	69	1.27	7.30 ± 4.04	1.0 ± 0	0	0
FF plots (experimental)	50	1.43	14.02 ± 4.23	1.0 ± 0	0	0
Lougher Ridge	205	N/A	23.5 ± 9.7	N/A	N/A	1592
Spring 2004						
Native	3	0 P, 2 T, 1 Bud	20.67 ± 11.11	1.33 ± 0.58	16.37 ± 28.35	49.11
FL plots (experimental)	753	1.12	13.69 ± 5.34	1.08 ± 0.31	0.02 ± 0.50	13.67
FF plots (experimental)	15	0.86	17.53 ± 4.71	1.2 ± 0.56	0.91 ± 3.53	13.67
Lougher Ridge	868	1.59	20.74 ± 8.21	1.93 ± 2.45	50.81 ± 67.93	8739.04

Notes and footnotes appear on following page.

Table A8. Summary of demographic data collected from the Site 300 Drop Tower experimental and native populations and the Lougher Ridge experimental population. (Values are means ± 1 SD)

Notes:

FL = Flashing subpopulation.

FF = Fire frequency subpopulation.

N = Number of plots.

NA = Not available.

P = Pin-flowered plants.

T = Thrum-flowerd plants.

SD = Standard deviation.

[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] **In the native population, branch number was defined as the number of stems branching from the main stem. In the experimental population, branch number was defined as the number of inflorescences per plant.**

[c] **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, 1991). If the estimated seed production for an individual plant was a negative number, it was defined as zero. 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.**

Table A9a. Species composition of *Amsinckia grandiflora* nearest neighbors at the Drop Tower native and experimental (Exp) populations: 1997–2001.

Species	Native 1997 (%)	Native 1998 (%)	Native 1999 (%)	Exp FL 1999 (%)	Native 2000 (%)	Exp FL 2000 (%)	Exp FF 2000 (%)	Native 2001 (%)	Exp FL 2001 (%)	Exp FF 2001 (%)
Achillea millefolium	5	5	–	–	5	–	–	–	–	–
Allium serra	–	1	–	–	–	–	–	–	–	–
Amsinckia grandiflora	–	–	–	–	–	7	–	–	4	5
Amsinckia tessellata	–	–	–	–	3	5	–	–	4	1
Amsinckia sp.										
Astragalus didymocarpus	–	–	–	–	3	–	–	–	–	–
Avena sp.	18	13	-	7	15	11	24	21	21	21
Bromus diandrus	22	9	17	5	5	2	2	14	2	16
Bromus hordeaceus	31	21	50	33	3	5	1	14	7	7
Bromus madritensis	1	–	–	–	–	–	–	–	–	1
Bromus sp.	–	–	–	–	5	5	28	–	–	–
Castilleja exserta	–	–	–	–	–	–	–	–	–	1
Clarkia sp.	–	3	–	–	5	–	1	7	5	5
Claytonia parviflora	1	1	–	12	–	16	6	–	–	–
Collinsia heterophylla	3	9	17	–	–	–	–	–	–	1
Delphinium hesperium	1	3	–	–	3	2	–	–	–	–
Dichelostemma capitatum	–	–	–	–	–	–	–	–	–	–
Erodium cicutarium	4	5	–	24	18	16	4	21	41	21
Galium aparine	11	23	17	2	5	–	4	7	2	1
Lepidium nitidum	–	–	–	–	–	–	–	–	–	–
Lithophragma affinis	–	–	–	–	–	2	–	–	–	–
Lupinus albifrons	–	1	–	–	–	–	–	–	–	–
Lupinus bicolor	–	–	–	–	–	–	1	–	–	4
Minuartia californica	–	–	–	–	–	–	–	–	–	–
Phacelia tanacetifolia	–	–	–	–	3	–	–	–	–	–
Poa secunda	–	1	–	–	–	–	11	–	5	9
Sonchus sp.	1	-	–	–	–	–	–	–	–	–
Thysanocarpus curvipes	–	–	–	–	–	–	–	–	–	–
Vulpia microstachys	–	–	–	–	–	–	–	–	–	–
Vulpia myuros	–	–	–	10	20	30	11	7	9	5
Unknown dicot	3	3	–	7	8	2	2	7	–	2
Unknown Liliaceae	–	–	–	–	–	–	–	–	–	–
Unknown Poaceae	–	–	–	–	–	–	–	–	–	–
No. of species (S)	12	14	4	8	14	12	12	8	10	15
n	100	129	6	42	39	45	151	14	56	244
Shannon's Index (H′)[a]	1.92	2.16	1.31	1.59	2.40	2.14	1.93	1.97	1.80	2.35

Notes:

FL = Flashing subpopulation.

FF = Fire frequency subpopulation.

n = Total number of plants.

[a] Shannon and Weaver (1949). $H' = -\Sigma$ (of $i = 1$ to S) $(n_i/n) * \ln(n_i/n)$ where S is the number of species observed; n is the number of individuals observed; and n_i is the number of individuals in the ith species.

Table A9b. Species composition of *Amsinckia grandiflora* nearest neighbors at the Drop Tower native and experimental (Exp) populations: 2002–2004.

Species	Native 2002 (%)	Exp FL 2002 (%)	Exp FF 2002 (%)	Native 2003 (%)	Exp FL 2003 (%)	Exp FF 2003 (%)	Native 2004 (%)	Exp FL 2004 (%)	Exp FF 2004 (%)
Achillea millefolium	–	–	–	–	–	–	–	0.27	–
Allium serra	–	–	–	–	–	–	–	–	–
Amsinckia grandiflora	–	22.2	–	–	–	–	–	3.47	–
Amsinckia tessellata	–	–	–	–	–	–	–	–	–
Amsinckia sp.	12.5	–	–	–	–	–	–	0.40	–
Astragalus didymocarpus	–	–	–	–	–	–	–	–	–
Avena sp.	50.0	11.1	21.7	–	12.31	8	33.33	7.87	40
Bromus diandrus	12.5	–	–	25	–	2	33.33	1.87	6.67
Bromus hordeaceus	12.5	–	–	–	1.54	2	–	6.8	
Bromus madritensis ssp. *rubens*	–	–	–	–	–	–	–	0.13	–
Bromus sp.	–	–	–	–	–	–	–	–	–
Castilleja exserta	–	–	–	–	1.54	–	–	1.07	–
Clarkia sp.	–	–	13.0	–	7.69	6	–	2.13	–
Claytonia parviflora	–	–	–	–	–	–	–	0.13	–
Collinsia heterophylla	–	11.1	–	–	–	–	–	–	–
Delphinium hesperium	–	–	–	–	3.08	–	–	0.53	–
Dichelostemma capitatum	–	–	–	–	–	–	–	0.13	
Erodium cicutarium	–	44.4	21.7	50	36.92	48	–	37.87	46.67
Galium aparine	12.5	–	–	–	–	–	–	0.27	–
Lepidium nitidum	–	–	–	–	–	–	–	0.13	–
Lithophragma affinis	–	–	4.3	–	–	-	–	0.4	–
Lupinus albifrons	–	–	–	–	–	–	–	–	–
Lupinus bicolor	–	–	4.3	–	1.54	–	–	1.07	–
Minuartia californica	–	–	–	–	–	–	–	0.27	–
Phacelia tanacetifolia	–	–	–	–	–	–	–	0.13	–
Poa secunda	–	–	–	–	–	2	–	1.33	2
Sonchus sp.	–	–	–	–	–	–	–	–	–
Thysanocarpus curvipes	–	–	–	–	1.54	–	–	–	–
Vulpia microstachys	–	–	–	–	–	–	–	5.2	–
Vulpia myuros	–	–	30.4	–	24.62	12	33.33	–	6.66
Unidentified dicot	–	–	–	–	–	–	–	0.13	–
Unknown Liliaceae	–	–	–	–	–	–	–	0.13	–
Unknown Poaceae	–	11.1	4.3	25	9.23	20	–	10	–
No. of species (S)	5	5	7	3	10	8	3	26	4
n	8	9	23	4	65	50	3	750	15
Shannon's Index (H′)[a]	1.39	1.43	1.68	1.04	1.75	1.53	1.10	2.06	1.08

Notes:

FL = Flashing subpopulation.

FF = Fire frequency subpopulation.

n = Total number of plants.

[a] Shannon and Weaver (1949). $H' = -\Sigma$ (of $i = 1$ to S) $(n_i/n) * \ln(n_i/n)$ where S is the number of species observed; n is the number of individuals observed; and n_i is the number of individuals in the ith species.

Table A10. Constancy, percent mean cover for all plots in each subpopulation, and I.V. for cover data collected from the native and experimental populations in 2003. (Page 1 of 2)

	Native 2003 (N = 2)				FL 2003 (N = 57)				FF 2003 (N = 20)			
	Mean % cover	SD % cover	Constancy	I.V.	Mean % cover	SD % cover	Constancy	I.V.	Mean % cover	SD % cover	Constancy	I.V.
Achillea millifolium	–	–	–	–	1.01	3.95	8.77	0.10	–	–	–	–
Allium serra	–	–	–	–	0.04	0.33	1.75	0.02	–	–	–	–
Amsinckia grandiflora	2.50	0.00	100.00	1.025	0.70	1.13	28.07	0.29	1.00	1.26	40.00	0.41
Amsinckia menziesii	–	–	–	–	2.02	3.73	42.11	0.44	–	–	–	–
Amsinckia sp.	–	–	–	–	1.75	4.89	22.81	0.25	0.50	1.03	20.00	0.21
Avena sp.	12.50	17.68	50.00	0.63	15.92	14.31	71.93	0.88	13.75	11.74	100.00	1.14
Bromus diandrus	5.00	7.07	50.00	0.55	0.88	4.21	7.02	0.08	5.00	16.06	15.00	0.20
Bromus hordeaceus	7.50	10.61	50.00	0.58	0.61	1.18	22.81	0.23	1.00	3.38	15.00	0.16
*Bromus madritensis*ssp. *Rubens*	5.00	7.07	50.00	0.55	0.31	0.83	12.28	0.13	–	–	–	–
Castilleja exerta	–	–	–	–	2.59	3.10	64.91	0.68	2.50	4.44	50.00	0.53
Cirsium sp.	–	–	–	–	–	–	–	–	0.75	3.35	5.00	0.06
Clarkia sp.	1.25	1.77	50.00	0.51	7.32	6.07	92.98	1.00	4.25	3.90	90.00	0.94
Claytonia sp.	–	–	–	–	0.31	0.83	12.28	0.13	–	–	–	–
Delphinium sp.	–	–	–	–	4.17	5.73	73.68	0.78	0.13	0.56	5.00	0.05
Dichelostemma capitatum	–	–	–	–	0.39	1.55	8.77	0.09	0.38	0.92	15.00	0.15
Erodium cicutarium	11.25	12.37	100.00	1.11	22.11	10.68	100.00	1.22	43.38	24.34	95.00	1.38
Galium aparine	5.00	7.07	50.00	0.55	0.18	1.32	1.75	0.02	–	–	–	–
Grindelia camporum	–	–	–	–	0.44	3.31	1.75	0.02	0.13	0.56	5.00	0.05
Lepidium nitidum	–	–	–	–	0.53	2.10	12.28	0.13	–	–	–	–
Lithophragma affine	–	–	–	–	1.75	3.89	31.58	0.33	–	–	–	–
Lotus wrangelliannus	10.00	14.14	50.00	0.60	–	–	–	–	–	–	–	–
Lupinus albifrons	10.00	14.14	50.00	0.60	–	–	–	–	–	–	–	–
Lupinus bicolor	–	–	–	–	9.82	7.44	96.49	1.06	4.00	4.17	70.00	0.74
Minuartia californica	–	–	–	–	0.04	0.33	1.75	0.02	–	–	–	–
Phacelia distans	–	–	–	–	0.09	0.46	3.51	0.04	–	–	–	–
Poa secunda	–	–	–	–	5.57	5.61	68.42	0.74	25.13	12.84	100.00	1.25
Thysanocarpus curvipes	–	–	–	–	2.02	2.85	50.88	0.53	–	–	–	–
Triteleia laxa	–	–	–	–	0.13	0.56	5.26	0.05	–	–	–	–
Tropidocarpum gracile	–	–	–	–	0.13	0.56	5.26	0.05	–	–	–	–
Vulpia microstachys	–	–	–	–	1.32	7.40	8.77	0.10	–	–	–	–
Vulpia myuros	12.50	17.68	50.00	0.63	22.32	20.59	68.42	0.91	6.50	13.77	25.00	0.32

Table A10. Constancy, percent mean cover for all plots in each subpopulation, and I.V. for cover data collected from the native and experimental populations in 2003. (Page 2 of 2)

	Native 2003 (N = 2)				FL 2003 (N = 57)				FF 2003 (N = 20)			
Species	Mean % cover	SD % cover	Constancy	I.V.	Mean % cover	SD % cover	Constancy	I.V.	Mean % cover	SD % cover	Constancy	I.V.
Unknown Liliaceae	–	–	–	–	0.13	0.56	5.26	0.05	–	–	–	–
Unknown Poaceae	15.00	21.21	50.00	0.65	11.23	14.22	59.65	0.71	2.63	3.67	45.00	0.48
Unknown dicot	–	–	–	–	0.18	0.64	7.02	0.07	–	–	–	–
Bare	15.00	7.07	100.00	1.15	12.76	8.76	98.25	1.11	17.88	16.29	95.00	1.13
Thatch	20.00	0.00	100.00	1.2	10.83	8.02	98.25	1.09	7.38	8.49	70.00	0.77

Notes:

Constancy = Number of times a species occurs/total number of plots) × 100.

FL = Flashing subpopulation.

FF = Fire frequency subpopulation.

I.V. = Importance values. (Constancy + Mean Cover)/100.

N = Number of plots.

SD = Standard deviation.

Table A11. Constancy, percent mean cover for all plots in each subpopulation, and I.V. for cover data collected from the native and experimental populations in 2004. (Page 1 of 2)

	Native 2004 (N = 10)				FL 2004 (N = 45)				FF 2004 (N = 20)			
Species	Mean % cover	SD % cover	Constancy	I.V.	Mean % cover	SD % cover	Constancy	I.V.	Mean % cover	SD % cover	Constancy	I.V.
Achillea millifolium	3.00	4.05	50.00	0.53	0.72	2.70	11.11	0.12	0.25	1.12	5.00	0.05
Amsinckia grandiflora	0.25	0.83	10.00	0.10	8.78	9.09	84.44	0.93	0.63	1.11	25.00	0.26
Amsinckia menziesii	3.00	6.10	50.00	0.53	1.56	2.46	40.00	0.42	0.25	0.77	10.00	0.10
Amsinckia sp.	–	–	–	–	0.89	2.78	15.56	0.16	0.13	0.56	5.00	0.05
Avena sp.	21.00	17.76	80.00	1.01	16.17	10.72	95.56	1.12	25.88	25.23	90.00	1.16
Blepharizonia sp.	–	–	–	–	0.56	3.73	2.22	0.03	–	–	–	–
Bromus diandrus	6.25	7.19	60.00	0.66	2.94	4.98	37.78	0.41	1.38	4.48	20.00	0.21
Bromus hordeaceus	5.50	4.05	90.00	0.96	3.00	3.87	64.44	0.67	5.75	5.97	85.00	0.91
Bromus madritensis	13.00	10.53	90.00	1.03	0.28	0.79	11.11	0.11	0.25	0.77	10.00	0.10
Camissonia sp.	–	–	–	–	0.22	0.72	8.89	0.09	0.13	0.56	5.00	0.05
Capsella bursa-patoris	0.25	0.79	10.00	0.10	0.11	0.52	4.44	0.05	–	–	–	–
Castilleja exerta	–	–	–	–	3.89	3.90	80.00	0.84	2.13	3.17	45.00	0.47
Minuartia californica	–	–	–	–	0.72	2.24	13.33	0.14	–	–	–	–
Cirsium sp.	–	–	–	–	0.06	0.37	2.22	0.02	0.50	2.24	5.00	0.06
Clarkia sp.	0.75	1.21	30.00	0.31	2.22	1.94	71.11	0.73	2.50	3.14	55.00	0.58
Claytonia sp.	0.50	1.05	20.00	0.21	0.50	1.01	20.00	0.21	0.25	1.12	5.00	0.05
Collinsia heterophylla	0.50	1.05	20.00	0.21	–	–	–	–	0.13	0.56	5.00	0.05
Delphinium sp.	1.50	3.16	30.00	0.32	2.17	2.80	51.11	0.53	0.75	1.18	30.00	0.31
Dichelostemma capitatum	–	–	–	–	0.06	0.37	2.22	0.02	–	–	–	–
Erodium cicutarium	8.25	13.39	80.00	0.88	30.89	16.70	97.78	1.29	26.50	17.93	90.00	1.17
Galium aparine	5.25	7.31	50.00	0.55	0.06	0.37	2.22	0.02	0.13	0.56	5.00	0.05
Grindelia camporum	–	–	–	–	–	–	–	–	0.13	0.56	5.00	0.05
Lepidium nitidum	–	–	–	–	0.33	1.56	6.67	0.07	–	–	–	–
Lithophragma affine	0.50	1.05	20.00	0.21	0.72	3.09	11.11	0.12	0.23	0.70	10.00	0.10
Lotus wrangelliannus	2.00	3.29	40.00	0.42	–	–	–	–	–	–	–	–
Lupinus albifrons	0.50	1.05	20.00	0.21	0.06	0.37	2.22	0.02	–	–	–	–
Lupinus bicolor	–	–	–	–	5.72	6.21	91.11	0.97	4.00	6.15	70.00	0.74
Medicago polymorpha	–	–	–	–	0.06	0.37	2.22	0.02	–	–	–	–
Monolopia major	0.50	1.05	20.00	0.21	0.00	0.00	0.00	0.00	–	–	–	–

Table A11. Constancy, percent mean cover for all plots in each subpopulation, and I.V. for cover data collected from the native and experimental populations in 2004. (Page 2 of 2)

	Native 2004 (N = 10)				FL 2004 (N = 45)				FF 2004 (N = 20)			
Species	Mean % cover	SD % cover	Constancy	I.V.	Mean % cover	SD % cover	Constancy	I.V.	Mean % cover	SD % cover	Constancy	I.V.
Phacelia distans	0.50	1.58	10.00	0.11	0.28	0.79	11.11	0.11	–	–	–	–
Poa secunda	0.50	1.58	10.00	0.11	7.33	7.86	77.78	0.85	19.75	16.42	95.00	1.15
Stylomecon heterophylla	0.25	0.79	10.00	0.10	–	–	–	–	–	–	–	–
Thysanocarpus curvipes	–	–	–	–	1.06	1.46	37.78	0.39	–	–	–	–
Trifolium sp.	–	–	–	–	0.06	0.37	2.22	0.02	–	–	–	–
Vulpia microstachys	0.25	0.79	10.00	0.10	3.61	6.60	42.22	0.46	2.88	6.90	35.00	0.38
Vulpia myuros	4.50	10.85	40.00	0.45	21.56	22.85	64.44	0.86	5.13	15.10	20.00	0.25
Unknown dicot	0.75	1.69	20.00	0.21	0.22	0.72	8.89	0.09	–	–	–	–
Unknown Asteraceae	–	–	–	–	–	–	–	–	0.25	1.12	5.00	0.05
Unknown Liliaceae	–	–	–	–	0.06	0.37	2.22	0.02	0.13	0.56	5.00	0.05
Unknown Poaceae	16.50	17.00	60.00	0.77	1.89	4.80	15.56	0.17	6.88	11.86	45.00	0.52
Bare	13.50	9.44	90.00	1.04	47.00	19.70	100.00	1.47	23.38	18.14	90.00	1.13
Thatch	55.00	21.21	100.00	1.55	2.11	3.33	48.89	0.51	15.63	16.97	75.00	0.91

Notes:

Constancy = Number of times a species occurs/total number of plots) × 100.

FL = Flashing subpopulation.

FF = Fire frequency subpopulation.

I.V. = Importance values. (Constancy + Mean Cover)/100.

N = Number of plots.

SD = Standard deviation.

Table A12. Dry biomass by dominant grass type in FL plots at the Site 300 Drop Tower experimental population. Values are means ± 1 SE.

	Poa secunda plots[a]		Annual grass plots[b]		All plots	
Year	Final dry biomass ($g/0.1\ m^2$)[c]	N	Final dry biomass ($g/0.1\ m^2$)[c]	N	Final dry biomass ($g/0.1\ m^2$)[c]	N
2004	6.32 ± 1.53	2	6.63 ± 1.82	3	6.50 ± 1.28	5
2003	14.1 ± 1.6	3	13.0 ± 4.6	2	13.66 ± 1.31	5
2002	16.58 ± 3.30	3	16.6 ± 3.3	7	18.80 ± 1.57	10
2001	7.3 ± 0.81	5	9.0 ± 1.99	5	8.30 ± 1.04	10
2000	10.6 ± 2.9	5	17.6 ± 4.1	5	14.13 ± 2.52	10
1999	13.5 ± 3.1	5	20.6 ± 8.2	5	16.80 ± 1.97	10
1998	28.5 ± 2.2	6	21.7 ± 5.9	4	25.77 ± 2.74	10
1994	9.9 ± 0.9	13	8.7 ± 0.9	20	NA	

Notes:

FL = Flashing subpopulation.

NA = Not applicable.

N = Number of plots.

SE = Standard error.

[a] **Plots established with fixed densities of *Poa* in 1993 and 1994. (Includes plots planted with low, medium and high densities of *Poa*.)**

[b] **Plots cleared of all perennial grasses 1993 through 1994.**

[c] **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, May 1999, May 2000, May 2001, May 2002, and May 2003.**

Table A13. Density of *Poa secunda* per 60 cm × 60 cm plot in the experimental flashing subpopulation. (Page 1 of 2)

	Planted *Poa* plots			Existing *Poa* plots			Plots cleared of perennial grasses
	Low density	Medium density	High density	Low density	Medium density	High density	
1993[a]							
Total	11	22	45	4	5.6	10.6	0
1999[a]							
Total	2.4±0.9 (5)	3.2±0.9 (5)	9.8±4.4 (5)	1.8±0.4 (5)	1.2±0.5 (5)	1.6±1.4 (5)	0.7±0.2 (25)
Unburned	2.4±0.9 (5)	2.5±1.5 (2)	12.3±7.3 (3)	2 (1)	1.3±0.7 (3)	0.3±0.3 (3)	0.9±0.2 (15)
Burned	N/A	3.7±0 (3)	6.0±3.0 (2)	1.8± 0.7 (4)	1±1 (2)	3.5±3.5 (2)	0.5±0 (10)
2000[b]							
Total	4.2±0.6 (5)	8±2.5 (5)	10.6±4.1 (4)	8.6±2.7 (5)	5.1±1.8 (4)	5.6±1.6 (5)	2.4±0.9 (24)
Unburned	3.8±0.3 (4)	3.5±2.1 (2)	8.0 (1)	3.0 (1)	4.7±2.9 (3)	4.3±2.7 (3)	1.5±0.5 (13)
Burned	6.0 (1)	11.0±2.6 (3)	14.3±5.9 (3)	10.0±2.9 (4)	9.0 (1)	7.5±0.7 (2)	3.5±2.0 (11)
2001							
Total	4.0±0.7 (5)	5.8±0.9 (5)	8.2±1.9 (5)	5.4±0.8 (5)	3.8±1.3 (4)	4.0±1.8 (5)	2.4±0.7 (25)
Unburned	3.5±0.8 (4)	4.5±0.7 (2)	7.0±2.8 (2)	3.0 (1)	3.3±2.0 (3)	2.7±0.8 (3)	2.2±0.6 (14)
Burned	6.0 (1)	5.5±0.7 (2)	4 (1)	6.0±0.8 (4)	5.0 (1)	6.0±7.1 (2)	2.7±1.4 (11)
2002[b,c]							
Total	4.4±0.2 (5)	6.6±0.9 (5)	12.4±1.4 (5)	4.6±0.8 (5)	3.6±1.6 (5)	5.0±1.6 (5)	2.3±0.6 (25)
Unburned	4.5±0.3 (4)	6.0±2.8 (2)	12.0±2.8 (2)	3.0 (1)	4.3±2.9 (3)	4.0±1.2 (3)	2.1±1.4 (14)
Burned	6.0 (1)	6.0±1.4 (2)	10.0 (1)	5.0±1.1 (4)	2.5±3.5 (2)	6.5±6.4 (2)	2.5±1.4 (11)
2003[a]							
Total	3.2±1.6 (5)	2.0±1 (5)	5.2±1.4 (5)	2.8±0.8 (5)	3.8±2.2 (4)	3.2±1.4 (5)	1.5±0.4 (25)
Unburned	3.5±0.8 (4)	3.0±2.8 (2)	8.0±0 (2)	3 (1)	4.0±3.2 (3)	3.0±1.2 (3)	1.4±0.5 (14)
Burned	2 (1)	0.5±0.7 (2)	2 (1)	3.3±0.9 (4)	3 (1)	3.5±5.0 (2)	1.6±0.8 (11)
2004							
Total	3.0±1.0 (5)	3.6±1.1 (5)	7.3±1.8 (4)	3.5±1.1 (4)	3.2±1.2 (5)	4.4±1.6 (5)	2.0±0.5 (25)
Unburned	3.5±1.1 (4)	2.5±2.1 (2)	9 (1)	2 (1)	4.3±1.6 (3)	3.3±0.81(3)	1.8±0.7 (14)
Burned	1 (1)	3±0 (2)	3 (1)	4±1.2 (4)	1.5±2.1 (2)	6±5.7 (2)	2.2±0.9 (11)

Notes and footnotes appear on following page.

Table A13. Density of *Poa secunda* per 60 cm × 60 cm plot in the experimental flashing subpopulation. (Page 2 of 2)

Notes:

- **Values are means ± 1 SE.**
- **Numbers in parentheses indicate number of plots (N).**
- **Bold lines indicate burn events.**
- **For all totals, *Poa* densities are averaged across burned, unburned and transition plots.**
- **Plots established at fixed densities or cleared of perennial grass in 1993 and 1994.**
- **Burned vs. unburned refers to controlled burns conducted in 1998 and 1999.**
- **There was a slight shift in the burn line in 1999 compared to 1998. In addition, after the 1999 burn, two high density and one medium density *Poa* planted plots were in a transition zone between the burned and unburned area.**
- **All plots in the FL population were burned in 2003.**

SE = Standard error.

[a] **Significant difference in *Poa* density between plot types: *Poa* planted, *Poa* existing, cleared of perennial grass ($p < 0.05$).**

[b] **Significant difference in *Poa* density in burned compared to unburned plots ($p < 0.05$).**

[c] **Significant interaction between starting density and plot type ($p < 0.05$).**

Table A14. Density of *Poa secunda* per 1 m^2 plot in the fire frequency experimental subpopulation. Values are means ± 1 SD. Italics indicates plots burned the previous year.

	All frequencies N = 20	Fire frequency: Control N = 5	Low N = 5	Medium N = 5	High N = 5
2004[a]	19.2 ± 8.7	8.0 ± 4.2	19.6 ± 6.1	21.8 ± 2.9	*27.2 ± 7.0*
2003	24.5 ± 8.3	20.6 ± 9.4	27.2 ± 5.4	23.6 ± 6.9	*26.4 ± 11.4*
2002[b]	27.2 ± 7.8	20.6 ± 6.4	*29.0 ± 3.4*	*30.8 ± 7.0*	*27.6 ± 10.5*
2001	21.7 ± 5.3	22.0 ± 5.8	22.0 ± 5.2	21.2 ± 4.1	21.6 ± 7.2
2000	29.3 ± 6.0	31.6 ± 4.4	30.0 ± 2.0	29.2 ± 1.3	26.2 ± 11.4
1999	33	33	33	33	33

Notes:

Plots planted in 1999.

Averages broken down by burn frequency (control = unburned, low = burned every fifth year, medium = burned every third year, high = burned every other year). There are five plots for each of the four burn frequencies.

Burn treatments began summer 2001.

N = Number of plots.

SD = Standard deviation.

[a] Significant difference between control plots, the combination of low & medium frequency plots, and high frequency plots (ANOVA, $F_{2,17} = 17.882$, $p \leq 0.0001$).

[b] Significant difference between control plots and all other plots (Wilcoxon rank sum, W = 13.5, $p = 0.04$).

Table A15. Densities of *Amsinckia grandiflora* per 1 m^2 plot in the fire frequency experimental subpopulation. Values are means ± 1 SD.

	All frequencies N = 20	Fire frequency[a]: Control N = 5	Low & Medium N = 10	High N = 5
2004[a]	0.8 ± 1.3	2.2 ± 2.0	0.4 ± 0.5	0
2003	1.3 ± 1.1	2.0 ± 3.5	3.2 ± 2.9	1.6 ± 1.1
2002[b]	2.5 ± 2.7	5.6 ± 4.8	1.0 ± 1.7	2.6 ± 3.7

Notes:

Burn frequencies: Control = unburned, Low = burned every fifth year, Medium = burned every third year, High = burned every other year). There are five plots for each of the four burn frequencies.

Burn treatments began summer 2001.

N = Number of plots.

SD = Standard deviation.

[a] Probability of difference between control plots, the combination of low & medium frequency plots, and high frequency plots (Kruskal-Wallis rank sum test, $X = 5.16$, $p = 0.08$).

[b] Significant difference between control plots and all other plots (Wilcoxon rank sum, W = 65, $p = 0.01$).

Section B
Blepharizonia plumosa
Monitoring and Research

Section B

Blepharizonia plumosa Monitoring and Research

B-1. Introduction

Several populations of *Blepharizonia plumosa* (the big tar plant, known also as *Blepharizonia plumosa* subsp. *plumosa*) were identified during a habitat survey in 1996 at Site 300 (Preston, 1996; 2002). Listed as *Blepharizonia plumosa* subsp. *plumosa* by the California Native Plant Society (CNPS), it is an extremely rare late-season flowering annual plant included on the CNPS List 1B (CNPS, 2001). The CNPS List 1B includes plants that are rare, threatened, or endangered. The CNPS R-E-D code (rarity-endangerment-distribution) for *B. plumosa* is 3-3-3, indicating that this plant is limited to one population or several restricted ones, is endangered throughout its range, and is endemic to California. The CNPS also noted that possibly the only remaining populations exist on private property in the hills near Livermore, California. Populations have been previously identified in Alameda, Contra Costa, San Joaquin, Stanislaus, and Solano Counties (Skinner and Pavlik, 1994). Preston (1996) noted that a population was discovered at Contra Loma Regional Park, south of Antioch in 1979, but that surveys conducted by the East Bay Regional Park District in 1991 were unable to relocate the species. In 1994, several more populations were discovered on private property southwest of Brentwood (CNDDB, 1996). Another small population was found at Chaparral Springs, near Mount Diablo (Preston, 1996). Current status of these populations is unknown. Also, during the 1996 and 2002 habitat surveys of Site 300, a few populations of the more common big tarplant, *Blepharizonia laxa* (also known as *Blepharizonia plumosa* subsp. *viscida*), were found.

The genus *Blepharizonia* has recently been taxonomically revised. Baldwin et al. (2001) found that what had been considered two similar plant subspecies are truly two co-occurring, separate species. *Blepharizonia plumosa* subsp. *plumosa* retained the specific moniker *B. plumosa*, and *B. plumosa* subsp. *viscida* is now known as *B. laxa*. The most current nomenclature for these species will be used throughout this report. Both *B. plumosa* and *B. laxa* are dicots within the family Asteraceae (the sunflower family), and members of the tribe Helenieae (Karis and Ryding, 1994). They are both summer annual forbs, which germinate with the onset of the first substantial fall/winter rains and flower July through October. The plants are heterocarpic, producing dimorphic flowers within the same inflorescence. Disc seeds are produced from the central or disc flowers of the inflorescence and ray seeds are produced from the peripheral ray flowers. The disc flowers are whitish in color while the ray flowers are white with purple veins and deeply three lobed (Bremer, 1994).

Blepharizonia plumosa can generally be distinguished from *B. laxa* by fruit morphology and leaf color (Hickman, 1993; personal observation). The most distinctive characteristic of *B. plumosa* is the pappus of 1.5 to 3mm in length on the disc fruits. This pappus, sometimes described as plumose (thus the name *plumosa),* contrasts with the very minute pappus of the ray fruits (Figure B1). The plants also have a pale green color as their foliage is sparsely glandular below the inflorescence. Older plants have many inflorescences on lateral side branches.

Blepharizonia laxa, although also endemic to California, exists in large numbers and has a much larger range that extends farther south into the inner South Coast Ranges including San Benito County (Hickman, 1993). The disc and ray seeds of *B. laxa* appear quite similar and have a short pappus from 0–1 mm in length (Figure B1). *Blepharizonia laxa* is much more glandular than *B. plumosa*, giving the plant a more yellow-green color and a much stronger scent. They also tend to be slightly taller than *B. plumosa* (personal observation). Older plants have inflorescences mostly terminal on slender wand-like, bracted peduncles (Hickman, 1993).

Many areas at Site 300 are annually burned in the late spring/early summer as a means of wildfire control (Figure B2). Although rare outside of Site 300, *B. plumosa* is quite common at Site 300, occurring in large numbers in areas that are routinely burned. This is interesting, for at the time of the annual spring burns at Site 300, the plant is in a green vegetative stage, and thus very susceptible to fire damage. It is possible that the larger Site 300 *B. plumosa* population may be acting as a metapopulation. Smaller subpopulations may be established or extinguished, depending on fire uniformity and intensity. And although fire is potentially fatal to individual *B. plumosa* plants directly in its path, it may provide the amount of disturbance necessary to reduce competition and allow for subpopulation establishment, thus maintaining a metapopulation consisting of ephemeral individual populations.

While common throughout its range, *B. laxa* is very uncommon at Site 300. *Blepharizonia laxa* populations occur sporadically in both unburned and burned areas. The two species occur sympatrically (together) in only a few locations. That the two species appear to differ in their habitat requirements may indicate some ecological differentiation between them.

For conservation and management purposes, a thorough understanding of the population dynamics of *B. plumosa* is necessary. *Blepharizonia laxa* is also of interest as comparisons of rare and common congeners can provide important information for rare plant management (Bevill and Louda, 1999; Pantone et al., 1995) and can illuminate differences that affect comparative abundance (Byers, 1998). Therefore, between 1996 and 2001, we collected basic demographic and population biology data on *B. plumosa* and *B. laxa*. Between 1996 and 2001, populations of *B. plumosa* and *B. laxa* were delineated for monitoring purposes. Figure B2 shows the location of the four populations that were monitored. This monitoring showed that *B. plumosa* and *B. laxa* do not survive direct contact with prescribed burns, but survive in small patches of unburned habitat within the burns.

We have begun to discern ecological differences between *B. plumosa* and *B. laxa* (Gregory et al., 2001), however we cannot yet explain the relative differences in abundance between the two species at Site 300. Therefore, current and future work focus on understanding the population dynamics of *B. plumosa* across the entire site. If indeed *B. plumosa* is acting as a large metapopulation, smaller subpopulations may be of less importance. But we must verify that *B. plumosa* is indeed acting as a metapopulation and understand how it is maintained before we can be certain subpopulations loss will not threaten the overall metapopulation. By continued work with *B. laxa* we will gain a better understanding of the mechanisms controlling the relative abundance of the two species at Site 300.

B-2. Methods and Materials

B-2.1 Seedling Recruitment

In the spring of 2003, we began to examine differences in seedling recruitment between burned and unburned areas. During the fall of 2002, the location of mature *B. plumosa* plants were marked in several burned and unburned patches. Although an attempt was made to pair burned and unburned areas in adjacent locations, it was not possible to find enough paired sites to allow for this comparison. Mature plants were marked in Elk Ravine, along the edge of power pole rings (herbicide treated areas surrounding the poles) on a fire trail south of Elk Ravine, along Route 1 south of Elk Ravine, at Building 867, and at Building 812. Three additional locations were chosen to the north of Building 801 where no adult plants had been marked the previous year. Three locations were chosen at Building 801: (1) dense annual grassland, (2) open annual grassland, and (3) roadside north of Building 801.

On May 16, 2003 and May 23, 2003 these sites were revisited and the number and size of all *B. plumosa* seedlings within a 5-foot radius circle or half circle were measured. Half circles were used in areas that were obviously on the habitat's edge such as the edge of a road or fire pole ring.

B-2.2. Site-wide Mapping

During site-wide mapping conducted by LLNL in 2003 and 2004, surveys for *Blepharizonia* were conducted by driving the Site 300 fire trail system at slow speeds while surveying for *Blepharizonia* from the vehicle. In addition, we stopped at vantage points and scanned the landscape with binoculars for *Blepharizonia*. *Blepharizonia* is one of the few white-flowered plants blooming at Site 300 during the survey, so it is easy to identify using binoculars. When a *Blepharizonia* plant or population was found, it was mapped using a Trimble Geo XT handheld GPS. In addition, the species *(B. plumosa* or *B. laxa)*, an estimate of population size (< 10, 10–50, 50–200, 200–500, 500–1,000, 1,000–5,000, or > 5,000 plants), whether the site was burned or unburned, and population location (roadside, grassland, scrub, or power pole ring) was recorded. *Blepharizonia* mapping was conducted on October 14–17 and 20, 2003; September 29 and 30, 2004; and October 8 and 15, 2004.

Previous surveys of Site 300 occurred in 1996, 1997, 1999, 2000, 2001, and 2002. On September 27, 1996; October 4, 1996; and September 23, 1997, Robert Preston surveyed the entire site for flowering *B. plumosa* populations and visually estimated population locations and sizes, hand-mapping them on a large-format map (Preston, 2002). On October 22 and 29, 1999 and on seven dates between October 20 and November 8, 2000, all areas of Site 300 were surveyed for flowering *B. plumosa* populations. On three dates between October 25 and November 8, 2001, the northern and western areas of Site 300 were surveyed for flowering *Blepharizonia* populations. The remainder of the site was not surveyed due to manpower limitations. All *B. plumosa* and *B. laxa* populations found were mapped using a Trimble GPS unit in 1999, 2000, and 2001. The number of individuals were either counted or visually estimated for each population mapped. On seven dates between September 25, 2002 and October 30, 2002, all areas of Site 300 were surveyed for flowering *Blepharizonia* populations. All *B. plumosa* and *B. laxa* populations found were manually mapped using a large-scale topographic map (1 in.:600 ft). The number of individuals were either counted or visually estimated for each population mapped.

B-3. Results

B-3.1. Seedling Recruitment

The results of the seedling recruitment study are shown in Table B1. On average, there were 6.65 ± 11.88 seedlings per m^2 (mean ± SD) in burned plots compared to an average of 3.11 ± 3.61 seedlings per m^2 in unburned plots. This difference is largely due to the extremely high number of seedlings in one burned location (Building 812 berm). However, the average height of *B. plumosa* was clearly larger ($t = 7.66$, $df = 335$, $p \ll 0.0001$) in burned areas (10.11 ± 7.3 cm) compared to unburned areas (5.50 ± 3.43 cm).

B-3.2. Site-wide Mapping

Figures B3 through B5 summarize the results of *Blepharizonia* mapping and/or burning conducted between 1996 and 2004. This relationship between *Blepharizonia* location and burning is shown in greater detail in the map enlargements that follow the summary maps (Figures B6 through B14).

Blepharizonia population size appears to be reduced due to direct impacts of burning and expanded in years following prescribed burns. Although populations re-emerge during years of limited burning, they appear to shrink after several years without burning. For example, the northeast corner of the site, east of Building 801, was last burned in the spring of 2001. In 2001 (the fall immediately following the burn of this site; Figure B4c), only small populations of *B. plumosa* were found east of Building 801. In 2002, the area east of Building 801 was not burned, and the distribution of *B. plumosa* was greatly expanded compared to 2001 while *B. plumosa* populations were smaller throughout the site in 2002 (Figure B4d). Alternatively, the size of the *B. plumosa* population in that area has decreased each year since 2002 (2003 and 2004; Figures B5a and B5b).

Blepharizonia populations also appear to thrive in areas where unburned patches occur within the burned area or in areas where artificial firebreaks provide shelter from the burn. The area surrounding Building 851, located in the western half of Site 300, is burned annually. The size of the *B. plumosa* population surrounding Building 851 was similar in 2003 and 2004 although throughout the rest of the site *B. plumosa* population decreased. This is probably a result of the extremely patchy nature of the burn in the Building 851 area. The bulk of the Building 851 *B. plumosa* population occurs in an extremely steep north-facing canyon that is often difficult to burn and avoids the impacts of intense fire. In addition, an herbicide-treated firebreak occurs around the perimeter of Building 851 that provides additional protection to *B. plumosa* from the prescribed burns. Despite the fact that prescribed burns occur annually in the entire area surrounding Building 851, *Blepharizonia plumosa* is abundant adjacent to this firebreak and in the patches on unburned habitat on the slopes that surround Building 851.

B-4. Recommendations and Future Work

By mapping *B. plumosa* populations on a yearly basis, we are gaining a better understanding of the mechanisms at work controlling the distribution of this species. *Blepharizonia plumosa* is so widespread at Site 300 that mapping over multiple years is required to provide information on the relationship between population presence and burn frequency. Intensity and timing of burning may have profound effects on *B. plumosa* population dynamics and, in absence of the ability to control these effects, many years of data are needed to shed light on the relationship between *B. plumosa* and the annual burns that occur at the site.

The information gained from monitoring the burn survivorship at Building 850, Elk Ravine, and Building 812 in 2001 and 2002 was useful in interpreting the site-wide data. We have shown conclusively that *B. plumosa* does not survive direct contact with the flames, but rather survives in patches of unburned habitat. However, it is now important to determine if seedling recruitment is enhanced in burned vs. unburned areas. That is, while burning may cause direct mortality of plants in the year of the burn, it may enhance seedling recruitment either through reduction in plant competition or enhanced germination the following year if the area is not again burned. Mapping results from the northeastern portion of the site, near Building 801, suggest this to be the case. As such, we would expect to see a decline in this population over time if the area is not periodically burned. The 2004 seedling recruitment experiment comparing recruitment in burned and unburned patches did not yield conclusive information because of the difficulty in controlling for factors other than burned/unburned in these patches (such as the size and number of maternal plants). The 2004 experiment did show that seedlings in unburned patches are larger than those in burned patches.

In 2005, we plan to continue studying *Blepharizonia* seedling recruitment in burned and unburned patches by measuring the amount of viable seed in burned and unburned patches. This, along with the yearly site-wide mapping, should help us to predict the frequency of burning required to maintain *B. plumosa* populations. Middle Canyon will continue to be tracked in order to compare ecological requirements between *B. plumosa* and *B. laxa*.

Developing a method of measuring burn intensity would allow us to more clearly understand the fluctuations in population size near Buildings 801 and 851. By mapping unburned patches immediately following controlled burns at Buildings 801 and 851 annually, we would be able to compare the distribution of *B. plumosa* in relationship to the patchiness of the burns and possibly explain why the *B. plumosa* population surrounding Building 851 continues to persist despite annual burns. Mapping burn patchiness may also help to explain population size fluctuations throughout the site. Through personal observations, the intensity of the burns appear to be a relatively consistent site wide occurrence. In some years, the burns appear be to patchy throughout the site, possibly due to less than average cover of annual grasses, and in other years, the burns are more complete throughout the site.

The importance of gene flow among Site 300 *B. plumosa* locations is unknown. The Site 300 *B. plumosa* population may be acting in one of three ways: (1) a true metapopulation, in that gene flow is semi-restricted, with most of the gene flow occurring within subpopulations, with limited gene flow occurring between subpopulations, (2) one large population, with extensive gene flow occurring between all subpopulations, or (3) many small populations, with no gene flow among them. We have been operating under the hypothesis that the Site 300 *B. plumosa* population is either a true metapopulation (scenario 1) or a single large population (scenario 2). Under either case, the loss of a small subpopulation may not impact the larger Site 300 population depending on its size and location. However, should individual populations be the case (scenario 3), each population is valuable and irreplaceable and theoretically should be protected. The best method to determine the population structure at this level is through molecular and/or genetic analysis of plants from subpopulations across the site. Should funding opportunities arise, this work should be considered.

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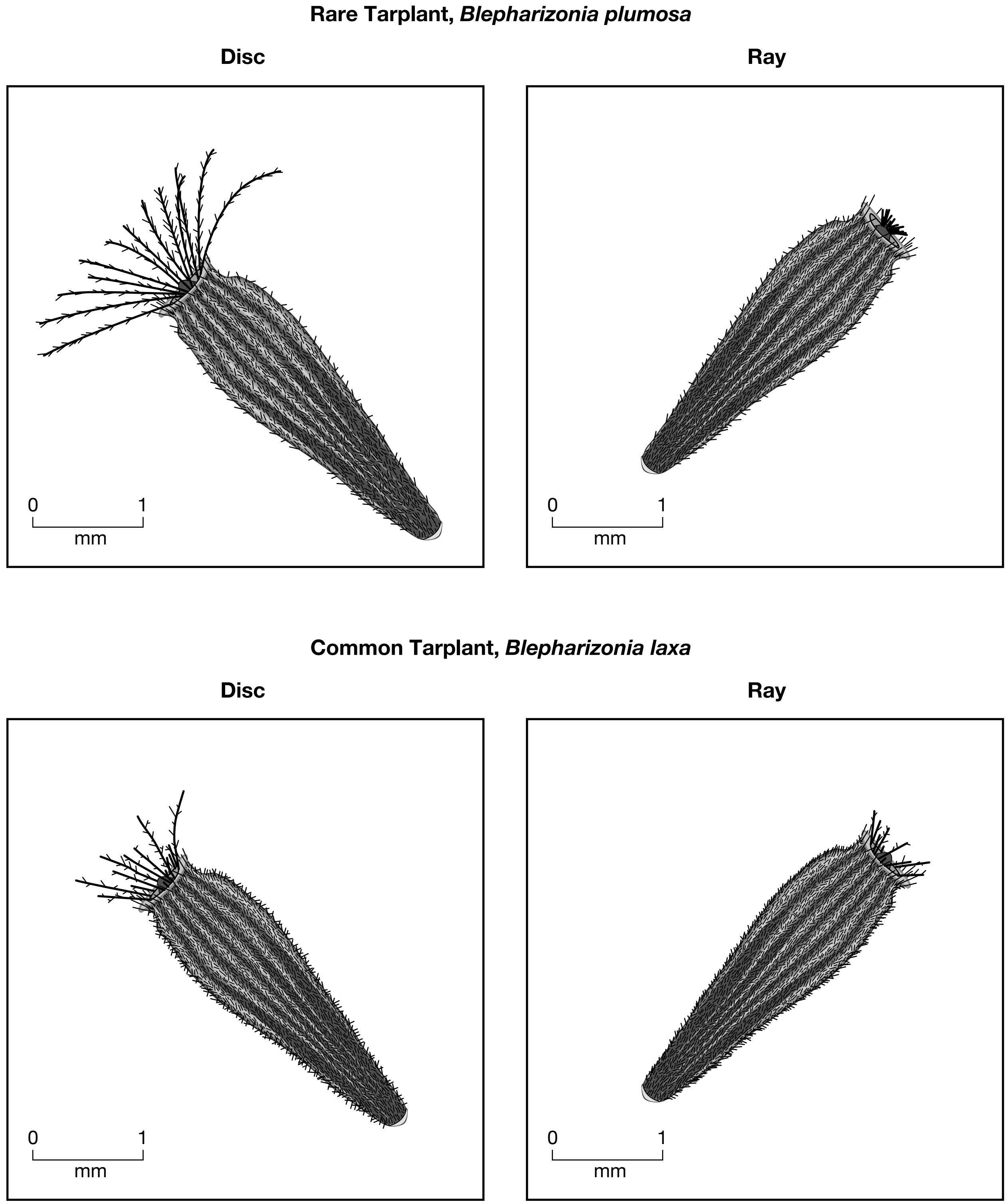
Section B
Figures



ERD-S3R-05-0042

Figure B1. ***Blepharizonia plumosa*** **fruit and** ***Blepharizonia laxa*** **fruit.**

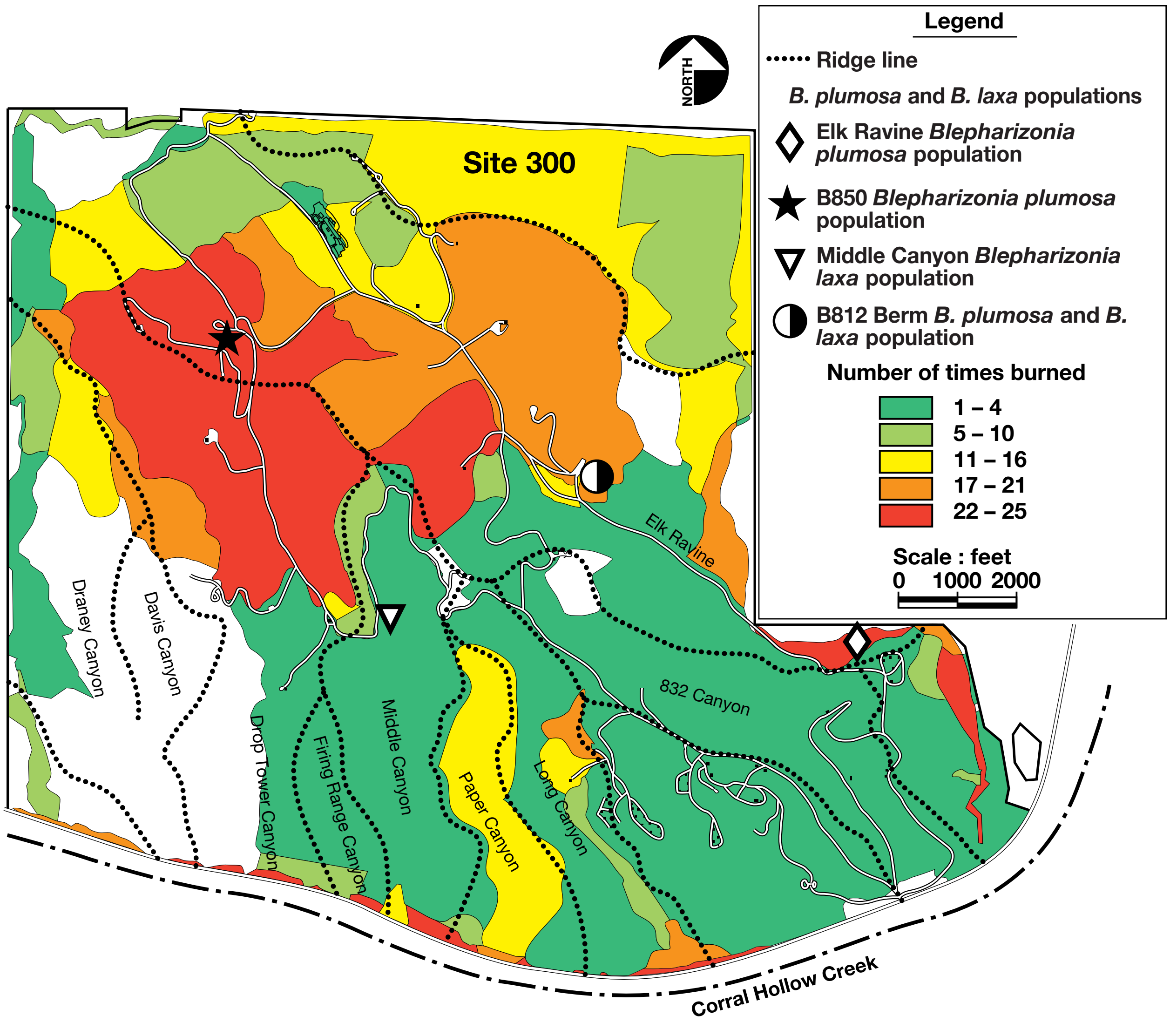
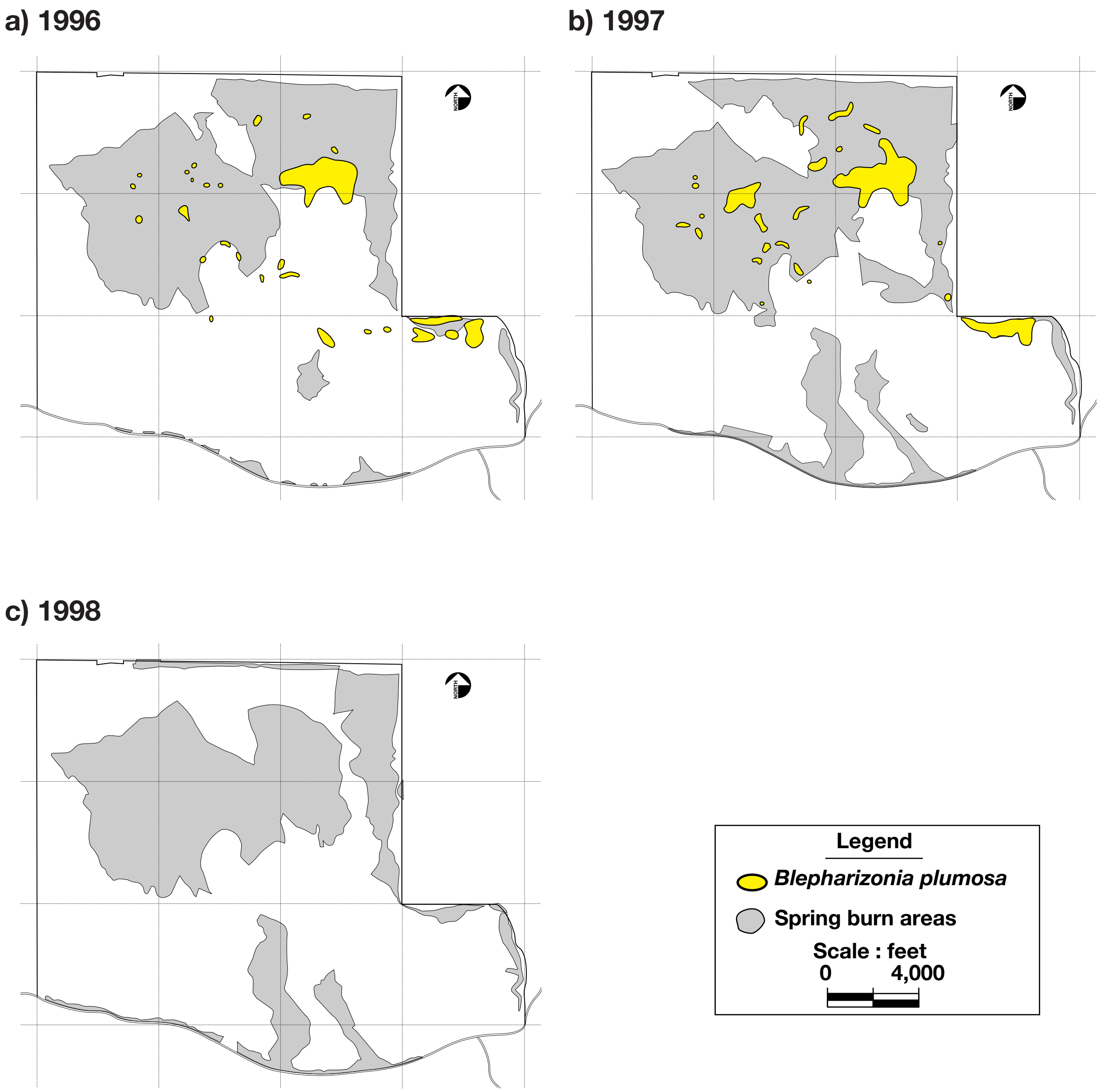
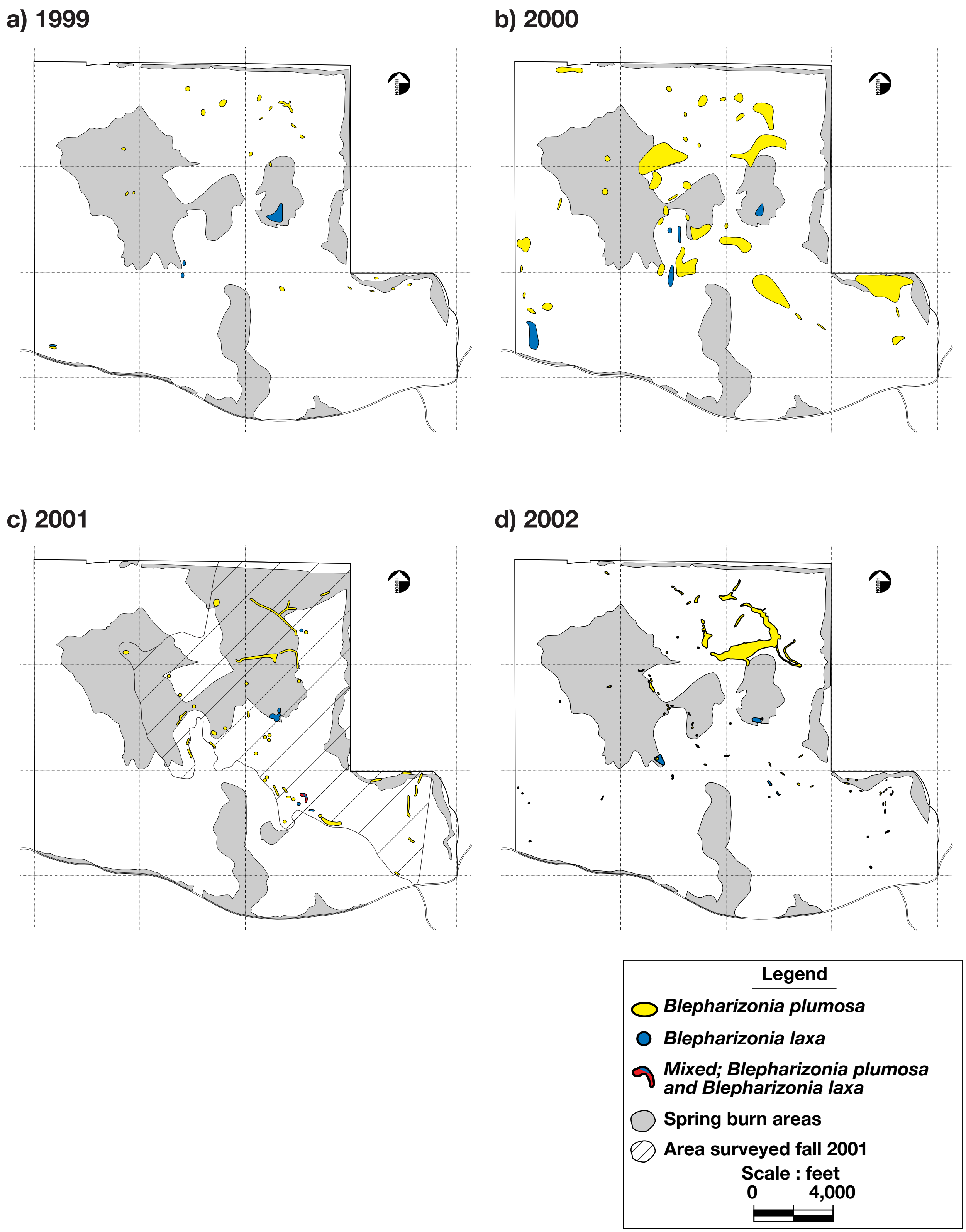


Figure B2. Location of *Blepharizonia plumosa* and *Blepharizonia laxa* populations monitored at LLNL Site 300 with twenty-five year fire frequency.



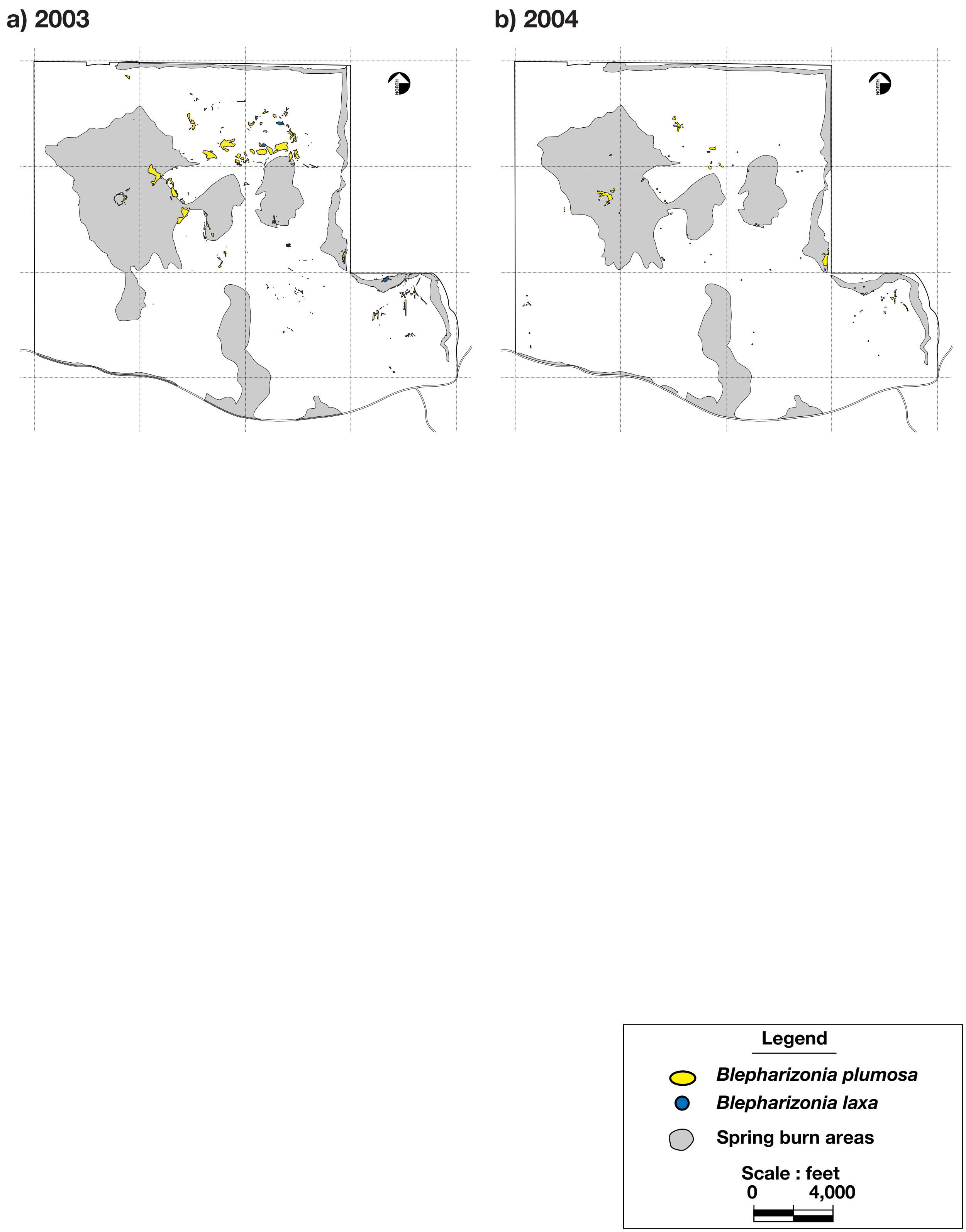
ERD-S3R-05-0045

Figure B3. ***Blepharizonia*** **populations mapped in the fall of 1996–1997. Areas burned in each spring are shown, a) 1996, b) 1997, c) 1998. For map enlargements, refer to Figures B6 through B8.**



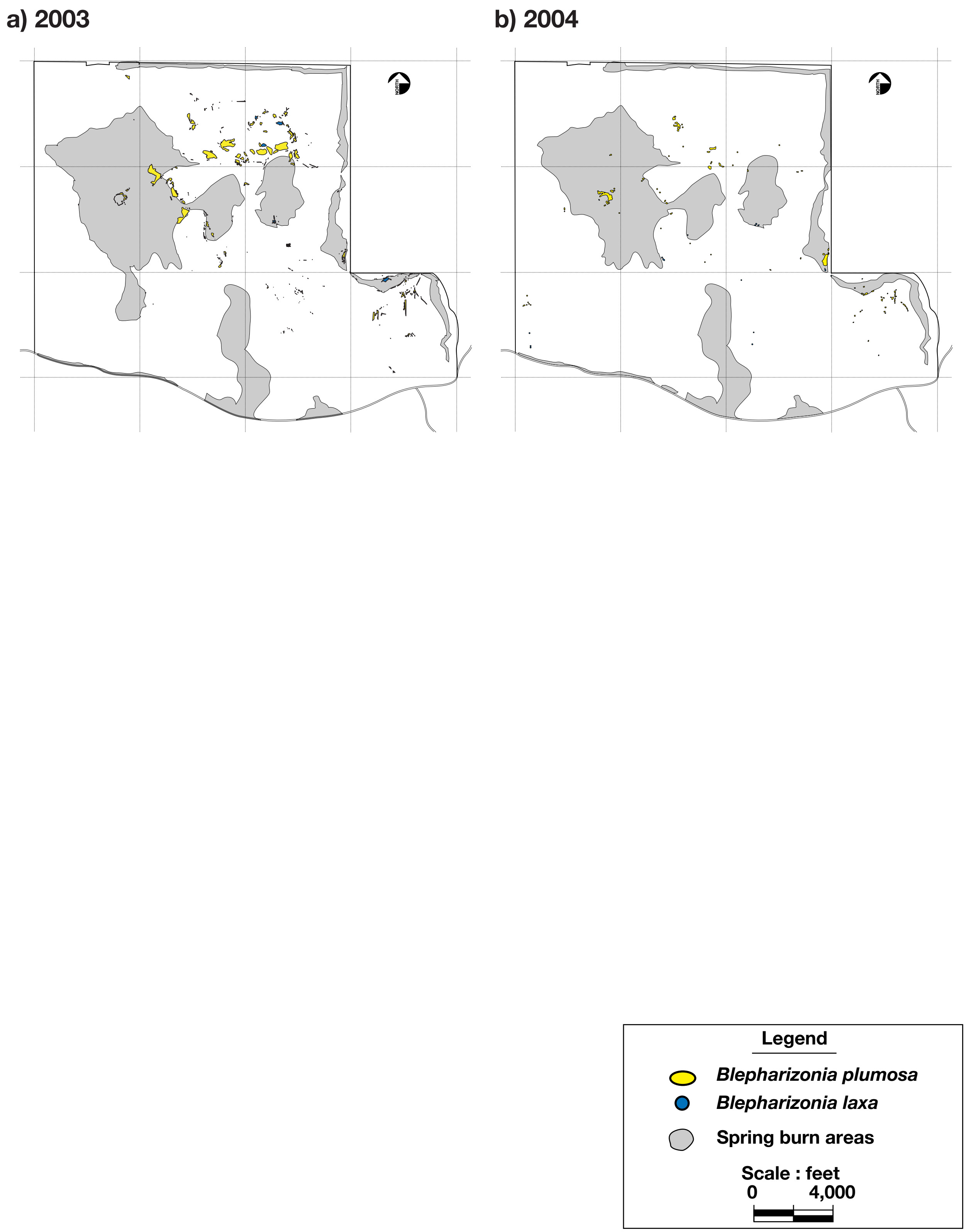
ERD-S3R-05-0046

Figure B4. ***Blepharizonia*** **populations mapped in the fall of 1999–2002. Areas burned in each spring are shown, 1)1999, b) 2000, c) 2001, d) 2002. For map enlargements, refer to Figures B9 through B12.**



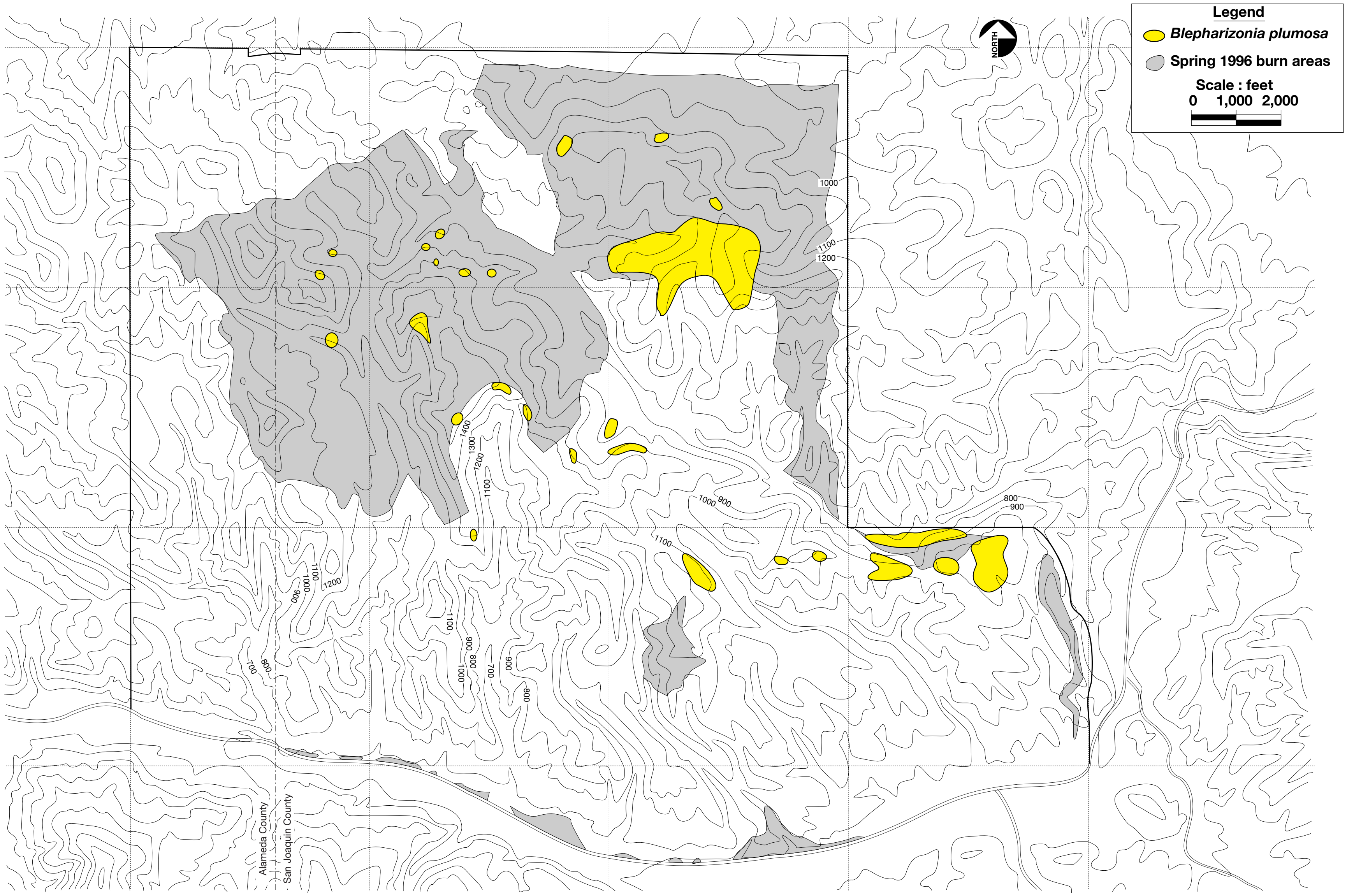
ERD-S3R-05-0053

Figure B5. ***Blepharizonia*** **populations mapped in the fall of 2003–2004. Areas burned in each spring shown, a) 2003, b) 2004. For map enlargements, refer to Figures B13 and B14.**



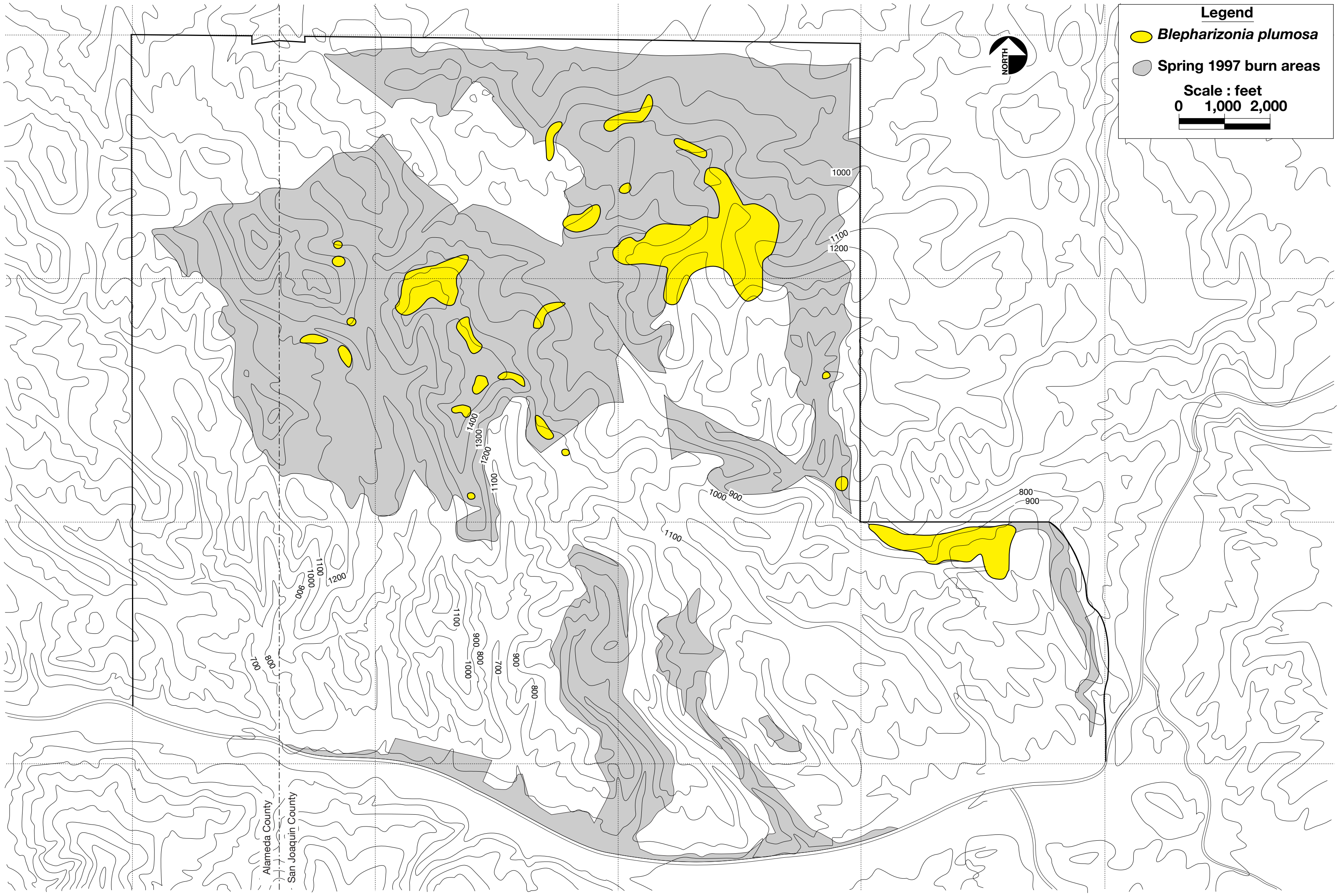
ERD-S3R-05-0053

Figure B5. ***Blepharizonia*** **populations mapped in the fall of 2003–2004. Areas burned in each spring shown, a) 2003, b) 2004. For map enlargements, refer to Figures B13 and B14.**



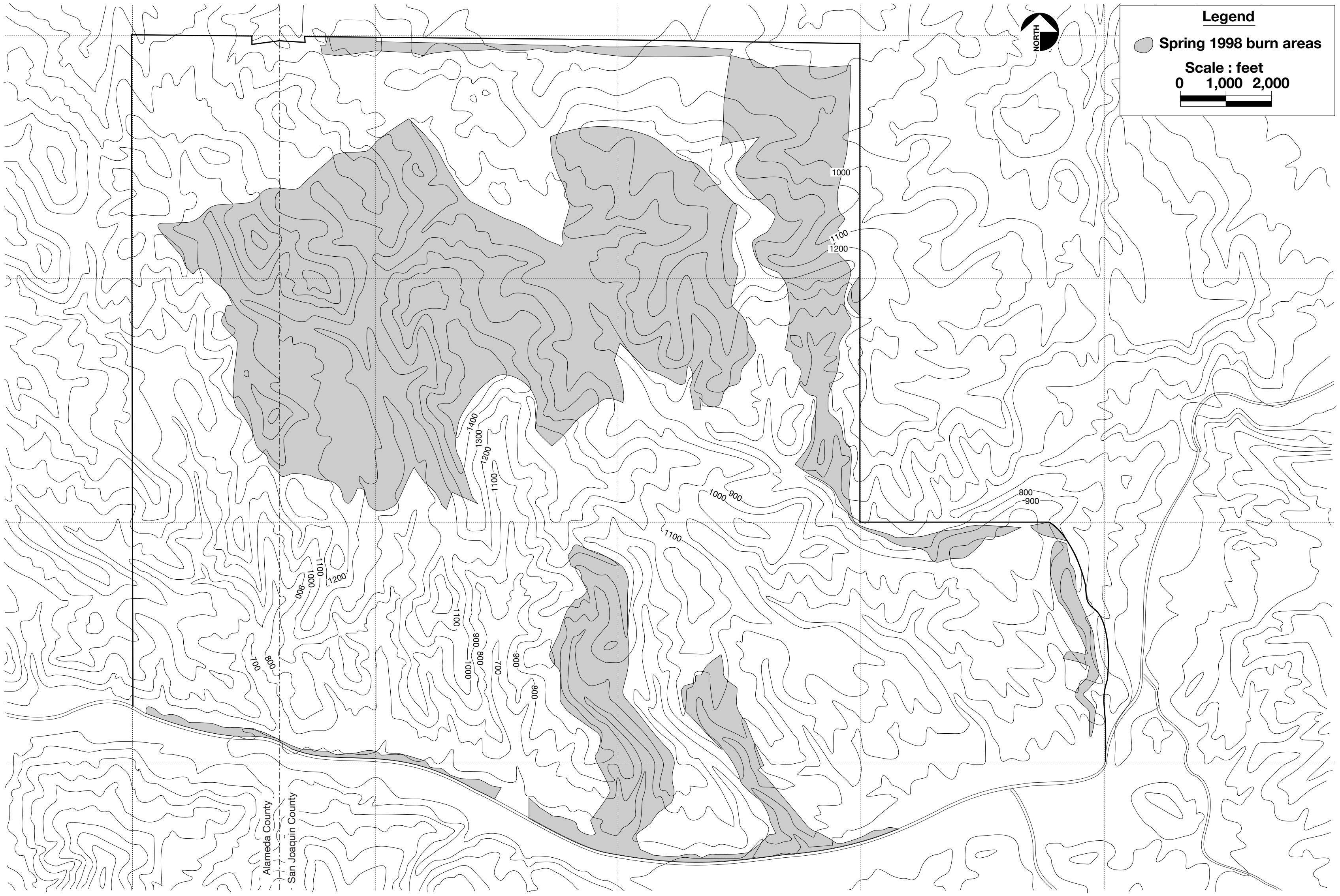
ERD-S3R-05-0050

Figure B6. Enlargement of Figure B3a. *Blepharizonia* mapped in the fall of 1996 by R. Preston (Preston, 2002). Areas burned in spring of 1996 shown.



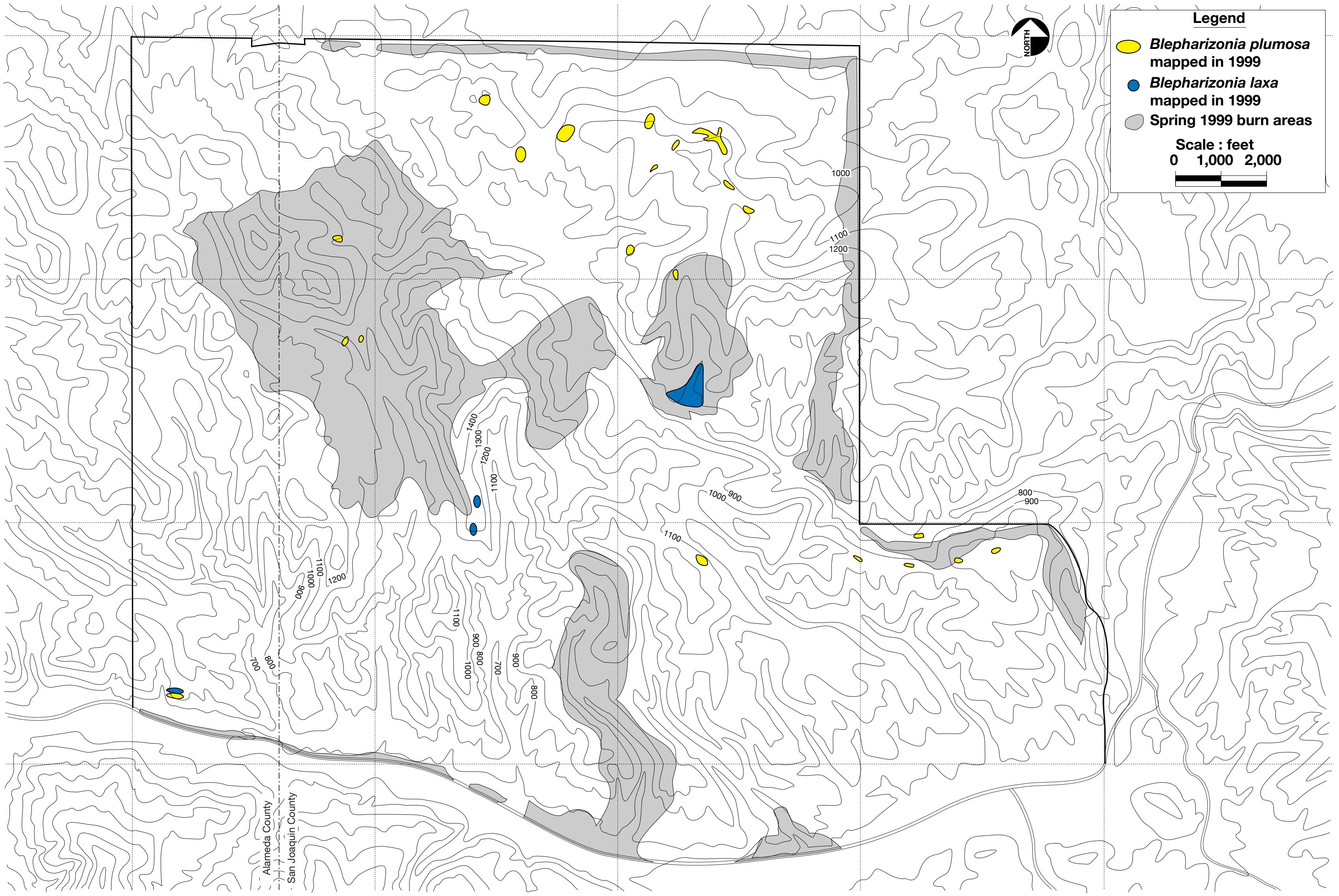
ERD-S3R-05-0047

Figure B7. Enlargement of Figure B3b. *Blepharizonia* populations mapped in the fall of 1997 by R. Preston (Preston, 2002). Areas burned in spring of 1997 shown.



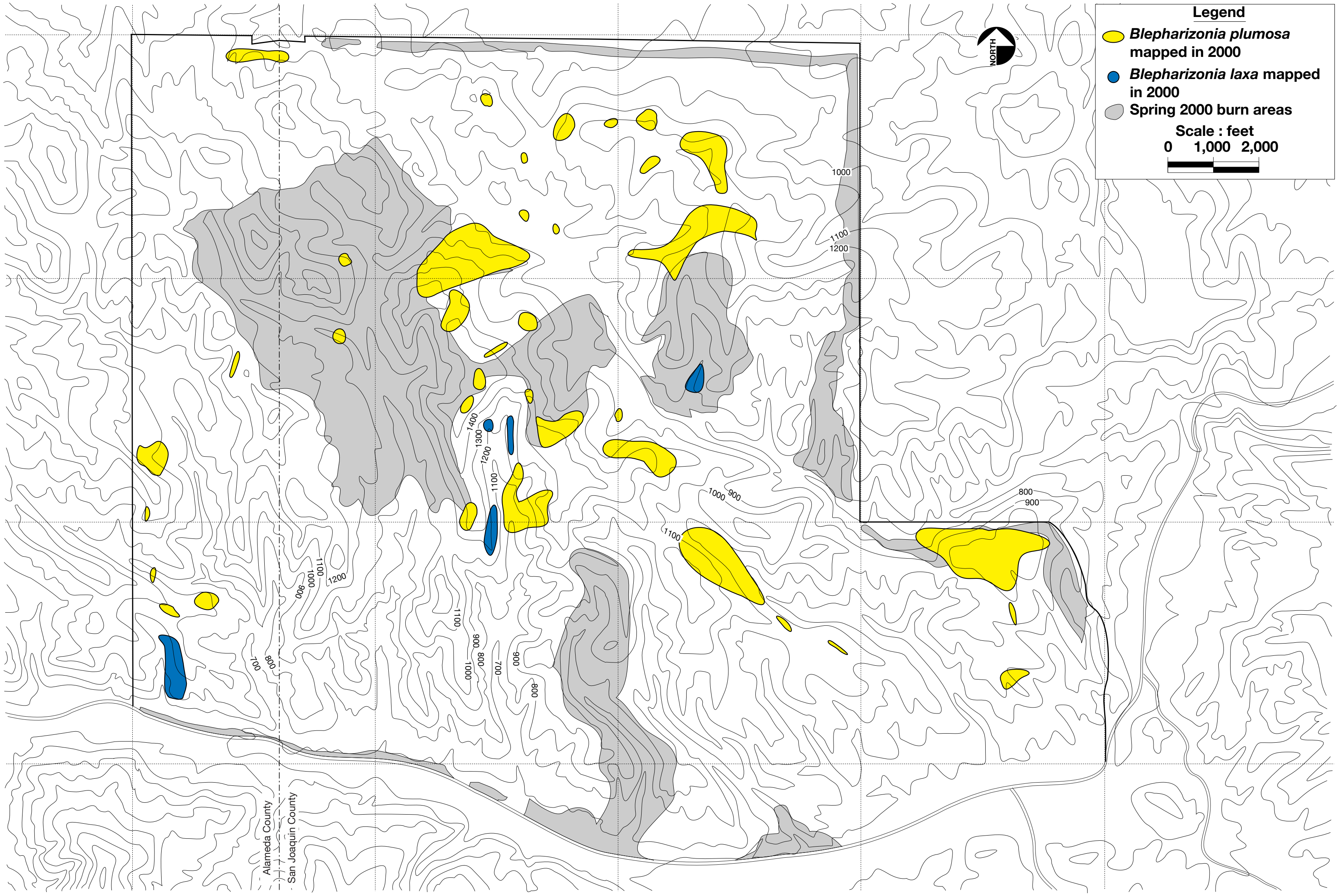
ERD-S3R-05-0052

Figure B8. Enlargement of Figure B3c. Areas burned in spring of 1998 shown. *Blepharizonia* populations not mapped.



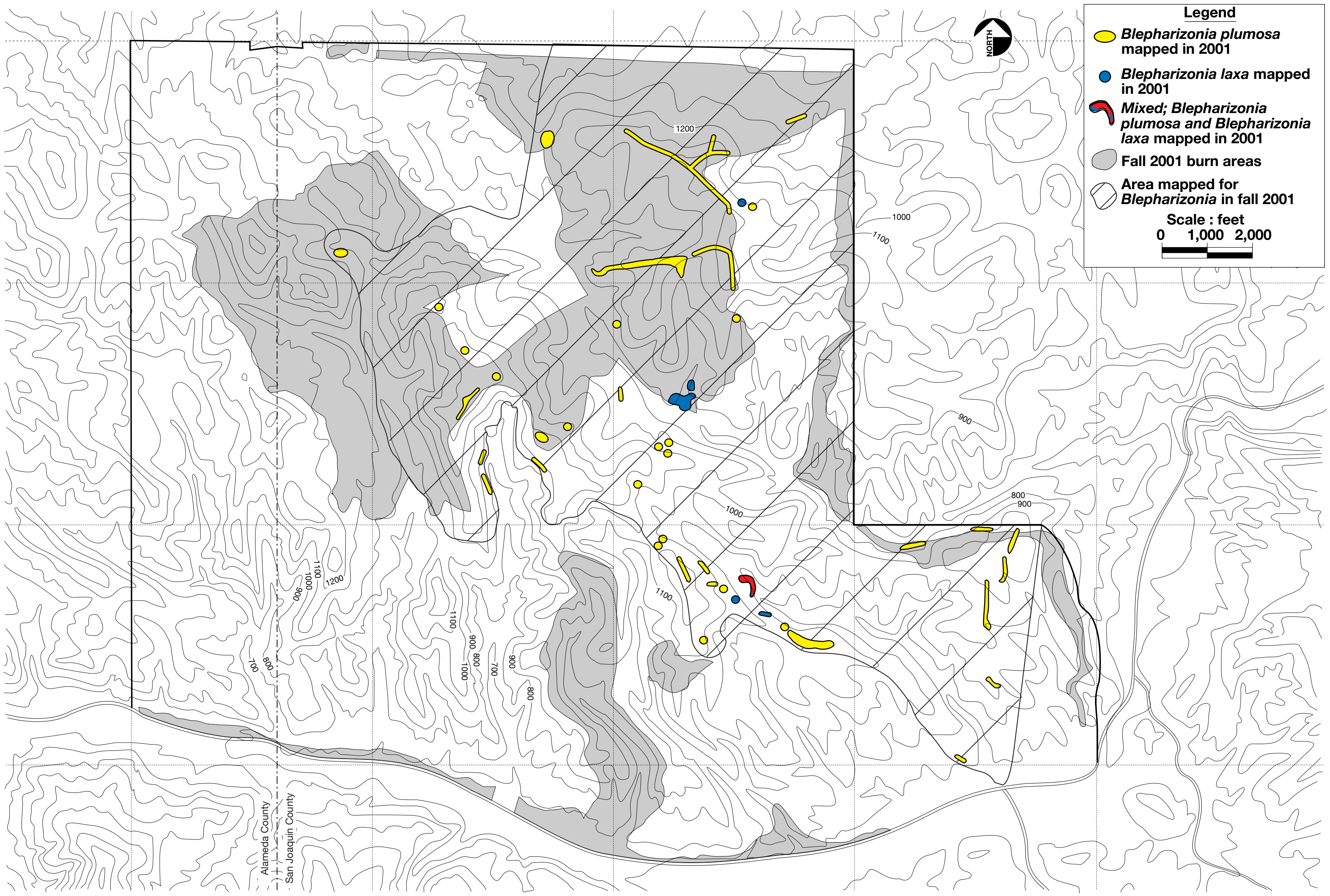
ERD-S3R-05-0048

Figure B9. Enlargement of Figure B4a. *Blepharizonia* populations mapped in the fall of 1999. Areas burned in spring of 1999 shown.



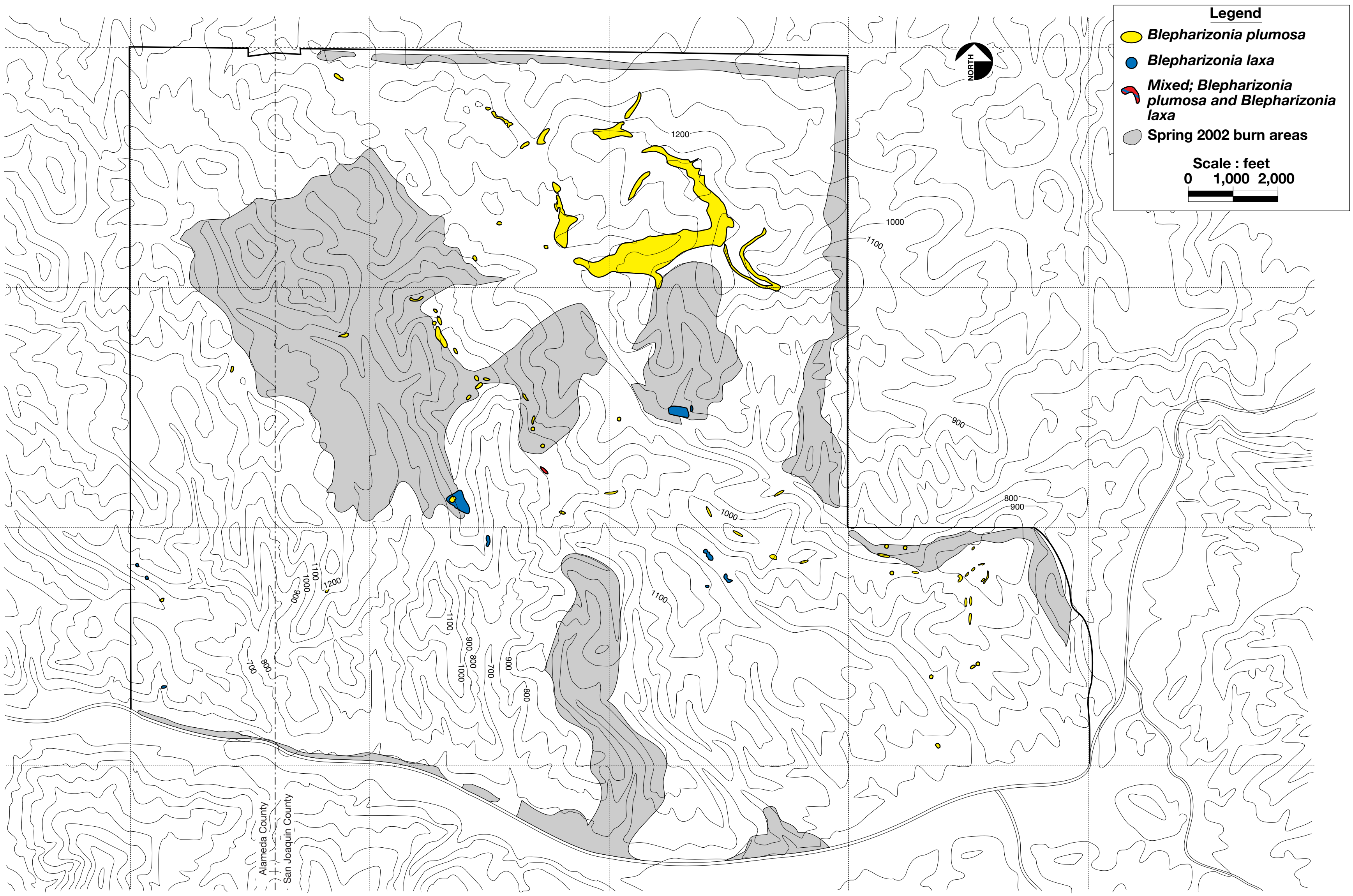
ERD-S3R-05-0049

Figure B10. Enlargement of Figure B4b. *Blepharizonia* populations mapped in the fall of 2000. Areas burned in summer of 2000 shown.



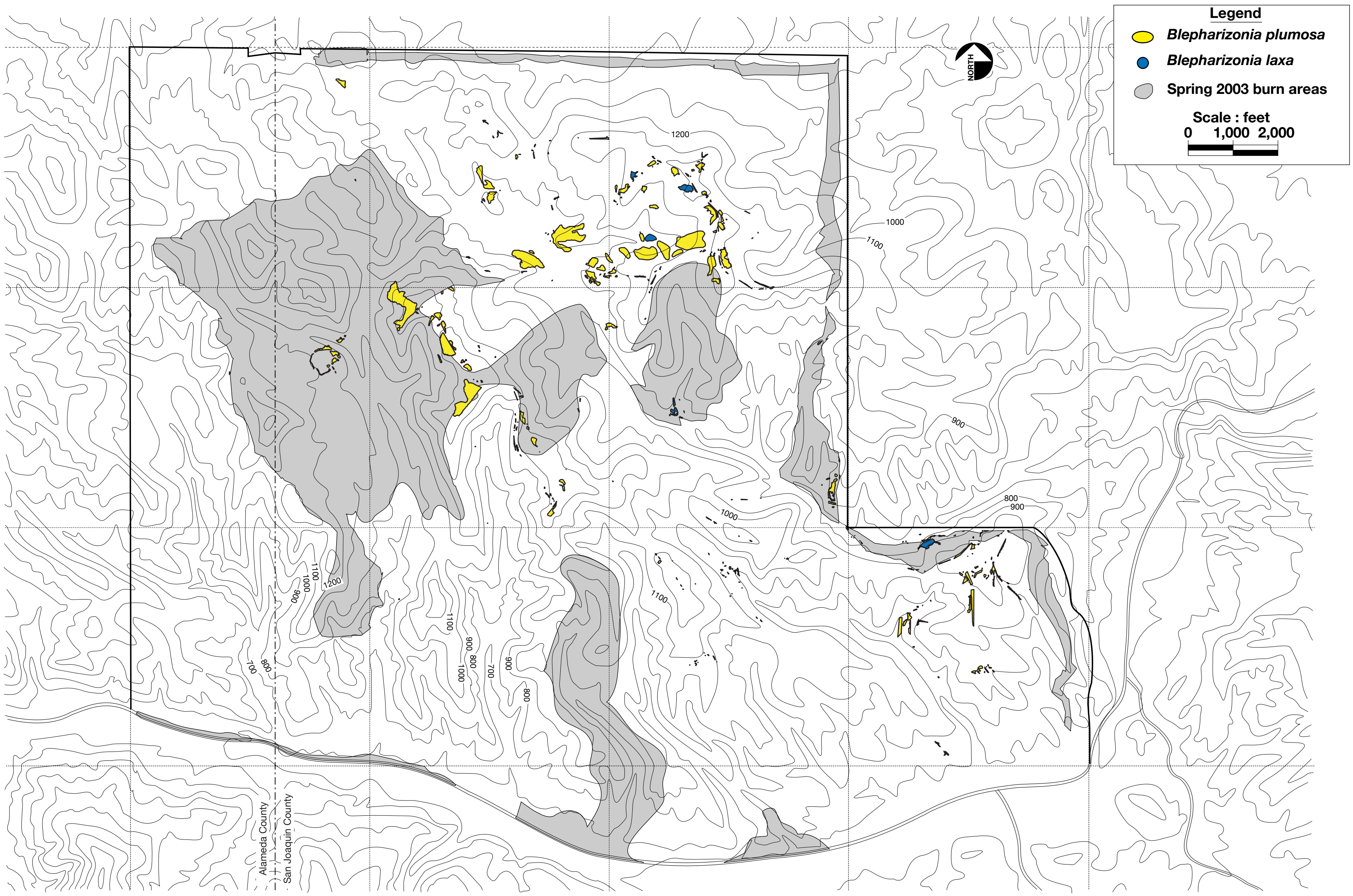
ERD-S3R-05-0051

Figure B11. Enlargement of Figure B4c. *Blepharizonia* populations mapped in the fall of 2001. Areas burned in spring of 2001 shown.



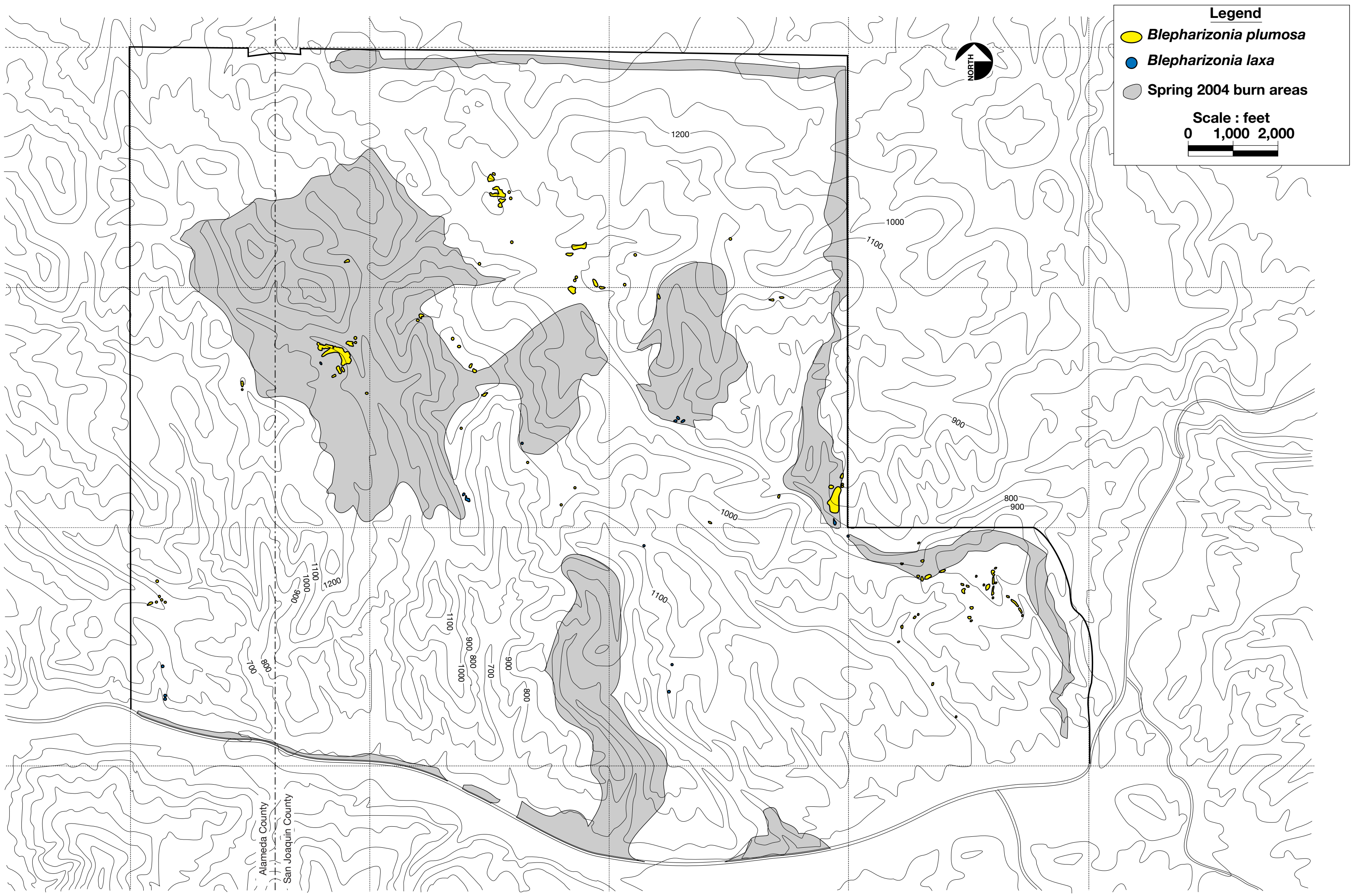
ERD-S3R-05-0044

Figure B12. Enlargement of Figure B4d. *Blepharizonia* mapped in the fall of 2002. Areas burned in spring of 2002 shown.



ERD-S3R-05-0054

Figure B13. Enlargement of Figure B5a. *Blepharizonia* populations mapped in the fall of 2003. Areas burned in spring of 2003 shown.



ERD-S3R-05-0055

Figure B14. Enlargement of Figure B5b. *Blepharizonia* populations mapped in the fall of 2004. Areas burned in spring of 2004 shown.

Section B
Tables

Table B1. Comparison of seedling recruitment in burned and unburned sample areas surrounding the location of flowering plants during the previous fall.[a]

Burned locations	Average height[a] (cm)	Number of seedlings	Sample area (m^2)	Seedling density (seedlings/m^2)
Route 1	14.36	7	3.65	1.92
Route 1	7.55	2	3.65	0.55
Elk Ravine	11.90	5	7.29	0.69
Building 812 Berm	8.72	111	3.65	30.44
Building 812 gully	15.37	23	3.65	6.31
Building 867	NA	0	3.65	0.00
Average	**11.58**			**6.65**
SD	**3.41**			**11.88**

Unburned locations	Average height[a] (cm)	Number of seedlings	Sample area (m^2)	Seedling density (seedlings/m^2)
Fire trail power pole ring	11.58	6	3.65	1.65
Fire trail power pole ring	4.38	33	3.65	9.05
Fire trail power pole ring	10.67	6	3.65	1.65
Elk Ravine	4.91	28	7.29	3.84
Building 801 (open)	3.63	22	7.29	3.02
Building 801 (dense)	NA	0	7.29	0.00
Building 801 (road)	8.69	34	3.65	9.32
Building 812 gully	4.67	3	3.65	0.82
Average	**6.93**			**3.11**
SD	**3.30**			**3.61**

Notes:

The number of maternal plants is not considered in the analysis.

NA = Not applicable.

SD = Standard deviation.

[a] **Mean seedling height is significantly greater in burned locations compared to unburned locations (p < 0.0001).**

Section C
Eschscholzia rhombipetala Monitoring

Section C

Eschscholzia rhombipetala Monitoring

C-1. Introduction

Eschscholzia rhombipetala (the diamond-petaled poppy) is an extremely rare spring-flowering annual plant currently included on the California Native Plant Society (CNPS) List 1B (CNPS, 2001). This species was formerly included on the CNPS List 1A (Skinner and Pavlik 1994), which includes plants that are presumed extinct. The historic range of this species includes the inner north Coast range, the eastern San Francisco Bay region, and the inner South Coast Ranges. The last herbarium collections of *E. rhombipetala* were made in 1950 in San Luis Obispo County, and the species has since been presumed extinct. In 1993, a population of *E. rhombipetala* was discovered in the northern part of the Carrizo Plain by a plant taxonomist from California Polytechnic State University, San Luis Obispo (Keil, 2001). This population was observed again in 1995 but has not been seen since. At this location, they grow on heavy clay soils that accumulate water in the spring, forming vernal pools. The poppies grow in an ecotone on the higher areas between an *Amsinckia*-dominated mound and a *Layia*-dominated swale, in open patches. They grow as almost an understory to the taller *Lasthenia*, *Phacelia*, and various grasses (Clark, 2000).

Collections of *E. rhombipetala* have been made at Corral Hollow, both in 1937 (UC765993) and in 1949 (Espeland and Carlsen, 2003). A population of *E. rhombipetala* was identified during a habitat survey in 1997 at Site 300 (Preston, 2000). This original population (site 1) is located in the extreme southwest corner of the site (Figure C1). Like the Carrizo plain population, it occurs in an ecotone on heavy clay soils. The ecotone at Site 300 was formed by a landslide within a minor east-west drainage to a major north-south trending canyon. The landslide formed a slump at the bottom of the slide, with sharp scarp faces on the northern and southern sides of the slump. This *E. rhombipetala* population is found on the southern side of the slump (a north-west facing aspect) near the edge of the scarp, some distance into the surrounding grassland, and in the slump itself. The surrounding grasslands are composed primarily of the exotic grasses *Avena* and *Bromus*, with *Sonchus* and *Brassica* species being the primary forbs. The slump contains various grasses, along with another rare plant, *Blepharizonia plumosa* (Section B), as well as *Blepharizonia laxa*.

A second population (site 2) of *E. rhombipetala* was discovered in spring of 2002 in another habitat survey, less than 2.3 km from the first population (Figure C1). This population occurs on a steep, northwest-facing slope on clay soil. While it may occur on an historic slump, the soil of the population area is not noticeably more active than its surroundings. The second population at site 2 occurs in a grassland of exotic species similar to that at site 1.

In the spring of 2004, a third population (site 3) was found in the northwestern corner of Site 300 in an area known as Round Valley only 0.4 km from site 2 and 1.7 km from site 1. Unlike sites 1 and 2, this population is found in a relatively flat valley surrounded by small hills. At site 3, *E. rhombipetala* occurs with another rare plant *California macrophylla* (Section D).

Eschscholzia rhombipetala is a small, erect annual, 5 to 30 cm tall. A member of the poppy family (Papaveraceae), it has typical poppy characteristics, but is quite diminutive and thus easily overlooked. The flower's yellow petals are 3 to 15 mm long from a barrel-shaped receptacle, and when in bud, may be erect or nodding, with a blunt or short point. The fruit is a capsule, generally 4 to 7 cm long, containing numerous round, net-ridged black seeds 1.3 to 1.8 mm wide (Clark, 1993).

All Site 300 *E. rhombipetala* populations are located in remote portions of Site 300, outside of the programmatic areas. However, for conservation and management purposes, an understanding of the population dynamics of *E. rhombipetala* is desirable. Therefore, we are collecting census data on the *E. rhombipetala* populations, as well as characterization data on the surrounding plant community. These data will provide information concerning the mechanisms controlling the abundance and distribution of *E. rhombipetala*. The results of this analysis will inform continued monitoring and management activities of the Site 300 *E. rhombipetala* populations.

C-2. Methods and Materials

C-2.1. Census

Eschscholzia rhombipetala populations were censused on March 25, 2003 (sites 1 and 2), March 26, 2004 (sites 1 and 2), and April 4, 2004 (site 3). Height, flower number and capsule length were recorded for all three sites. For site 1, the geographic feature was record for each *E. rhombipetala*. Site 1 was divided into three different areas based on the geographic feature: slump (SL), within 50 cm of the scarp next to the slump (SC), and the surrounding grassland (GR).

C-2.1.1. Data Analysis

Linear regression was performed using PROC GLM in SAS (SAS, 1990) to examine the relationship between plant height and number of floral units (buds + flowers + capsules) and capsule length for 2004 census data (and previously form 1998, 2000, 2001, and 2002 census data). Too few plants were present to conduct this analysis with 2003 census data.

ANOVA was performed using the analysis of variance model AOV in R version 1.9.0, followed by Tukey's separation of means was used to compare the mean height and mean number of flower units in three locations (site 1 grassland, site 1 scarp, and site 1 slump) for 2001 census data and four locations (site 1 grassland, site 1 scarp, site 1 slump, and site 2) for 2002 census data. In 2003, too few plants were present to do this comparison. In 2004, a t-test was used to compare mean height and mean number of floral units in site 3 and all site 1 locations combined (site 2 was not included due to small sample size).

C-2.2. Vegetation Sampling

Vegetation data were collected from 60 cm × 60 cm plots on the same dates that the populations were censused. For each plot, species were identified, and their percent cover was visually estimated. Percent bare ground and percent thatch cover was also recorded. Vegetation plots were placed at all locations where *E. rhombipetala* occurred in sites 1 and 2 in 2003 and

2004. This included four plots in 2003 and seven plots in 2004. Additional plots were taken in areas were no *E. rhombipetala* was found so that a total of at least ten plots were sampled at each of four locations: site 1 slump, site 1 scarp, site 1 grassland, and site 2. At site 3, five plots were placed in areas containing *E. rhombipetala* and five were haphazardly placed within the boundaries of the *E. rhombipetala* population, but at specific sites not containing *E. rhombipetala*.

C-2.2.2. Data Analysis

Logistic regression using PROC LOGISTIC in SAS version 6.0 (SAS, 1990) was performed on vegetation data from all plots with complete data sets collected from 1999 through 2004 from all three sites combined to determine effects of vegetation on *E. rhombipetala* presence/absence.

Analyses were conducted to examine differences in the vegetation at different sites and the slump, scarp, and grassland portions of site 1. ANOVA was used to compare the difference in percent cover of each of six categories of vegetation (bare ground, thatch, annual grasses, exotic forbs, and native forbs). In 2003, site 1 scarp, site 1 slump, site 1 grassland, and site 2 were compared. In 2004, site 1 scarp, site 1 slump, site 1 grassland, site 2 and site 3 were compared. ANOVA was performed followed by Tukey's separation of means.

C-3. Results and Discussion

C-3.1. Census

The *E. rhombipetala* population at site 1 and site 2 were quite small in 2003 and 2004 (Table C1 and Figure C2). Site 2 contained only two plants in 2003 and one plant in 2004, and site 1 contained only 10 plants in 2003 and 19 plants in 2004. Despite the small populations at site 1 and site 2, the total Site 300 *E. rhombipetala* population (sites 1, 2, and 3 combined) consisted of 409 plants in 2004 with the addition of site 3.

The distribution of *E. rhombipetala* at sites 1, 2, and 3 is shown in Figures C3 through C5, respectively. In 2003 and 2004, *E. rhombipetala*'s distribution at site 1 was limited to a small portion of the scarp and the adjacent grassland. The distribution at site 2 was also reduced from previous years. The few plants that were present in 2003 and 2004 occurred in the northwestern edge of the previous distribution.

Figure C6 shows the heights of *E. rhombipetala* by site for 2001 through 2004. *Eschscholzia rhombipetala* at all site 1 locations combined and at site 2 were 6.1 ± 2.0 cm (mean ± SD) and 4.0 ± 2.8 cm tall in 2003, and 7.5 ± 2.2 cm and 6.2 cm tall in 2004 respectively. Site 3, in addition to being the largest population in 2004, contained larger plants (12.0 ± 2.6 cm tall). Site 3 plants were significantly taller than site 1 plants in 2004 ($t = -7.1$, $df = 175$, $p << 0.0001$). At all three locations in 2003 and 2004, plants as short as 2 cm were observed flowering and the largest plants recorded were approximately 18 cm tall.

Location also had an effect on plant performance (Figure C7 and Table C2); the mean number of floral units per plant was greater at site 3 then at all site 1 locations combined ($t = -3.6$, $df = 175$, $p < 0.0005$). In 2004, site 3 had 2.9 ± 1.9 floral units per plant while site 1 (combined) plants had 1.3 ± 1.1 floral units. The one *E. rhombipetala* present at site 2 in 2004 had 3 floral units. In 2003, the average number of floral units per plant at sites 1 and 2 (site 1, 0.7 ± 0.5; site 2, 2.5 ± 0.7 floral units) was similar to the number of floral units in 2004, and site 1 and 2 had the same ranking in respect to average number of floral units. In 2003 and 2004, all site 1 and site 2 plants had less than three floral units at the time of census while site 3 plants had up to 12 floral units per plant with many plants possessing greater than three floral units.

In 1998, 2001, and 2004 about 30% of plant reproductive output was best explained by plant height. In 2000, 23% of plant reproductive output was explained by plant height and in 2002 12%. Clearly, even in years with stronger associations between plant size, reproductive output factors other than size may determine plant fitness. There was a significant positive relationship between plant height and number of floral units (buds + flowers + capsules) as well as between plant height and capsule length at site 3 in 2004 (Table C3); Larger plants had greater reproductive output than smaller plants. The slope of the regression of number of floral units to plant height was 0.38 and the intercept was -1.71 ($p < 0.0001$, $r^2 = 0.293$). Data were too few in site 1 and site 2 in 2003 and 2004 to perform regression analyses. In 1998, 2000, 2001, 2002 (site 1), and 2004 slopes ranged from 0.09 to 0.38 and intercepts ranged from 0.26 to -1.17 ($p < 0.005$, $r^2 = 0.121$ to 0.325). Plant height was not a significant predictor of the number of floral units at site 2 in 2002 ($p > 0.05$). Because the site 2 population was not discovered until 2002, there is no data for this population prior to 2002. Similarly, site 3 was discovered in 2004, so no data is available prior to this year for site 3.

Plant height was also tied to capsule length variation. Larger capsules presumably contain more seeds, thus larger plants not only produce more capsules, but the capsules they produce contain more seeds. Again, in 1998, 2000 and 2001, slopes were low (0.35 to 0.48), intercepts were small (-0.98 to -0.11) and r^2 was high (0.412 to 0.66, $p < 0.001$). In 2002 and 2004, capsule lengths were longer than they had been in previous years.

When cover data from all sites and all years are combined, *E. rhombipetala* absence is negatively correlated with percent bare ground and native grass cover (negative values for the parameter estimates in Table C4). *Eschscholzia rhombipetala* is more likely to be found where the vegetation is more open and where native grasses are also present and less likely to be found when thatch cover is high.

C-3.2. Vegetation Sampling

Table C5 shows the species composition for all three *E. rhombipetala* populations. The exotic annual grasses *Avena* sp., *Bromus hordeaceous, Bromus madritensis* subsp. *rubens* are present in all three populations. Site 1 is particularly diverse in native forbs containing 23 species of native forbs, while site 2 and 3 only contain seven and six native forbs species, respectively.

Figures C8 through C11 show the dominant vegetation types mapped visually in the *E. rhombipetala* population areas for 1999–2004 at sites 1 and 2. In 2003 and 2004, most of site 1 continued to be dominated by *Avena* sp. with *Bromus diandrus* and *Bromus madritensis* also common in some areas. The small strip of land along the scarp that has most frequently supported *E. rhomibipetala* since 1998 was dominated by *Avena* sp., *Poa* secunda and *Gutierrezia californica*. Grasslands surrounding site 2 in 2003 (vegetation mapping not mapped at site 2 in 2004) were also dominated by *Avena* sp, and the area that has historically supported *E. rhombipetala* was dominated by a vegetation of *Avena* sp. and *P. secunda*. Table C6 and Figure C13 show that in 2004 grasslands at sites 2 and 3 had much less bare ground and higher thatch compared to all site 1 locations. Site 3 also differs from sites 1 and 2 in that it is the only one of the three sites where no native perennial grasses were found.

The community composition of the three sites is summarized in Table C6 and Figures C12 and C13. Sites 2 and 3 had a similar composition in 2004. Both sites had less than 10% cover of bare ground and a large amount of thatch (site 2, 70 ± 19.7% cover; site 3, 72.3 ± 22.1% cover). Sites 1 and 2 also both have over 80% cover of annual grasses and less than 10 percent cover of native forbs. Site 2 did contain a small amount of perennial grass cover, which was completely absent in site 3. In 2004, site 1 locations were comprised of more bare ground, less thatch, and more native and exotic forb cover than sites 2 and 3. From 2003 to 2004, the amount of bare ground at site 2 appeared to decrease while the amount of thatch increased greatly. The composition of site 1 remained relatively constant.

C-4. Discussion and Future Work

In 2004, a new population (site 3) of *E. rhombipetala* was discovered at Site 300. Containing 389 *E. rhombipetala,* site 3 had the largest population of this species observed at Site 300 since monitoring began in 1998. In 2000 through 2002, site 1 contained over 180 *E. rhombipetala* each year, but in 2003 and 2004, this site contained less than 20 plants.

Site 2 has been censused for three consecutive years. Site 2's population size has followed a similar pattern as site 1; large in 2002 and much smaller in 2003 and 2004. Site 2 contained 76 *E. rhombipetala* in 2002 when this population was first discovered, and in 2003 and 2004 *E. rhombipetala* numbers were extremely small at site 2 (1 plant in 2003 and 2 plants in 2004). It remains to be seen whether populations at the three sites fluctuate synchronously or asynchronously. If the populations fluctuate asynchronously, similar to the populations of *Blepharizonia plumosa* found at Site 300 (Section B), then the *E. rhombipetala* populations have a better chance at persisting at Site 300 through a risk-spreading strategy over sites and years. If however, the populations fluctuate synchronously, similar to *Amsinckia grandiflora* populations found at Site 300 (Section A), then the species may have a narrower range of conditions under which it can do well and as such may be at higher risk for local extirpation.

The new population differs from the two older populations in several ways. Site 3 is found at the bottom of a small stable bowl shaped valley, while sites 1 and site 2 are located on steep northwest facing hillsides in areas that are disturbed by slumping soil. *Eschscholzia rhombipetala* at site 1 and site 2 is also often found in association with the native perennial grass, *P. secunda*, while *P. secunda* was not found at site 3. In addition, *E. rhombipetala* at site 3 are larger and have more floral units than plants at sites 1 and 2.

Using vegetation data from site 1 and site 2 collected in 1999 through 2002, there was a positive association of *E.* rhombipetala presence with bare ground. This, in addition to the better performance of plants in the active slump, indicate that some level of disturbance is necessary for plants of this species to do well. Vegetation data collected at site 3 seems to contradict this. While the disturbance of slumping soils at site 1 and site 2 clearly benefits *E. rhombipetala* at site 1 and site 2, some other factors appear to be in place to promote *E. rhombipetala* at site 3.

Our yearly census of *E. rhombipetala* at site 1 has shown a wide range in population size, from a low of 9 to a high of 285 individuals. Fluctuation in the size of small, annual plant populations are to be expected (Parson and Zedler, 1997; Pavlik and Espeland, 1998), but populations at all three sites are still quite small. Although the nine plants observed at site 1 in 1999 may have produced enough seed to generate a population of 171 plants the following year, the 2002 appearance of plants upslope from where plants had been previously observed may indicate the presence of a seed bank for this population.

In 1999–2002, at site 1, *E. rhombipetala* presence was tightly linked to more bare ground, more exotic forb cover, less exotic grass cover, and less thatch cover (Espeland and Carlsen, 2003). Adding more years to the data at site 1 (up through 2004), only the relationship to bare ground and thatch remained significant ($p < 0.05$ and $p < 0.001$ respectively, data not shown). When data from sites 2 and 3 are added, this relationship continues to hold, and a relationship between *E. rhombipetala* absence and native grass presence also appears (Table C6), probably due to the prevalence of *Vulpia microstachys*, a California native annual grass, at site 3. Sites 1, 2, and 3 are very different from one another in terms of vegetation and slope and yet the microhabitats in which *E. rhombipetala* are found are similar among the sites: flowering *E. rhombipetala* plants are found more often when the vegetation is open, exposing bare ground, and when there is less thatch accumulation. Other California forbs have shown similar sensitivity to thatch accumulation, as shown by increased plant performance in thatch removal studies (Meyer and Schiffman, 1999; Heady 1956). Exotic annual grasses tend to accumulate more thatch than native grasses and as such they may be particularly powerful inhibitors of native forbs. While clipping treatments may reduce the above ground biomass of live exotic grass plants and thus reduce thatch accumulation, results from clipping studies have been mixed (Hayes, 2002). The mixed results from clipping studies and the lack of relationship between *E. rhombipetala* plant presence and live exotic grass cover indicates that the positive connection between *E. rhombipetala* presence and bare ground may be due to more than merely the absence of thatch.

By continuing to collect size, fecundity and cover data, we hope to identify the environmental factors that positively influence *E.* rhombipetala fitness and create self-sustaining populations. Surprisingly little research has been performed on *Eschscholzia* ecology (Espeland and Myatt, 2001), and little is known about the response of California poppy and its relatives to soil condition, moisture, and inter-specific competition. *Eschscholzia californica* is known to have strong seed dormancy (Fox et al., 1995), but it is unknown if other species in the genus share this characteristic. Because of the extreme rarity of *E. rhombipetala,* we have as yet been unable to collect any data on germination and survivorship for this species.

C-5. References

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Section C
Figures

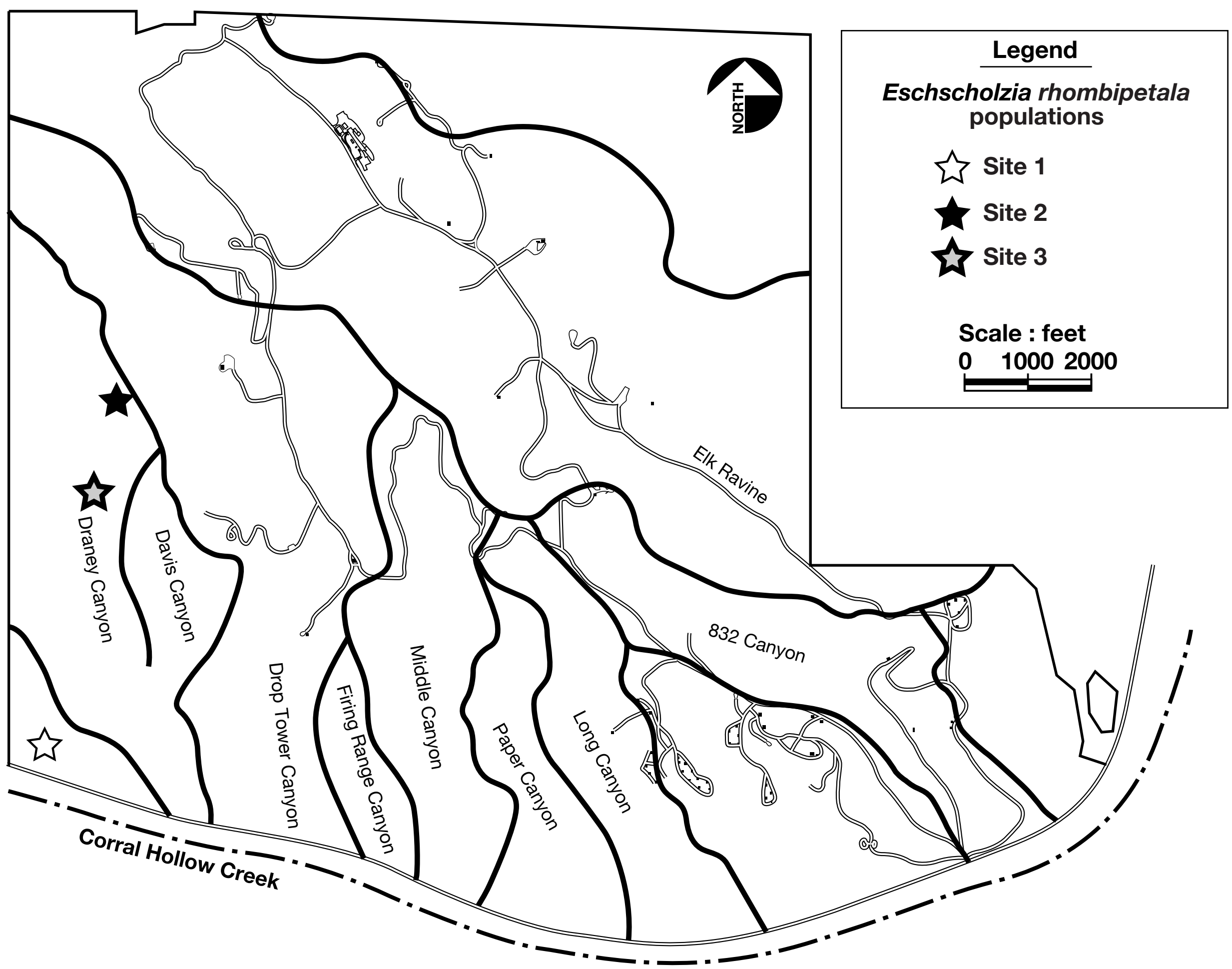

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Figure C1. Locations of *Eschscholzia rhombipetala* populations Lawrence Livermore National Laboratory (LLNL) Site 300.

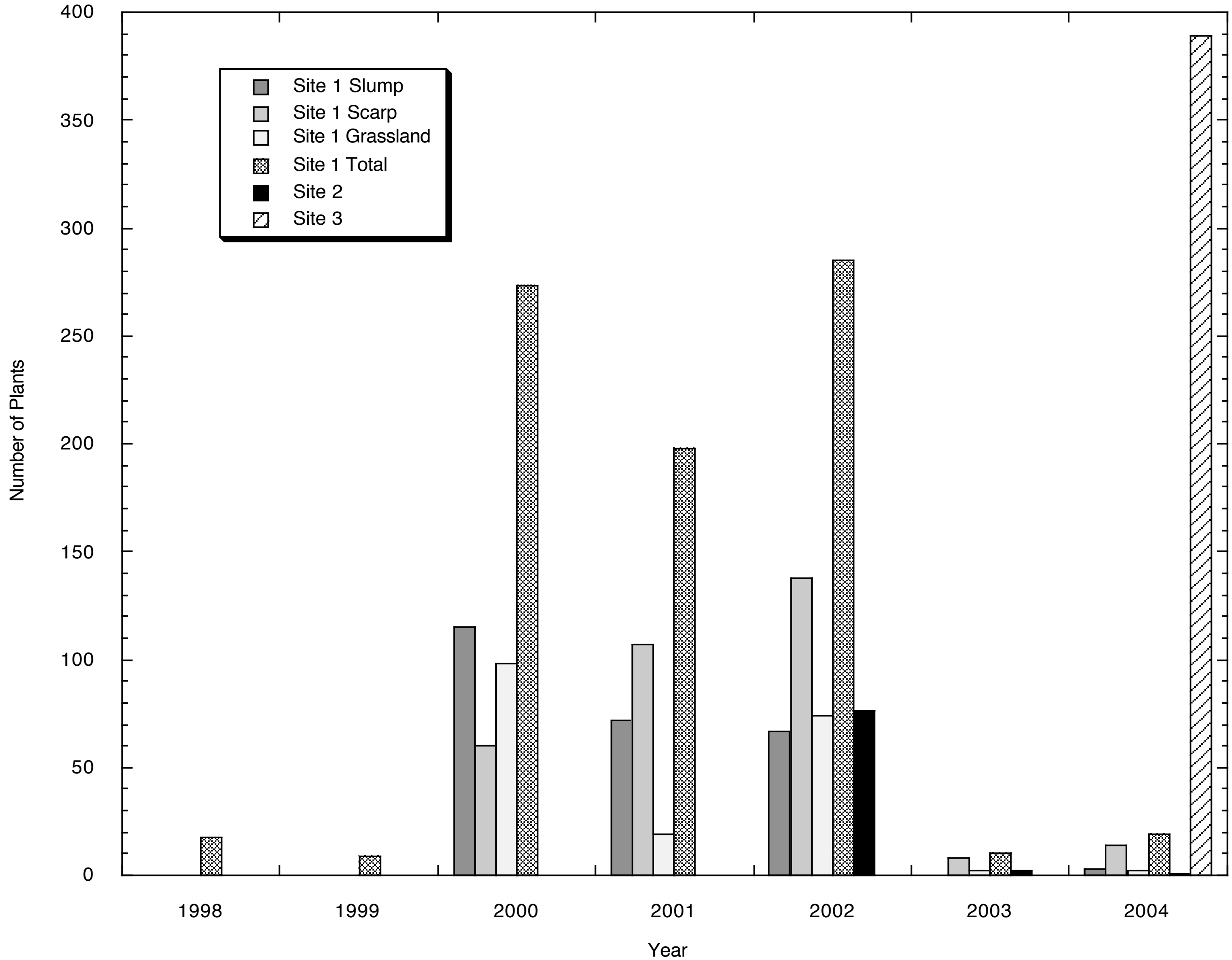


Figure C2. *Eschscholzia rhombipetala* populations size at sites 1, 2, and 3 for 1998 through 2004. Site 2 was first censused in 2002 and site 3 was first censused in 2004.

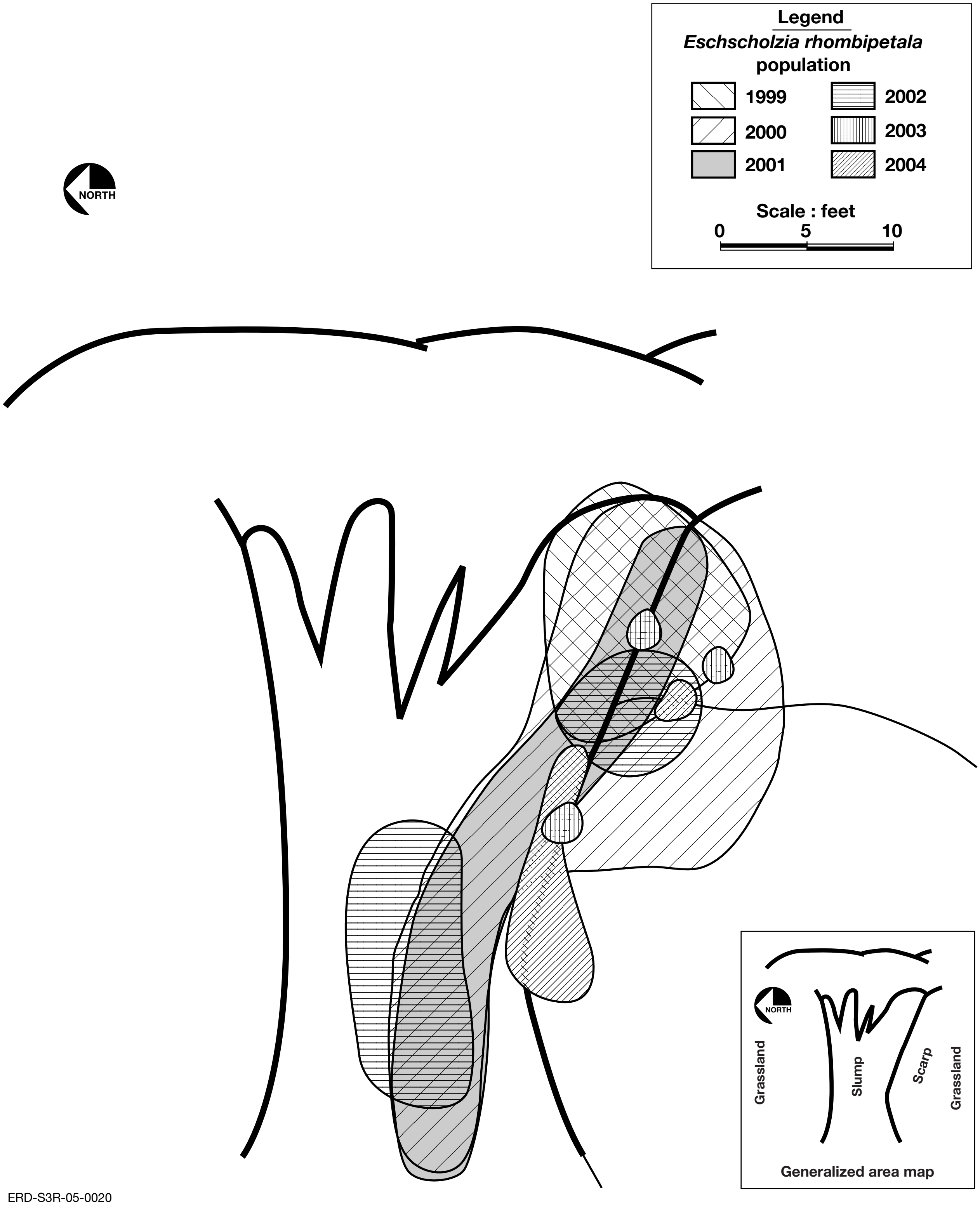


Figure C3. Site 1 *Eschscholzia rhombipetala* population location: 1999–2004.

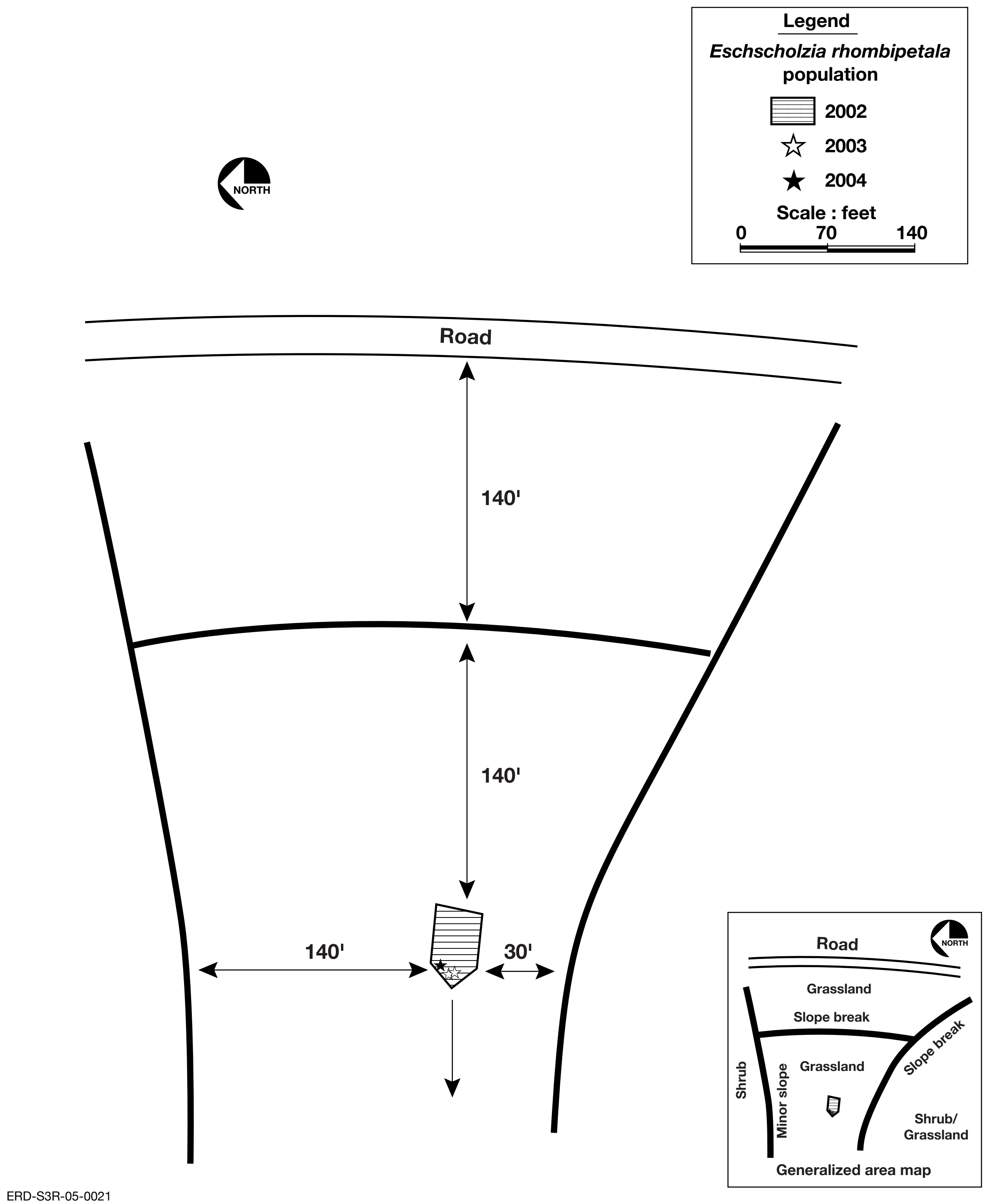
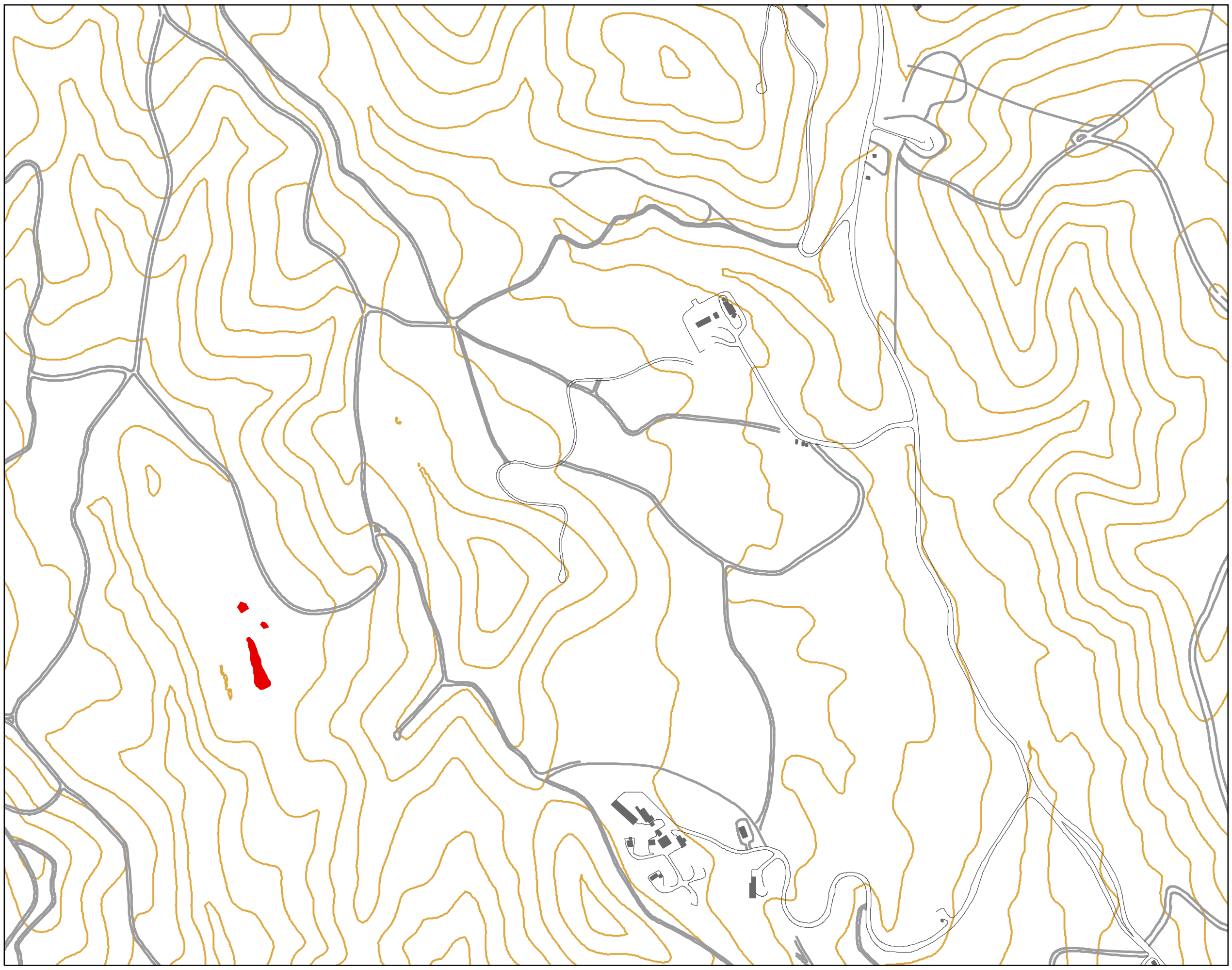


Figure C4. Site 2 *Eschscholzia rhombipetala* population location: 2002–2004.



Legend

Paved roads

Fire trails

***Eschscholzia rhombipetala* site 3**

0 125 250 500 Meters

Figure C5. Site 3 *Eschscholzia rhombipetala* population location: 2004.

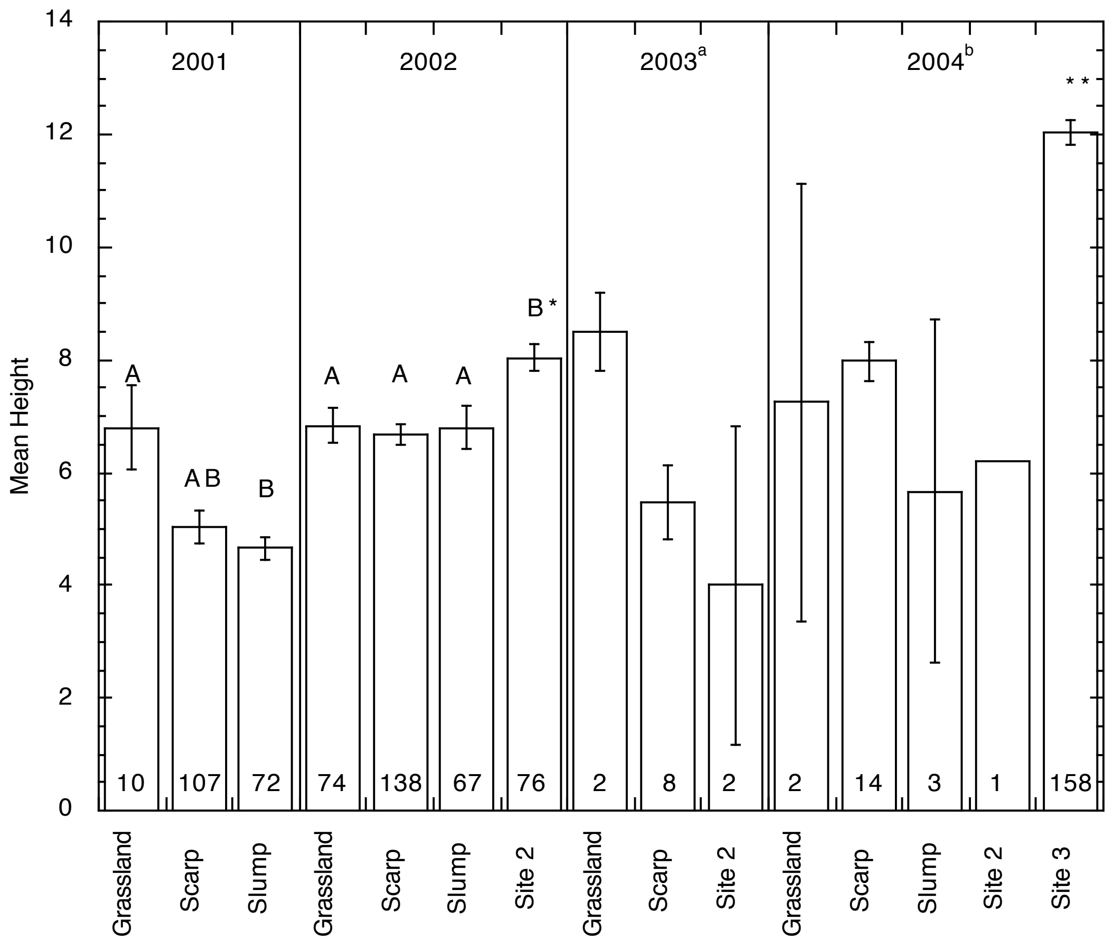


Figure C6. Mean height at site 1 by location (grassland, scarp, slump) and at sites 2 and 3. Different letters indicate a significant difference in mean number of floral units within that year. Error bars represent ± 1 standard error. Sample size shown inside bars.

Notes:

- * Indicates a significant difference between site 2 and all site 1 locations combined.
- ** Indicates a significant difference between site 3 and all site 1 locations combined.
- [a] No statistical analysis was done in 2003 due to small sample size.
- [b] In 2004, only site 3 and the combination of all site 1 locations were compared due to small sample size.

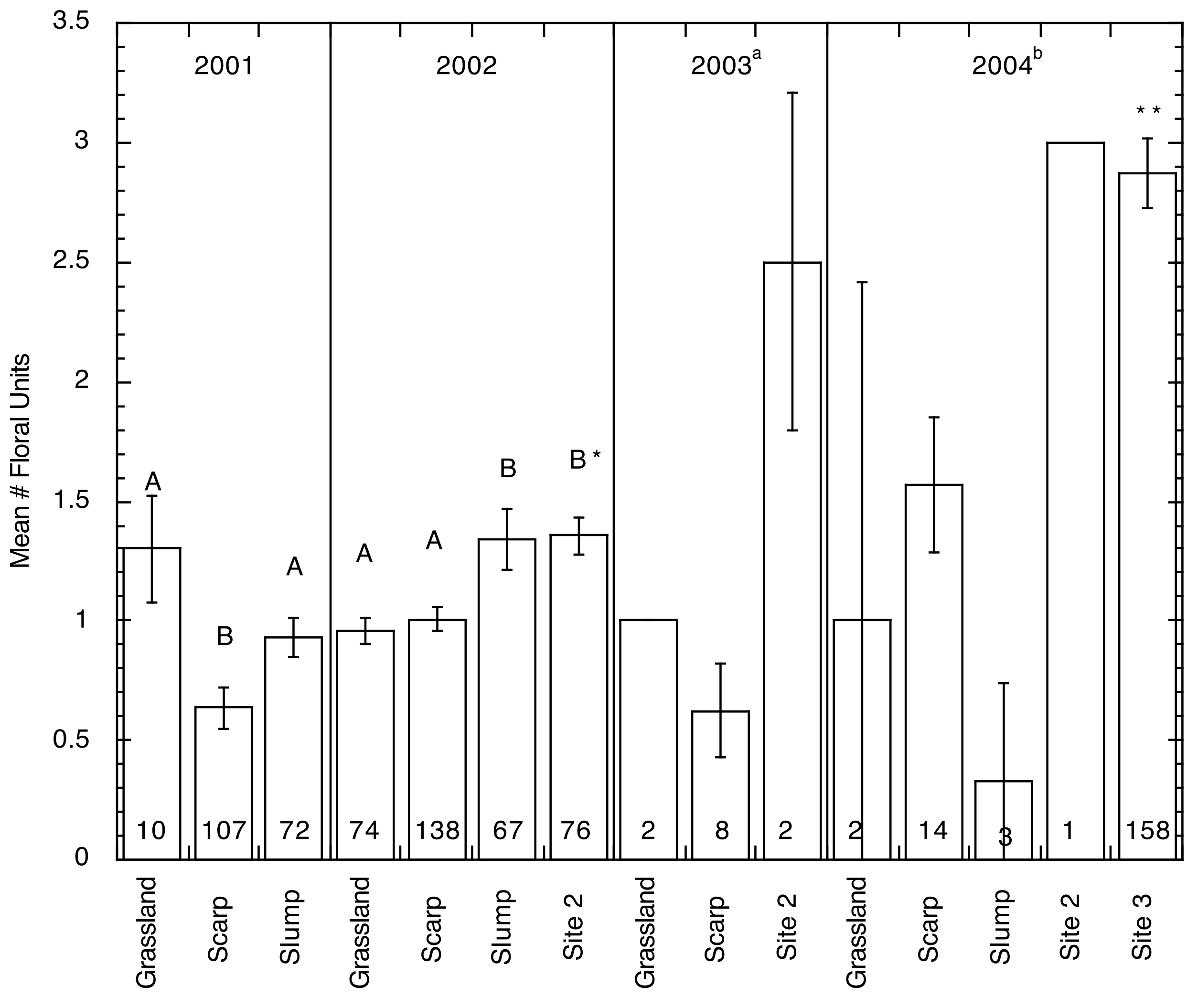


Figure C7. Number of floral units per plant at site 1 by location (grassland, scarp, slump) and at sites 2 and 3. Different letters indicate a significant difference in mean number of floral units within that year. Error bars represent ± 1 standard error. Sample size shown inside bars.

Notes:

- * Indicates a significant difference between site 2 and all site 1 locations combined.
- ** Indicates a significant difference between site 3 and all site 1 locations combined.
- [a] No statistical analysis was done in 2003 due to small sample size.
- [b] In 2004, only site 3 and the combination of all site 1 locations were compared due to small sample size.

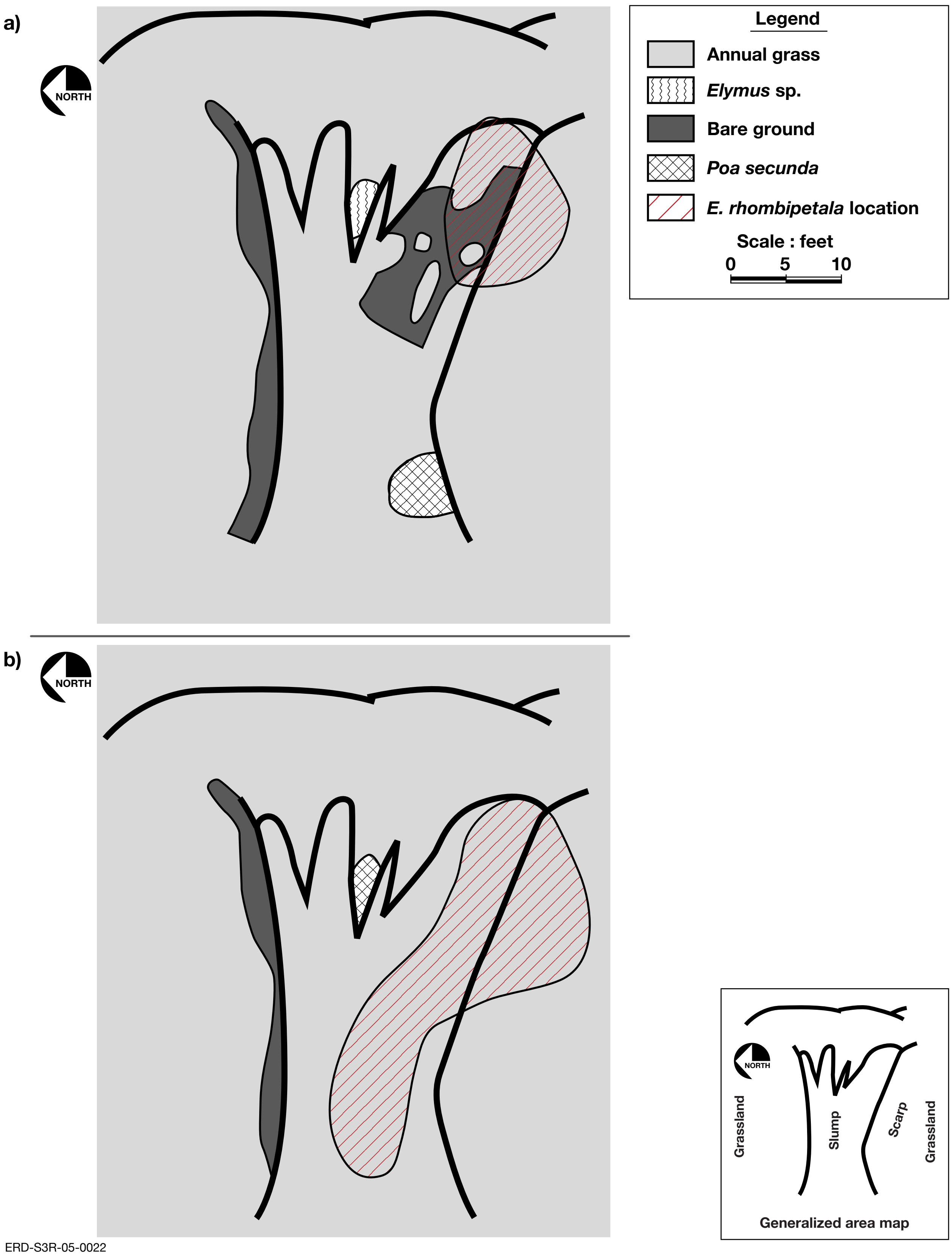


Figure C8. Dominant vegetation type and *Eschscholzia rhombipetala* location, site 1: a) 1999 and b) 2000.

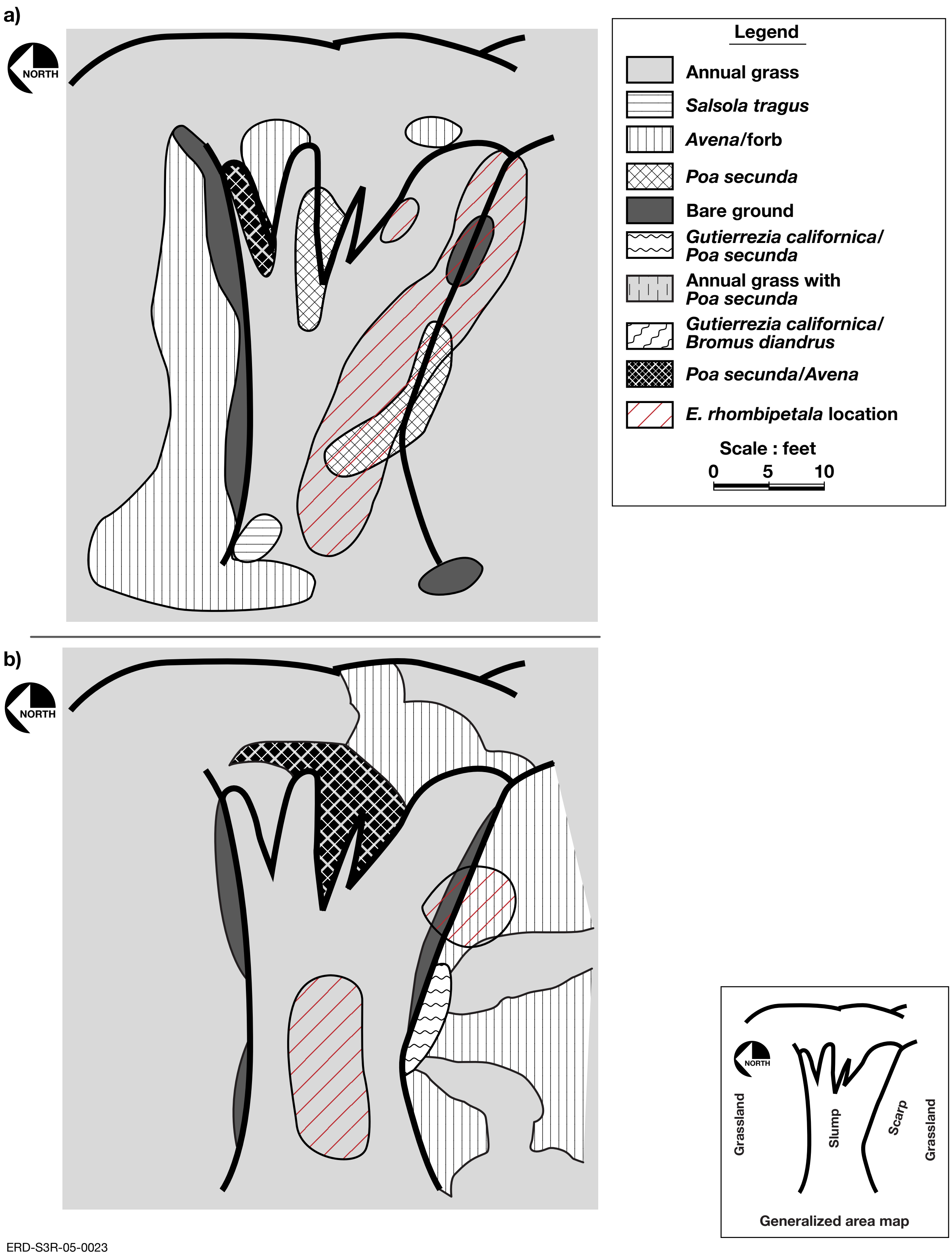


Figure C9. Dominant vegetation type and *Eschscholzia rhombipetala* location, site 1: a) 2001 and b) 2002.

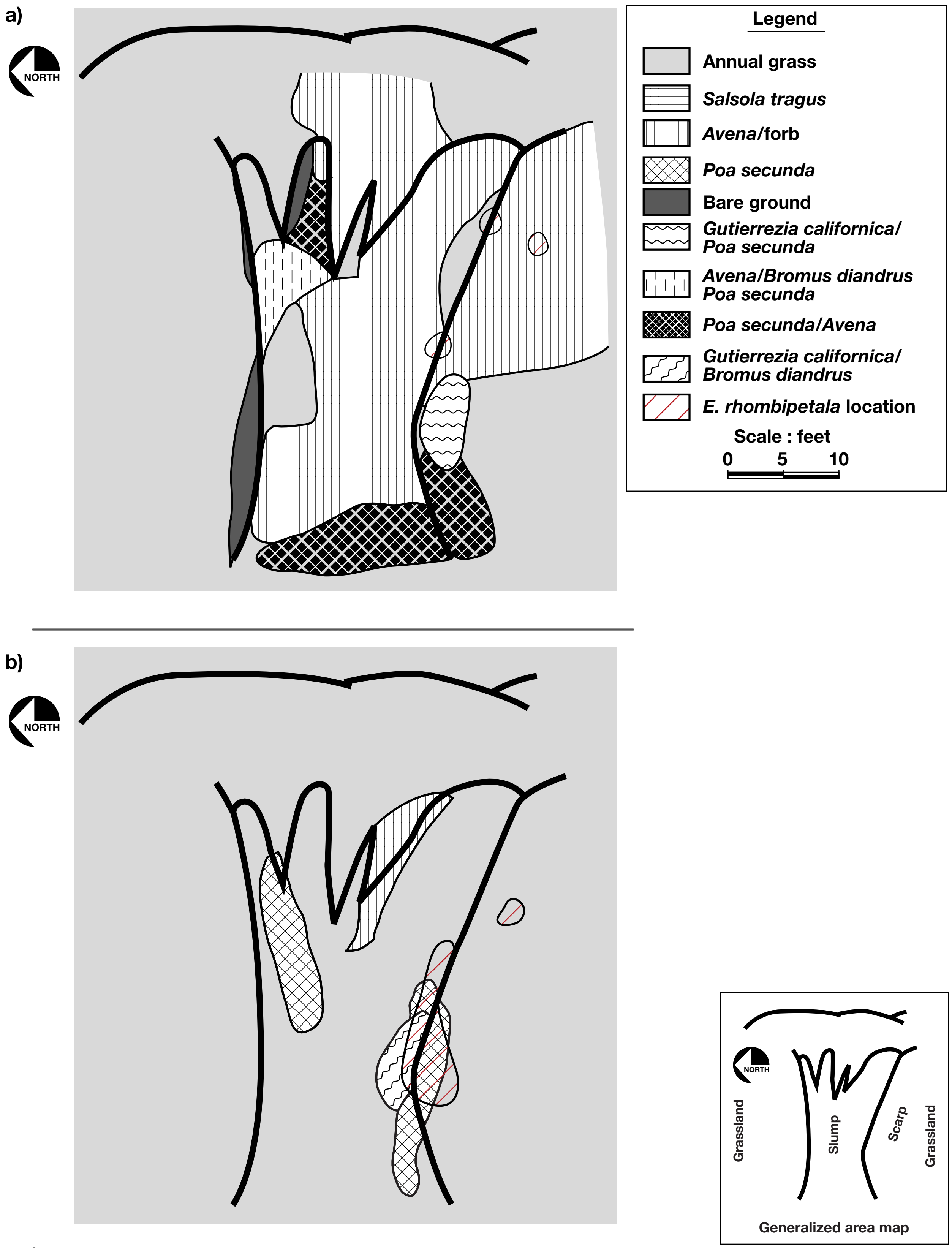


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Figure C10. Dominant vegetation type and *Eschscholzia rhombipetala* location, site 1: a) 2003 and b) 2004.

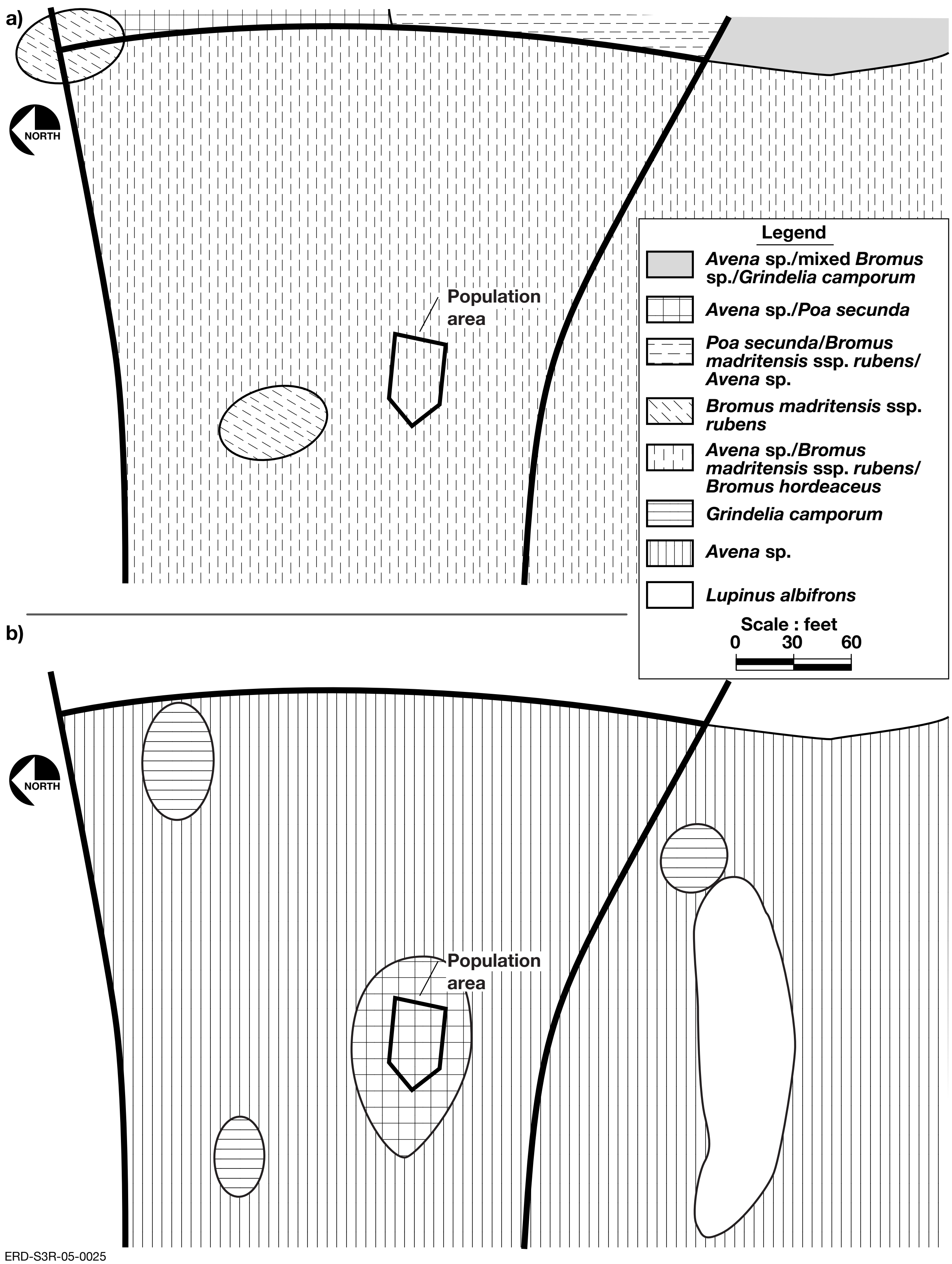

Figure C11. Dominant vegetation type and *Eschscholzia rhombipetala* location, site 2: a) 2002 and b) 2003. (Vegetation map not available for 2004.)

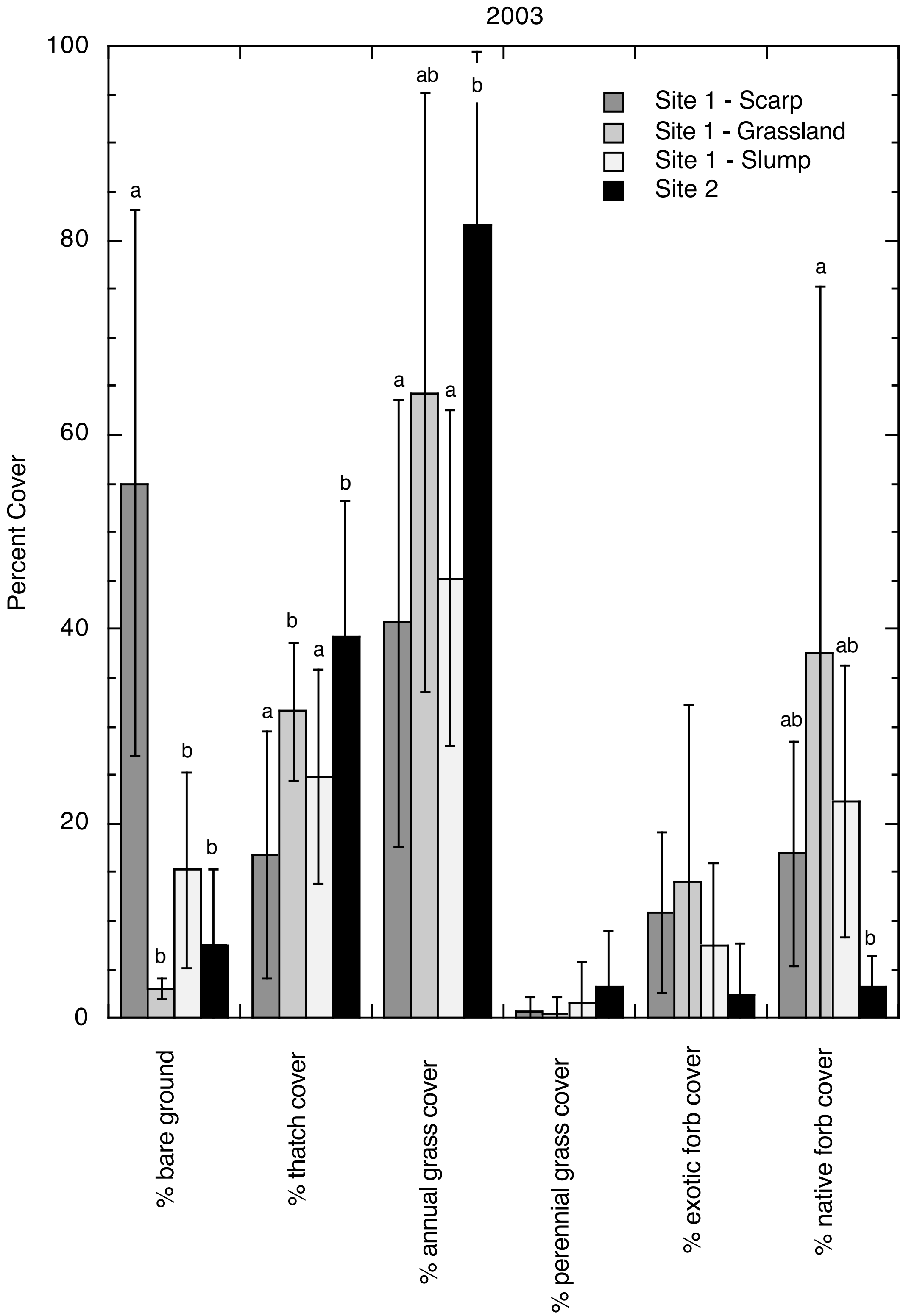

Figure C12. Vegetation characteristics of scarp, grassland, and slump plots at site 1 and over the entire site for site 2 in 2003. All values are means ± 1 standard deviation. Different letters indicate significant differences (*p* < 0.05) among locations among locations. There were no significant differences for % perennial grass cover and % exotic forb cover.

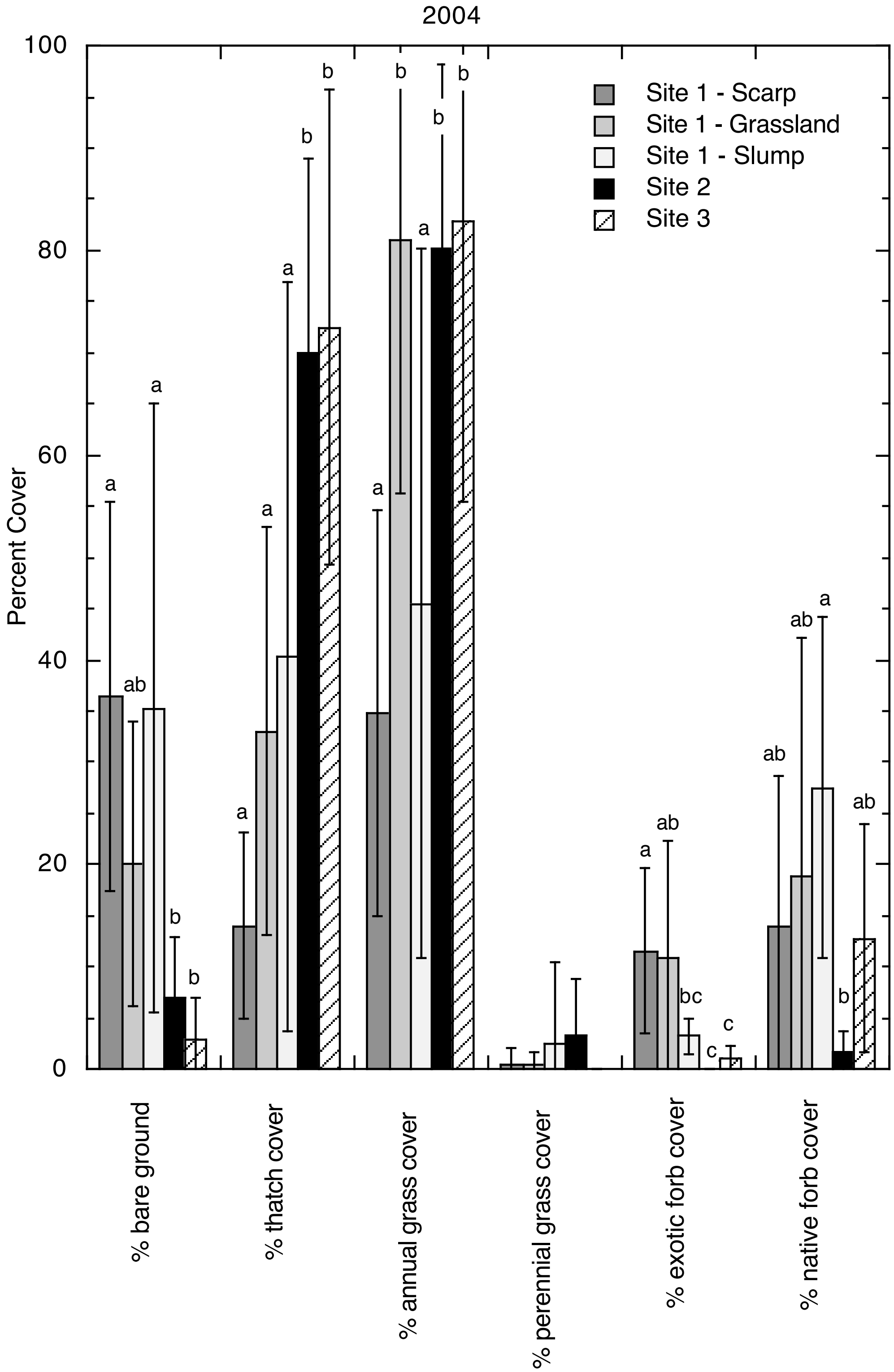

Figure C13. Vegetation characteristics of scarp, grassland, and slump plots at site 1 and over the entire site for sites 2 and 3 in 2004. All values are means ± 1 standard deviation. Different letters indicate significant differences ($p < 0.05$) among locations. There were no significant differences for % perennial grass cover.

Section C
Tables

Table C1. Summary of census data collected from sites 1, 2, and 3: 1998–2004.

	Site 1				Site 1	Site 2	Site 3
Year	**Grassland**	**Scarp**	**Slump**	**Location not recorded**	**Total**	**Total**	**Total**
1998				**18**	**18**		
1999				**9**	**9**		
2000	**98**	**60**	**115**	**0**	**273**		
2001	**19**	**107**	**72**	**0**	**189**		
2002	**74**	**138**	**67**	**0**	**285**	**76**	
2003	**2**	**8**	**0**	**0**	**10**	**2**	
2004	**2**	**14**	**3**	**0**	**19**	**1**	**389**

Note:

Site 2 was first discovered in 2002, and site 3 was first discovered in 2004.

Table C2. Height, number of floral units (buds + flowers + capsules) per plant, and capsule length for marked *Eschscholzia rhombipetala* plants: 1998–2004. All averages are ± one standard deviation.

Site	Date measured	Height (cm)	No. of floral units/plant	N[a]	Capsule length (cm)	N[b]
1	18 Apr 98	7.5 ± 2.8	0.4 ± 0.5	24	2.8 ±1.4	16
1	30 Apr 99	6.0 ± 1.8	0.7 ± 0.7	9	2.1 ± 0.6	6
1	24 Mar 00	5.5 ± 2.1	0.6 ± 0.5	171	2.3 ± 1.4	44
1	30 Mar 01	5.0 ± 2.5	0.3 ± 0.5	189	2.8 ± 1.8	72
1	29 Mar 02	6.8 ± 2.5	1.1 ± 0.7	280	3.4 ± 1.6	73
2	05 Apr 02	8.0 ± 2.1	1.4 ± 0.7	76	3.3 ± 0.3	63
1	25 Mar 03	6.1 ± 2.0	0.7 ±0.5	10	1.3	1
2	25 Mar 03	4.0 ± 2.8	2.5 ± 0.7	2	N/A	N/A
1	26 Mar 04	7.5 ± 2.6	1.3 ±1.1	19	3.2 ± 1.1	15
2	26 Mar 04	6.2	3	1	7.0	1
3	01 Apr 04	12.0 ± 2.6	2.9 ± 1.9	158	3.9 ± 2	124

Notes:

N = Number of plants.

N/A = No capsules present at time of census.

[a] **Number of plants measured is the same for the height and number of flower measurements. Plants with no flowers were included in the average.**

[b] **Number of plants measured for capsule length includes only those plants with capsules.**

Table C3. Linear regression (y = ax + b) of number of floral units (buds + flowers + capsules) and capsule length to plant height (x): 1998, 2000, 2001, 2002, and 2004. Data from 1999, 2003, and 2004 at sites 1 and 2 too few for regression.

Year	Slope (error)	Intercept (error)	Pr > |t|	R-square
Number of floral units (y)				
1998	0.09 (0.03)	0.26 (0.22)	0.0034	0.316
2000	0.14 (0.02)	0.09 (0.12)	<0.0001	0.228
2001	0.19 (0.02)	-0.17 (0.11)	<0.0001	0.325
2002 (site 1)	0.10 (0.02)	0.42 (0.12)	<0.0001	0.121
2002 (site 2)		>0.05		
2004 (site 3)	0.38 (0.05)	-1.71 (0.58)	<0.0001	0.293
Capsule length (y)[a]				
1998	0.35 (0.06)	-0.62 (0.52)	<0.0001	0.660
2000	0.48 (0.09)	-0.98 (0.63)	<0.0001	0.412
2001	0.42 (0.06)	-0.11 (0.42)	<0.0001	0.436
2002 (site 1)	0.25 (0.04)	1.08 (0.34)	<0.0001	0.235
2002 (site 2)	0.45 (0.06)	1.19 (0.49)	<0.0001	0.222
2004 (site 3)	0.25 (0.08)	0.68 (1.1)	< 0.003	0.072

[a] Only plants with capsules were included in this analysis.

Table C4. Results of the logistic regression: the effect of vegetation on *Eschscholzia rhombipetala* absence.[a] Site 1: 1999–2004, site 2: 2003–2004, and site 3: 2004.

Covariate x	*p*-value	β[a]	Odds ratio[b]	Confidence interval	Maximum measured x value[a]
Intercept α = 0.64	0.094	–	–	–	–
% bare ground	<0.006	-0.015	0.986	0.975–0.996	98
% thatch cover	<0.008	0.017	1.017	1.005–1.030	100
% exotic grass cover	0.775	-0.002	0.998	0.988–1.009	100
% native grass cover	<0.016	-0.035	0.965	0.938–0.993	75
% exotic forb cover	0.213	0.017	1.017	0.990–1.045	60
% native forb cover	0.733	0.007	1.007	0.967–1.049	47.5

Note:

– = Model was not significant. Values cannot be reported for β, Odds ratios, Confidence intervals, or Maximum measured x values.

[a] **Model fit (Wald) $p < 0.001$, $n = 353$ (234 plots with no *E. rhombipetala*, 119 plots with *E. rhombipetala*). The model is $p/(1-p) = \alpha + \beta_1 x_1 + \beta_2 x_2 + \ldots \beta_n x_n$ where p is the probability of *E. rhombipetala* absence from the plot, α is the intercept, β is the parameter estimate, and x is the covariate. In the model, bare ground, thatch, exotic grass, native grass, exotic forb, and native forb covers were used as covariates.**

[b] **Odds ratio is probability *E. rhombipetala* absent : probability *E. rhombipetala* present.**

Table C5. Plant species found in and around *Eschscholzia rhombipetala* populations: 1999–2004. Bold face indicates species found at all sites. All other species found only at site 1, unless superscripted with sites found.

Native	Exotic
Grasses	
Elymus sp.	***Avena* sp.**
Poa secunda[1,2]	*Bromus diandrus*
	Bromus hordeaceous
	Bromus madritensis* subsp. *rubens
	Hordeum murinum
	Vulpia myuros
	Vulpia microstachys[1,3]
Forbs	
Achillea millifolium	*Brassica* sp.
Amsinckia intermedia	*Carduus pynocephalus*
Amsinckia lycopsoides[2]	*Centaurea melitensis*
Amsinckia mensezii[1,2]	*Erodium botrys*
Astragolus sp.	***Erodium cicutarium***
Blepharizonia laxa	*Medicago polymorpha*
Blepharizonia plumosa	*Salsola tragus*
Brodiaea sp.	*Sanicula bipinnata*
Chamaesyce ocellata[3]	*Senecio vulgare*
Clarkia sp.[2]	*Sonchus asper*
Claytonia parviflora	
Collinsia sp.[3]	
Dichelostema capitatum	
California macrophylla[3]	
Eschscholzia rhombipetala	
Galium aparine[1,3]	
Grindelia camporum[2]	
Gutierrezia californica	
Hirschfeldia sp.	
Lepidium nitidum	
Lotus wrangellianus	
*Lupinus albifrons**	
Lupinus microcarpus[1,2]	
Lupinus succulentus	
Microseris douglasii	
Monolopia major	
Plantago erecta	
Stylomecon heterophylla	
***Trifolium* sp.**	
Vicia sp.	

Notes:

For plants identified only to genus, native versus exotic identifications were made using species lists generated by Preston (2002).

******Lupinus albifrons*** **is a shrub but is included with forbs for simplicity.**

Table C6. Vegetation characteristics of scarp, grassland, and slump plots at site 1 and over the entire site for sites 2 and 3 plots in 2003–2004. All values are averages ± one standard deviation.

Plot type	% bare ground[a,b]	% thatch cover[a,b]	% annual grass cover[a,b]	% perennial grass cover	% exotic forb cover[b]	% native forb cover[a,b]	N
Spring 2003							
Site 1, Scarp	55 + 28.1	16.7 ± 12.7	40.6 ± 23.0	3.8 ± 1.8	10.8 ± 8.3	16.9 ± 11.5	13
Site 1, Grassland	3 ± 1.1	31.5 ± 7.1	64.5 ± 30.8	5	14 ± 18.2	37.5 ± 37.8	10
Site 1, Slump	15.2 ± 10.1	24.8 ± 11.1	45.2 ± 17.3	8.75 ± 8.8	7.5 ± 8.4	22.3 ± 14.0	12
Site 2	7.5 ± 7.8	39.2 ± 14.1	81.5 ± 17.7	6.6 ± 7.2	2.3 ± 5.4	3.3 ± 3.0	13
Spring 2004							
Site 1, Scarp	36.5 ± 19	14.0 ± 9.1	34.8 ± 19.8	0.5 ± 1.6	11.5 ± 8.1	14 ± 14.7	10
Site 1, Grassland	20.0 ± 13.9	33.0 ± 19.9	81 ± 24.7	0.5 ± 0	10.8 ± 11.6	18.8 ± 23.3	10
Site 1, Slump	35.3 ± 29.8	40.3 ± 36.6	45.5 ± 34.7	2.5 ± 7.9	3.2 ± 1.7	27.5 ± 16.7	14
Site 2	6.0 ± 5.0	70 ± 19.7	80.2 ± 17.9	3.2 ± 5.6	0	1.6 ± 2.1	10
Site 3	4.3 ± 6.5	72.3 ± 22.1	82.8 ± 27.3	0	1 ± 1.3	12.8 ± 11.1	10

Note:

N = Number of plots.

[a] **In 2003, there was a significant difference in the percent cover of this vegetation category among locations ($p \leq 0.05$).**

[b] **In 2004, there was a significant difference in the percent cover of this vegetation category among locations ($p \leq 0.05$)**

Section D
California macrophylla

Section D
California macrophylla

D-1. Introduction

California macrophylla (Hook. & Arn.) J.J. Aldasoro, C. Navarro, P. Vargas, L. Saez and C. Aedo is an annual or biennial plant with long petioled leaves growing from short stems (Figure D1). Its leaves are reniform and shallowly lobed, and its flowers have white, sometimes with a red tint, petals that are approximately 6 to 8 mm long (Aldasoro et al., 2002). Flowers are ephemeral with petals typically falling off within one day. The fruit body is typically 8 to 10 mm long and divided into five segments, and a portion of the style persists above the fruit body extending 3 to 5 cm (Taylor, 1993).

Based on morphological data *C. macrophylla* has recently been segregated from the genus *Erodium* into the new monotypic genus *California* (Aldasoro et al., 2002). Aldasoro et al. (2002) describes three characteristics that separate *C. macrophylla* from species of *Erodium* (and the genus *Monsonia*): arrangement of stamens, mericarp bristle morphology, and leaf shape. All species in the genus *Erodium* have five fertile stamens and five staminodes. Unlike species of *Erodium*, *C. macrophylla* has five stamens with two lateral wing-like expansions on the filaments and no staminodes. *Erodium* species have a semicircular rim surrounding each bristle on the fruits. *California macrophylla* fruit bristles lack this rim. Finally, unlike *Erodium* species, the leaves of *C. macrophylla* are rounded with a cordate base and subpalmate veins. *Erodium* species have subpinnate or pinnate veins.

Of the six species of *Erodium* that are described in the Jepson Manual (Taylor, 1993), *Erodium macrophyllum (California macrophylla)* is one of two species native to North America (Taylor, 1993). *Erodium texanum* A. Gray is native to the southwestern United States and northern Mexico. The remaining four species are native to Mediterranean Europe or Australia (Taylor, 1993). The range of *C. macrophylla* is reported to extend from northern California to northern Mexico and southern Utah to the east (CNPS, 2001; Taylor, 1993). Gillespie (2003) argues that reports of *C. macrophylla* in southern Utah are based on a mislabeled specimen, and that this species only occurs outside of California in southern Oregon and northern Baja. In California, *C. macrophylla* occurs in the Great Valley, San Francisco Bay area, central and south coasts, and the Channel Islands (Taylor, 1993).

California macrophylla is a California Native Plant Society List 2 species (CNPS, 2001). List 2 includes plants that are rare, threatened, or endangered in California, but more common elsewhere. The CNPS R-E-D code for *California macrophylla* is 2-3-1 indicating that this species has a limited number of occurrences, is endangered in California, and more widespread outside of California (Tibor, 2001). The California Native Plant Society is currently considering upgrading *C. macrophylla* from List 2 to List 1B (Tibor, 2003).

In 2002, one population of 200 plants of *C. macrophylla* was observed at Site 300 during a site wide special status plant survey (Preston, 2002). This species was not known to occur at Site 300 prior to 2002, although herbarium specimens from the 1920's and 1930's record *C. macrophylla* presence in the Corral Hollow area and Altamont Hills (Baldwin et al., 2002). Five additional populations of *C. macrophylla* were discovered in 2003 and 2004 during wildlife surveys (van Hattem, 2004). All six populations occur in the far northwestern corner of Site 300 (Figure D2). Of the six Site 300 populations, populations 1 through 4 occur in annually graded dirt fire trails. These fire trail populations are restricted to disturbed portions of the fire trails that are graded annually in the spring in preparation for prescribed burns that are conducted at Site 300 in May or June.

The remaining two populations (population 5 and 6) occur in grasslands 100 to 500 feet from the fire trails. Both off road populations occur in areas that are not typically included in the annual prescribed burns at Site 300. Population 5 occurs in a small, relatively level bowl surrounded by small hills. This population occurs with another extremely rare annual forb, *Eschscholzia rhombipetala*. *Eschscholzia rhombipetala* and *C. macrophylla* have also historically been reported to occur together in San Luis Obispo County (Hoover, 1970). Population 6 is found on a west-facing hillside.

In 2003, *C. macrophylla* research and monitoring focused on determining differences in survivorship between *C. macrophylla* and the widespread invasive *Erodium cicutarium*. In 2004, research focused on describing and censusing the six populations of *C. macrophylla* that are known to occur at Site 300. Analyses were also conducted to determine the differences between fire trail populations and grassland populations.

D-2. Methods and Materials

D-2.1. *California macrophylla* and *Erodium cicutarium* Survivorship (2003)

Erodium cicutarium is a small (10–50 cm) annual plant included with *C. macropylla* in the genus *Erodium* prior to recent taxonomic revisions. *E. cicutarium* is native to Eurasia, has a worldwide distribution below 70 degrees north and south, and is considered a noxious weed throughout the continental United States (USDA, 2004). *E. cicutarium* can occur in a variety of habitats ranging from deserts to riparian areas although the largest North American populations of this species are found in California (U.S. Forest Service, 2004; Heady, 1977)

During the 2002/2003 growing season, the survivorship of *C. macrophylla* and *E. cicutarium* was measured in Population 1 (this was the only population known to occur at Site 300 in 2002). Population 1 occurs in a graded fire trail. In this area, *C. macrophylla* only occurs in areas that were disturbed by fire trail grading the previous year; no *C. macrophylla* seedlings were found in the grasslands adjacent to the fire trails that are annually burned. On December 12, 2002, 60 *C. macrophylla* and *E. cicutarium* seedlings were marked with small pin flags. A survey was conducted to determine the general distribution of seedlings in the populations, and seedlings were flagged where *C. macrophylla* and *E. cicutarium* were adjacent (within 4–5 cm) to each other. The plants were found in three general areas: the berm on the north side of the road (13 plants), and two patches within the roadbed referred to as lower road (30 plants) and upper road (12 plants). These three areas were naturally occurring concentrations of *C. macrophylla* population 1. Some plants originally marked were lost as a result of erosion in the fire trails during heavy winter rains. These plants were not included in calculations of percent survivorship.

Survivorship was measured on March 7 and April 9, 2003. On April 9, 2003, the height and number of floral units of all surviving *C. macrophylla* and *E. cicutarium* was recorded.

D-2.1.1. Data Analysis

T-tests were used to compare the average survivorship (until March) and persistence (until April) of *E. cicutarium* and *C. macrophylla*. Analyses were done used the t.test function in R version 1.9.0.

D-2.2. 2004 Spring Census

In 2004, we began censusing *C. macrophylla* populations 1 through 6. These populations of *C. macrophylla* were too large in 2004 to conduct a survey of individual plants, therefore the boundaries of each of the six populations were recorded using a Trimble handheld GPS and an estimate of the total population size was made. The GPS data was used to determine the area of each population.

Specific plant cover was also measured in each of the six populations between March 29 and April 8, 2004. Cover estimates were made using 60 cm × 60 cm quadrats. For populations 2 through 5, ten random locations within each population were chosen for cover estimates. Population 1 has a distribution divided between two adjacent fire trails, and cover was estimated in a total of 20 quadrats (10 on each of the two fire trails). Populations 1 through 4 occur along fire trails and therefore have a basically linear distribution. In these four populations, random locations were chosen by laying a tape measure along the linear population and sampling at random distance along and out from the tape. Site 5 was not located along a fire trail, so the tape was placed along one side of this off road populations and cover measurements were taken at random distances along the tape and into the population. Site 6 included small isolated patches, and cover measurements were taken from each of the small patches and immediately adjacent to the patches. Half of the quadrats at each population were placed at the nearest spot to these random locations containing *C. macrophylla* plants, and an equal number of quadrats were sampled from areas within the general distribution of *C. macrophylla* but not containing any *C. macrophylla* plants.

The number of *C. macrophylla* in each within population quadrat sampled was recorded in addition to the number of floral units present on each of these plants.

D-2.2.1. Data Analysis

All statistical analyses were conducted in R version 1.9.0. Specific cover data was combined into six categories: bare ground, thatch, exotic grass, native grass, exotic forb, and native forb. Bare ground, thatch, exotic forb, native forb, and native grass were not normally distributed. Nonparametric Kruskal-Wallis rank sum tests were used for each of the six vegetation categories to determine if there was a significant difference in median percent cover in four groups: (1) within grassland populations, (2) adjacent to grassland populations, (3) within fire trail populations, and (4) adjacent to fire trail populations. Pairwise Wilcoxson rank sum tests with corrections for multiple comparisons were used as post hoc test. Exotic grass was normally distributed, so an ANOVA, followed by Tukey's honest significant difference post hoc test were used for this vegetation category.

The average percent cover was calculated by species for each population (averages included only quadrats containing *C. macrophylla)*. Shannon's Index (H') was also calculated for each populations using the formula $H' = -\Sigma$ (of i = 1 to S) $(n_i/n) * \ln(n_i/n)$, where S is number of different species observed, *n* is the total average percent cover of all plant species, and n_i is the average percent cover of the *i*th species (Shannon and Weaver, 1949). This diversity index is an expression of the likelihood that two plants picked at random will be of two different species. It not only reflects the number of species present in the sample, but also gives an idea of the evenness of distribution for these species (Ludwig and Reynolds, 1988). The higher the number of species and the more evenly they are distributed, the higher the diversity index.

D-3. Results

D-3.1. *California macrophylla* and *Erodium cicutarium* Survivorship (2003)

Survivorship from December until March was high for both species (Table D1), and there was not a significant difference in the average survivorship (until March) of *E. cicutarium* compared to *C. macrophylla* ($t = -0.9447$, $df = 4$, $p = 0.40$). The average percent survivorship for north berm, lower road and upper road combined was 98.2% for *C. macrophylla* and 92.6% for *E. cicutarium*. Survivorship until March for both species on the north berm was 100%, while survivorship of *E. cicutarium* was lower (93.3% lower road; 88.0% upper road) than *C. macrophylla* (100% at both sites) in the both roadbed locations.

At the time of the April survivorship check, some plants of both species had senesced after flowering. Because of this, the April counts are a measure of how long each species persists into the year instead of a measure of what percentage of plants survive until flowering. Persistence until April is the percent of plants that were marked in December and were still alive in April. There was not a significant difference in the average persistence until April of *C. macrophylla* and *E. cicutarium* ($t = -1.62$, $df = 4$, $p = 0.18$). The average persistence for all three sites combined was 92.9% for *C. macrophylla* compared 66.1% of *E. cicutarium*. Although survivorship until March was 100% for both species on the north berm, persistence until April was low at this location for *C. macrophylla* (69.2%) and *E. cicutarium* (38.5%). *California macrophylla* persistence until April in both the upper and lower road sites was 100%. *Erodium cicutarium* persistence was lower than *C. macrophylla* in the upper (80%) and lower road (71.4%) sites.

The average height of *C. macrophylla* at all three locations in April 2003 was 10.5 ± 3.1 cm (mean ± SD, Table D2). These plants had an average of 1.4 ± 2.0 floral units/plant. *E. cicutarium* was smaller than *C. macrophylla* (6.0 ± 2.3 cm height: $t = 8.37$, $df = 91$, $p < 0.0001$), but the average number of floral units/plant (1.8 ± 1.4 floral units/plant: $t = 0.93$, $df = 87$, $p = 0.34$) was similar to *C. macrophylla*.

D-3.2. 2004 Spring Census

The size estimates and area of each Site 300 *C. macrophylla* population is given in Table D3. Of the six Site 300 populations, fire trail populations 1, 2, and 3 had the largest populations of *C. macrophylla* in 2004. They contained 2,200, 1,500, and 2,000 plants respectively. The two grassland populations were quite small compared to the fire trail populations. Population 5 had 45 plants and population 6 had only 30 plants in 2004. Population 4, another fire trail population, was estimated to contain only 100 plants. Population 4 was also the smallest fire trail population in area (352 m^2). The mean number of floral units per plant ranged from 1.2 ±

1.1 in population 6 to 3.0 ± 3.2 in population 3 (Table D4). Populations occurred at elevation between 360 m and 450 m.

All six populations were rich in native forbs (Table D5). Twenty-four native forb species, one native grass species, six exotic grass species, and five exotic forb species were found in all six populations combined. The fire trail populations 1 (17 species), 2 (21 species), and 3 (19 species) were particularly diverse. Shannon's Index was also highest in populations 1, 2, and 3.

Figure D3 shows that while there was a large diversity in native forbs, exotic grasses made up the greatest percent cover in fire trail and grassland populations. Two exotic grasses, *Avena* sp. and *Bromus diandrus,* and an exotic forb, *Erodium cicutarium,* were present in all six populations. *Avena* sp. had the large percent cover in five of the populations. In population 5, another exotic grass *Vulpia myuros* had the greatest percent cover. Although one native annual grass *Vulpia microstachys* was present in three populations, native perennial bunch grasses were not found in any of the six populations.

Figure D3 shows the mean percent cover of six vegetation categories for samples taken within fire trail populations, adjacent to fire trail populations, within grassland populations, and adjacent to grassland populations. As is expected, there was a significant difference in percent bare ground ($X^2 = 35.31$, df = 3, $p < 0.0001$) and thatch ($X^2 = 35.57$, df = 3, $p < 0.0001$) between these four groups. There was also a significant difference in exotic grass cover ($F_{3, 66} = 5.88$, $p = 0.001$), native forb cover ($X^2 = 16.30$, df = 3, $p = 0.001$), and exotic forb cover ($X^2 = 24.21$, df = 3, $p = < 0.0001$) between the sampling groups. No difference was observed in the percent cover of native grasses between the sampling locations.

D-4. Discussion

In 2004, four previously unknown populations of *C. macrophylla* were discovered at Site 300 despite the fact the site-wide botanical surveys had been conducted at Site 300 in 1986 and 2002 (Preston, 2002; Biosystems, 1986). It is possible *C. macrophylla* seeds are being moved around the site during grading of the fire trails and resulting in new populations of *C. macrophylla* in suitable fire trail locations.

There are significant differences in the community composition of the fire trail populations compared to the grassland populations. The fire trail populations had more bare ground and less thatch as would be expected in an area that is annually graded. There was also significantly less exotic grass cover in the fire trail population compared to the grassland populations.

In a recent study, Gillespie and Allen (2004) found that weeding (manually removing a exotic species) had a positive effect on *C. macrophylla* emergence survival and fecundity, and that exotic grasses competitively suppress *C. macrophylla*. In our study, fire trail populations did have a decreased exotic grass cover compared to areas outside of the fire trails. This decreased annual grass cover could, at least partially, contribute to the success on *C. macrophylla* in the fire trails.

In 2003, we did not find a significant difference between the survivorship or persistence of *C. macrophylla* and *E. cicutarium*. This may be the result of the low power of statistical test resulting from a small sample size (n = 3). Because six *C. macrophylla* populations have been located at Site 300 this survivorship experiment can be replicated in each of the six populations in the future giving more power to the analyses.

Although large portions of the Site 300 grasslands are burned annually in the spring to decrease the threat of wildfire, five of the six *C. macrophylla* populations occur in areas that have not been burned for more than 10 years. Population 1 is the only one of the six populations that occurs within are area were annual prescribed burns are conducted. Because the fire trails are graded annually to provide a firebreak, the actual fire trails where *C. macrophylla* occurs do not have enough fuel to burn, but the areas adjacent to the fire trails are burned.

Both fire trail and grassland populations are diverse in native forbs. Of the 39 species identified in these populations 23 are native forbs. The within fire trail samples were the most diverse in native forbs and had the highest percent cover of native forbs. Although a significant difference was not observed between fire trail populations and grassland populations, the within fire trail samples did have a significantly higher cover of native forbs compared to samples taken from the grassland adjacent to the fire trails.

Although *C. macrophylla* clearly appears to benefit from the disturbance caused by the annual grading of the fire trails, it is not associated with frequently burned sites as are several other native species at Site 300. Five of the six populations occur in areas that have not been burned for ten or more years. In the one fire trail population that occurs within an annually burned grassland, *C. macrophylla* is clearly restricted to within the boundaries of the fire trail that escape annually burning due to lack of cover.

Future research will focus on determining the ecological requirements of *C. macrophylla,* and developing a management regime of vegetation clearing and prescribed burns or (lack of prescribed burns) that is most appropriate for this species. Another interesting management question for this rare species is what allows the closely related exotic *E. cicutarium* to thrive in a multitude of habitats and disturbance regimes, while the native *C. macrophylla* is restricted to a narrow range of habitats.

D-5. References

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Section D
Figures

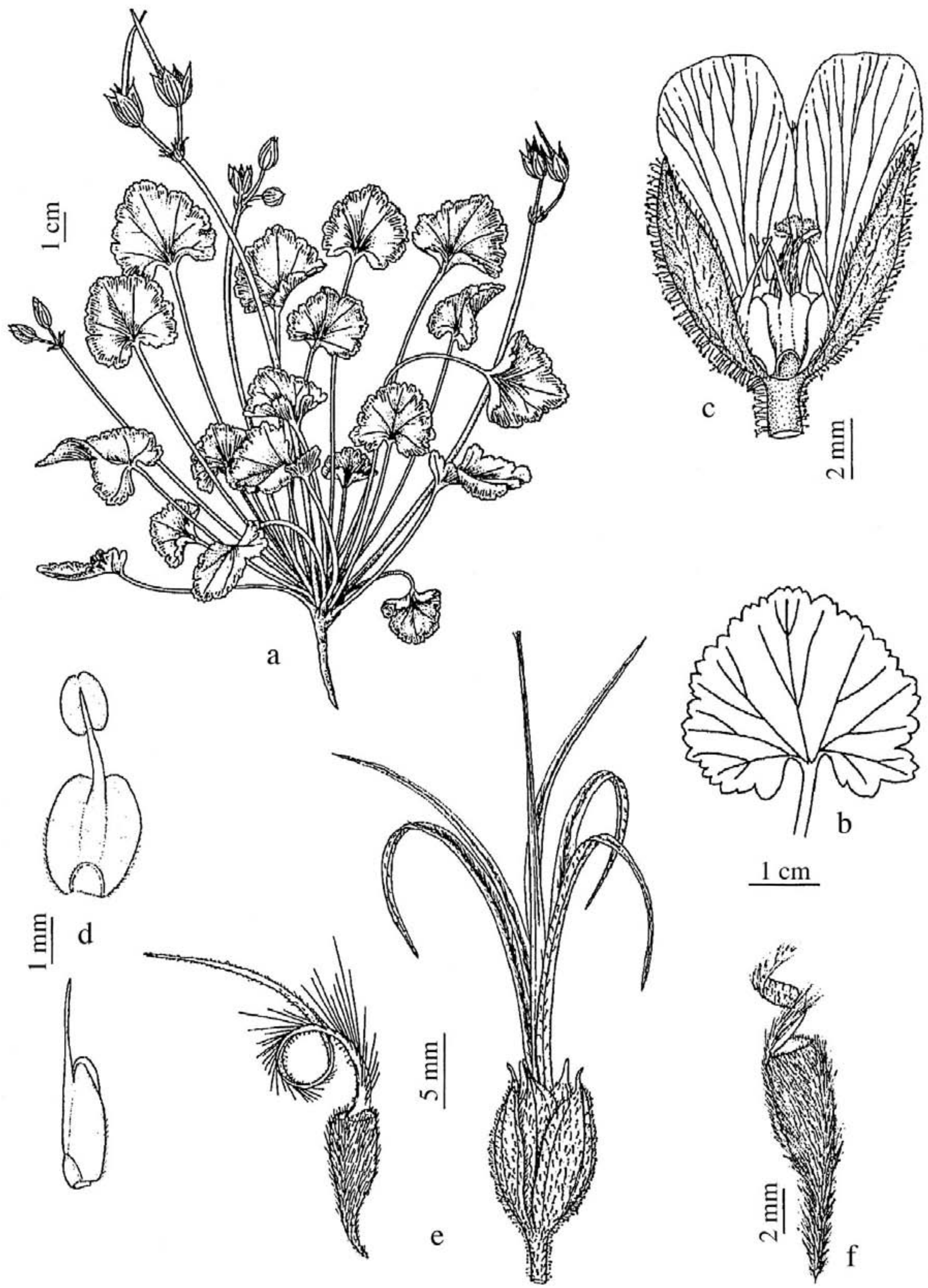

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Figure D1. ***California macrophylla*****: a) habit; b) basil leaf; c) open flower; d) stamen; e) fruit and mericarp; f) mericarp (from Aldasoro et al., 2002).**

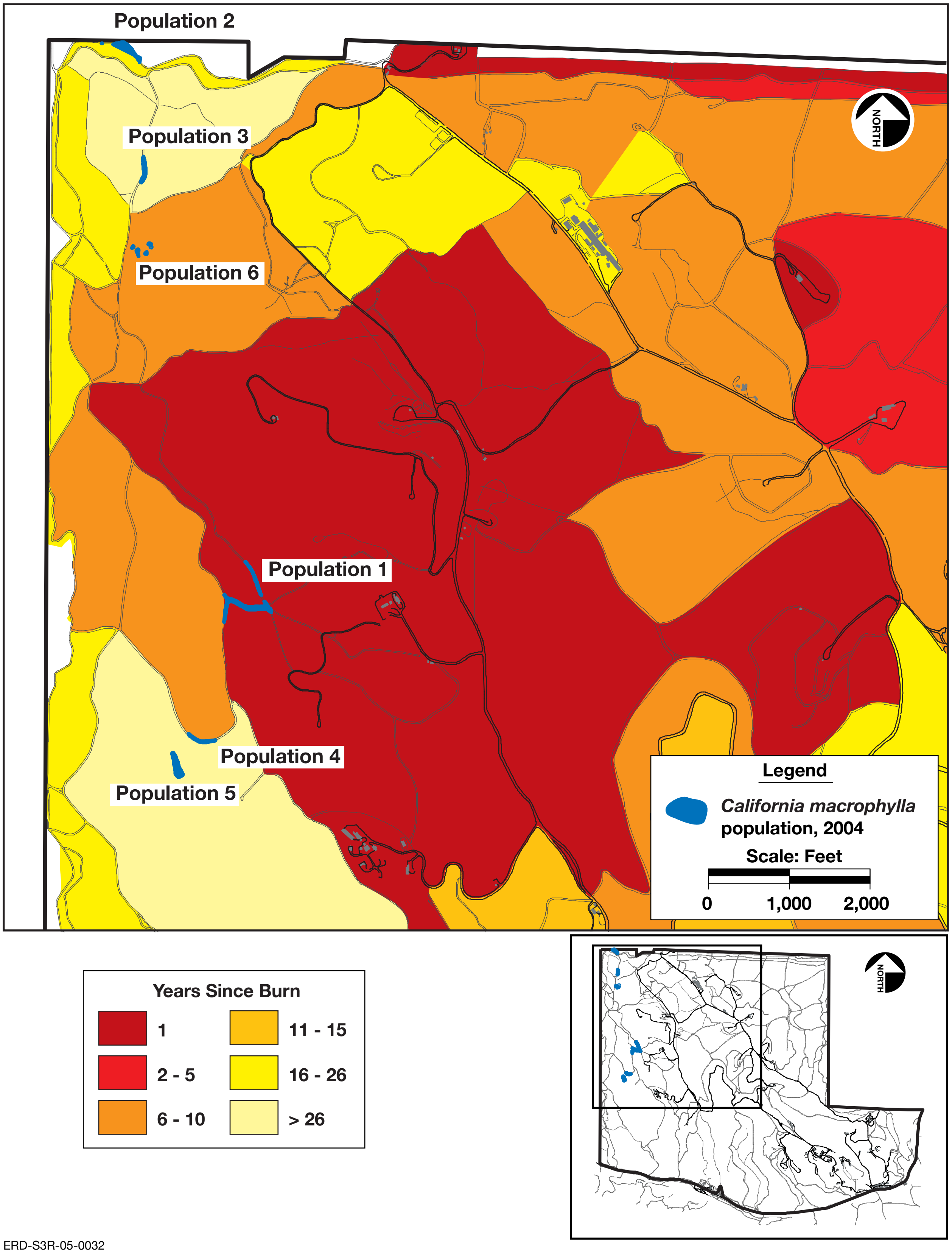

Figure D2. Locations of *California macrophylla* populations Lawrence Livermore National Laboratory (LLNL) Site 300, 2004.

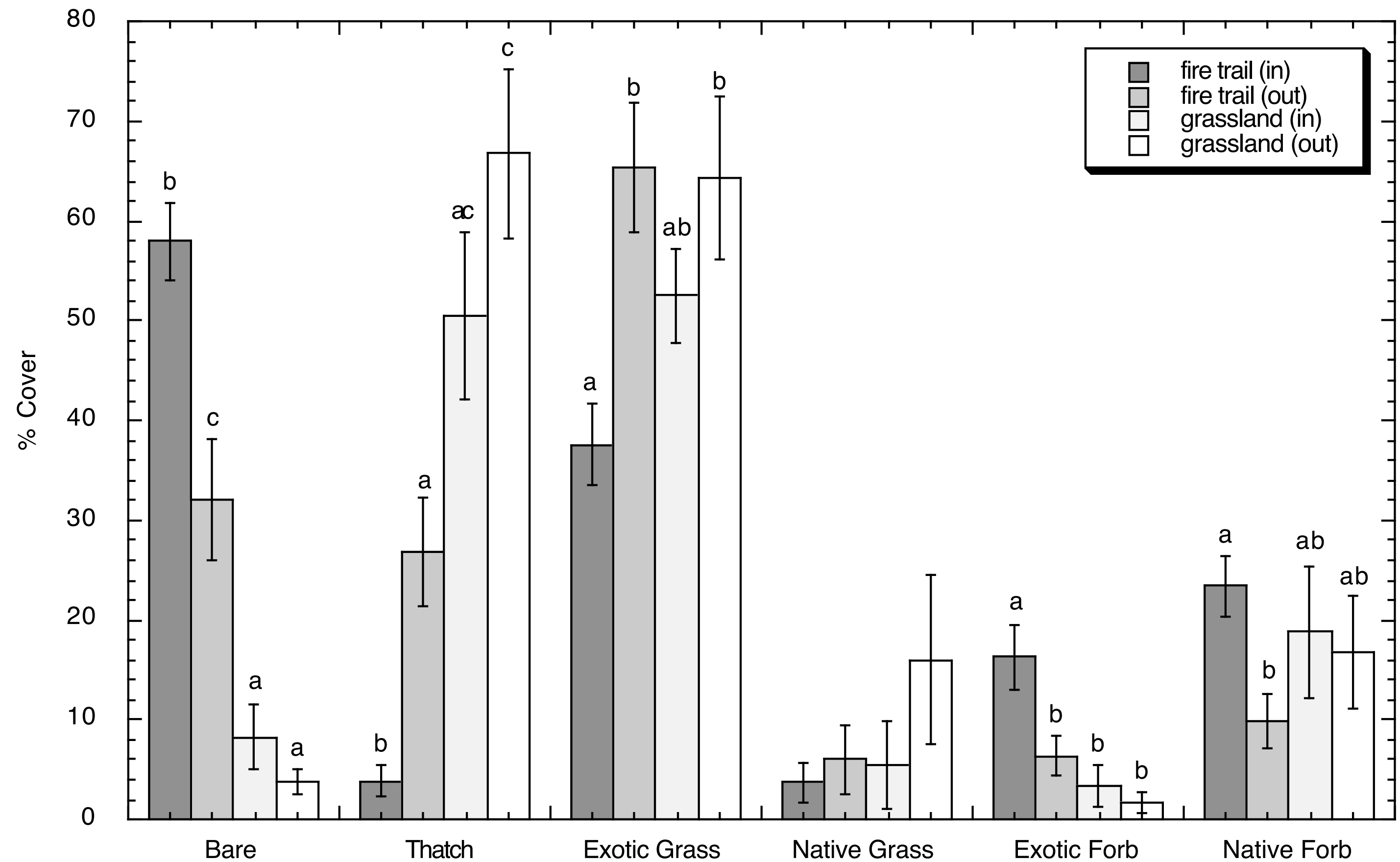

Figure D3. Mean percent cover of six categories of vegetative cover for *California macrophylla* populations in 2004. Letters above error bars indicate a significant ($p < 0.05$) difference among locations in the average percent cover. Sample locations are divided into four categories: fire trail locations containing *C. macrophylla*, fire trail locations not containing *C. macrophylla,* grassland locations containing *C. macrophylla*, grassland locations not containing *C. macrophylla.* A significant difference was not found for native grasses. Error bars are ± 1 standard error.

Section D
Tables

Table D1. Survivorship of *California macrophylla* and *Erodium cicutarium* in three fire trail locations: North Berm, Upper Road, and Lower Road.

		California macrophylla				*Erodium cicutarium*			
		North Berm	Upper Road	Lower Road	Total	North Berm	Upper Road	Lower Road	Total
Dec. 2002	no. marked	13	17	30	60	13	17	30	60
Mar. 2003	% survived	100.0	100.0	100.0	98.2	100.0	93.3	88.9	92.6
Apr. 2003[a]	% persisted	69.2	100.00	100.0	92.9	38.5	80.0	71.4	66.1

[a] Some plants may have senesced naturally by the time of the April census.

There is not a significant difference in survivorship between *C. macrophylla* and *E. cicutarium* ($t = -1.62$, $df = 4$, $p = 0.18$).

Table D2. Height and number of floral units per plant for *California macrophylla* and *Erodium cicutarium* in April 2003. All values are means ± one standard deviation.

	California macrophylla			*Erodium cicutarium*		
Location	Height	No. of floral units/plant	N	Height	No. of floral units/plant	N
North Berm	9.4 ± 1.5	1.0 ± 1.0	9	6.2 ± 0.8	3.2 ± 2.2	5
Upper Road	10.0 ± 2.9	1.2 ± 1.2	15	4.7 ± 2.0	1.4 ± 1.2	12
Lower Road	11.2 ± 3.4	1.6 ± 2.5	28	6.8 ± 2.5	1.6 ± 1.2	20
Total	10.5 ± 3.1	1.4 ± 2.0	52	6.0 ± 2.3	1.8 ± 1.4	37

Note:

N = Number of plants.

For all locations combined, *C macrophylla* is significantly taller than the *E. cicutarium* ($t = 8.37$, $df = 91$, $p < 0.0001$).

There is not a significant difference in the number of floral units between the two species ($t = 0.96$, $df = 87$, $p = 0.34$).

Table D3. Area, elevation, and estimated population size and density of all Site 300 *California macrophylla* populations in 2004.

Location	Population	Area (m^2)	Elevation (m)	Size estimate	Density (per 1 m^2)	Date of census
Fire trail	1	2077.1	419–450	2,200	0.10	Mar 29, 2004
	2	549.5	396–401	1,500	2.73	Mar 30, 2004
	3	617.9	433–445	2,000	3.24	Mar 30, 2004
	4	352.6	366–389	100	0.28	Apr 01, 2004
Grassland	5	1461.9	366–373	45	0.02	Apr 01, 2004
	6	181.7	434–450	30	0.17	Apr 08, 2004

Table D4. Number of floral units per plant for the six *California macrophylla* populations. Values are means ± one standard deviation.

Location	Population	Date of census	No. of floral units/plant	N
Fire trail	1	Mar 29, 2004	1.3 ± 1.6	26
	2	Mar 30, 2004	1.7 ± 1.8	48
	3	Mar 30, 2004	3.0 ± 3.2	36
	4	Apr 01, 2004	1.1 ± 0.8	13
Grassland	5	Apr 01, 2004	2.9 ± 2.4	45
	6	Apr 08, 2004	1.2 ± 1.1	17

Note:

N = Number of plants.

Table D5. Average percent cover of species found in *California macrophylla* populations in 2004. Values are mean percent cover ± one standard deviation.

	Population					
Species	**1 (N = 20)**	**2 (N = 10)**	**3 (N = 10)**	**4 (N = 10)**	**5 (N = 10)**	**6 (N = 10)**
Bare	73.0 ± 5.9	47.0 ± 26.6	55.0 ± 12.7	42.0 ± 12.6	3.5 ± 4.2	13.0 ± 11.9
Thatch	0.5 ± 1.6	2.0± 4.5	3.0 ± 6.7	13.5 ± 9.6	41.0 ± 26.1	60.0 ± 23.2
<u>Native Grass</u>	–					
Vulpia microstachys	8.0 ± 14.8	1.5 ± 2.2	–	–	11.0 + 17.5	–
<u>Native Forbs</u>	–					
Achyrachaena mollis	1.5 ± 2.1	–	1.0 ± 1.4	–	–	–
Amsinckia menziesii	1.3 ± 1.3	0.5 ± 1.1	0.5 ± 1.1	–	–	–
Amsinckia sp.	0.8 ± 1.2	–	0.5 ± 1.1	1.5 ± 1.4	–	3.0 ± 4.1
Astragalus sp.	–	0.5 ± 1.1	1.5 ± 2.2	–	–	–
Clarkia sp.	–	–	–	0.5 ± 1.1	–	–
Claytonia sp.	–	–	–	–	0.5 ± 1.1	–
Collinsia sparsiflora	–	–	–	–	0.5 ± 1.1	–
California macrophylla	4.8 ± 4.3	4.5 ± 3.3	5.5 ± 5.4	3.0 ± 1.1	15.5 ± 18.2	6.0 ± 3.8
Euphorbia spathulata	–	–	–	–	1.0 + 1.4	–
Juncus bufonius	–	5.0 ± 7.1	–	–	–	–
Lasthenia sp.	0.5 ± 1.1	–	1.0 ± 2.2	–	–	–
Lepidium nitidum	0.8 ± 1.7	1.5 ± 1.4	1.0 ± 1.4	–	–	–
Lotus wrangelianus	2.3 ± 2.2	1.0 ± 1.4	5.5 ± 6.7	2.0 ± 2.7	1.0 ± 1.4	–
Lupinus bicolor	–	1.5 ± 2.2	–	–	–	–
Lupinus sp.	0.3 ± 0.8	3.5 ± 6.5	3.0 ± 4.5	–	–	–
Lupinus succulentus	–	–	–	5.0 ± 11.2	–	–
Marah fabaceus	–	–	–	2.0 ± 4.5	–	–
Microseris douglasii	–	–	–	8.0 ± 13.0	–	–
Monolopia major	1.3 ± 1.3	1.0 ± 1.4	9.5 ± 12.0	–	–	–
Thysanocarpus curvipes	–	–	–	0.5 ± 1.1	–	–
Trifolium sp.	6.75 ± 9.7	1.5 ± 2.2	0.5 ± 1.1	1.0 ± 1.3	–	–
Trifolium willdenovii	–	0.5 ± 1.1	–	–	–	0.5 ± 1.1
Triteleia laxa	0.3 ± 0.8	1.5 ± 2.2	–	–	1.0 ± 1.4	1.0 ± 2.2
Vicia hassei	–	–	–	–	7.5 ± 9.8	–
<u>Exotic Grasses</u>						
Avena sp.	31.0 ± 13.1	25.5 ± 20.2	26.0 ± 20.4	29.0 + 17.5	20.0 ± 19.0	21.0 ± 4.2
Bromus diandrus	2.0 ± 3.3	6.0 ± 13.4	0.5 ± 1.1	9.0 + 8.9	6.0 ± 13.4	8.0 ± 11.5
Bromus hordeaceus	–	1.5 ± 2.2	0.5 ± 1.1	4.0 ± 6.3	7.0 + 9.7	–
Bromus madritensis	2.3 + 3.4	5.5 ± 6.7	–	–	6.0 ± 8.9	14.0 ± 11.4
Lolium multiflorum	–	5.0 ± 7.1	–	–	–	–
Vulpia myuros	2.5 ± 4.9	–	1.0 ± 2.2	–	23.0 ± 24.9	–
<u>Exotic Forbs</u>						
Erodium botrys	–	0.5 ± 1.1	1.5 ± 2.2	–	–	–
Erodium brachycarpum	–	–	4.5 ± 8.7	–	–	–
Erodium cicutarium	8.5 ± 8.7	6.0 ± 3.8	13.0 ± 8.4	13.0 ± 11.9	0.5 ± 1.1	6.0 ± 8.2
Medicago polymorpha	–	23.0 ± 30.9	2.0 ± 4.5	0.5 ± 1.1	–	–
Sonchus sp.	–	–	–	0.5 ± 1.1	–	–
<u>Unidentified</u>	–					
Unknown Geraniaceae	–	–	–	–	1.0 ± 1.4	–
Unknown Poaceae	–	–	–	4.0 ± 6.5	1.0 ± 1.4	2.0 + 4.5
Unknown dicot	–	–	–	–	–	0.5 ± 1.1
Total no. of species	**17**	**21**	**19**	**16**	**16**	**10**
Shannon's Index[a]	**2.0**	**2.4**	**2.3**	**2.2**	**2.1**	**1.8**

Notes:

N = Number of quadrats.

[a] **Shannon and Weaver (1949). H′ = - Σ (of *i* = 1 to S) (n_i/n) * ln (n_i/n) where S is the number of species observed; *n* is the sum of the percent cover for all species; and n_i is the average percent cover for the *i*th species.**