# FINAL REPORT

# A Comparison of Vegetation Management Techniques to Support Recovery of the Federally Endangered *Ambrosia pumila*

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## ABSTRACT

Non-native plant species are considered a threat to virtually all of the extant populations of the federally endangered *Ambrosia pumila*. The objective of this study was to compare the response of *A. pumila* among to several vegetation management techniques that included: mowing, application of Fusilade © II Turf and Ornamental Herbicide (a grass-specific herbicide to remove non-native species), hand-pulling of all non-native species, and a control. This study was replicated at three different sites in San Diego and Riverside Counties (Skunk Hollow Preserve, Mission Trails Regional Park, and San Diego National Wildlife Refuge), which in turn allows us to describe management options for the full geographical range in which *A. pumila* occurs.

Across all sites, hand-pulling and Fusilade ©II treatments showed the greatest increase in the number of *A. pumila* stems compared to the mowing and control treatments. Efficacy of the Fusilade ©II treatment depended on the dominant species at a given site because of the ineffectiveness of this grass-specific herbicide to kill *Vulpia spp*. We found that Fusilade ©II also effectively reduced the population of Erodium spp., non-native forb species. Furthermore, build up of dead biomass in plots treated with Fusilade ©II may have been another reason why the Fusilade ©II treatment was slightly less effective than the hand-pulling treatment. The dead biomass in the Fusilade ©II treated plots may have indirectly competed with *A. pumila* for light and space.

Based on results from this study, we recommend that for larger patches of *A. pumila,* application of Fusilade ©II may be an effective management tool to encourage the recovery of *A. pumila*. However, managers should use a combination of management tools because the widespread application of Fusilade ©II could simply shift the dominant exotic species from *Bromus spp*. to *Vulpia myuros* or an exotic forb that is not affected by Fusilade ©II. Therefore, a combination of Fusilade ©II and mowing would be the best management practice for larger patches of *A. pumila*.

## PREFACE

An important part of the mission of the Center for Natural Lands Management (CNLM) is to "conserve native species, their habitat and functioning ecosystems in perpetuity" as well as to "to own and/or manage lands in an ecologically beneficial manner consistent with local, state and federal environmental laws and with science-based stewardship." CNLM is the owner and manager of the Skunk Hollow Preserve, which is home to one of the few populations of *A. pumila* in

Riverside County. Non-native plant species are considered a threat to virtually all of the extant populations of *A. pumila* (USFWS 2002),and consequently the control of non-native plants is recommended for effective management for this species (e.g., City of San Diego 2005). However, at the time that this study was initiated, there were no guidelines regarding the most effective and low-risk method of managing non-native competition, other than the results of a pilot study conducted by CNLM staff (Maher and Stanton 2006). Being dedicated to science-based stewardship, CNLM began a pilot study in 2005 to assess the feasibility of hand-pulling and mowing to manage non-native species occurring in and around patches of *A. pumila* at Skunk Hollow Preserve. After collecting preliminary data, managers for Skunk Hollow Preserve solicited external funding to expand the study to determine whether their results would hold over larger areas, different site conditions, and different years (i.e., weather interactions). Thus, for this study we contacted and collaborated with land managers and biologists from two additional sites on which there are protected populations of *A. pumila*. We thank our collaborators at the Mission Trails Regional Park, Joshua Garcia and Tracey Walker; the City of San Diego, Betsy Miller and Melanie Johnson-Rocks; as well as John Martin and Jill Terp at the U.S. Fish and Wildlife Service's San Diego National Wildlife Refuge, for making this study possible. The expanded study began in February of 2008 and continued through May of 2009.

Additionally, this work could not have been done without the previous efforts of a few caring and motivated individuals. Particularly, we would like to thank Cindy Burrascano for her efforts to list *A. pumila* as an endangered species, her research on management of *A. pumila*, and her help in the field with this study. Mike Kelly researched the susceptibility of *A. pumila* to Fusilade ©II in a previous study (Kelly et al. 2007), which allowed us to use this grass-specific herbicide in this study. Finally, we thank Samantha Marcum, of the Partners for Fish and Wildlife Coordinator at the Carlsbad Fish and Wildlife Service Office, for her persistent efforts to fund this study. This study was funded by the Carlsbad Field Office of the U.S. Fish and Wildlife Service to support the recovery of *A. pumila*.

## INTRODUCTION

*Ambrosia pumila* is restricted to southern California and north-central Baja California where it occurs in flood terraces of river drainages (Johnson et al. 1999), valley bottomlands, open grasslands, and open areas in coastal sage habitat (Hogan and Burrascano 1996, Dudek 2000). Although less frequently, *A. pumila* is also found adjacent to vernal pools or in disturbed areas such as fire fuel breaks and along roadsides (Hogan and Burrascano 1996, Dudek 2000, USFWS 2002). In California there are approximately fifteen known extant populations of *A. pumila* (USFWS 2009), all of which are in San Diego and Riverside Counties. As a result of its highly restricted distribution and the loss of half of its known populations since the 1930s, the U.S. Fish and Wildlife Service ruled *A. pumila* endangered in 2002 (USFWS 2002).

*Ambrosia pumila* is a woolly gray-green herbaceous perennial plant species that occurs in isolated patches and spreads vegetatively by means of underground rhizome-like roots from which rise aboveground stems (USFWS 2002). This vegetative reproduction results in patches of aboveground stems made up of groups of genetically identical clones (McGlaughlin and Friar 2007). Although *A. pumila* appears to primarily reproduce clonally, some sexual reproduction must occur or has occurred in the past as evidenced by relatively high genetic diversity when compared to other rare and endangered clonal species (McGlaughlin and Friar 2007). However, field collections have not provided evidence that viable seed are produced (Johnson et al. 1999; Dudek 2000; USFWS 2002). Low viable seed production may be attributable to the loss of a critical pollinator (Johnson et al. 1999), the need for genetic diversity for pollination to occur (i.e. not self fertile), or inappropriate conditions for pollination (McGlaughlin and Friar 2007), which could include resource availability and/or surrounding habitat that blocks wind pollination. Aerial stems range from 5–50 cm tall (Keck 1959) and wind pollination may be inhibited by an over-story of non-native grasses and forbs (McGlaughlin and Friar 2007). Thus, non-native plants may contribute to the loss of *A. pumila* by directly competing with *A. pumila* for space and resources, as well as indirectly by blocking pollination by wind.

The objective of this study was to compare the response by *A. pumila* among several practical vegetation management techniques. The resulting information could provide land managers from both San Diego and Riverside Counties tested tools to better manage non-natives that co-occur with *A. pumila*. Currently, very little is known about the efficacy of different management options to reduce non-natives in and around patches of *A. pumila*, and presumably enhance the recovery of this endangered species. We therefore performed a study to examine the effects of different management techniques on non-native plants and populations of *A. pumila* that included: mowing, application of Fusilade © II Turf and Ornamental Herbicide (a grass-specific herbicide to remove non-native species), hand-pulling of all non-native species, and a control.

This study was replicated at three different sites in San Diego and Riverside Counties (Skunk Hollow Preserve, Mission Trails Regional Park, and San Diego National Wildlife Refuge). Because this study was replicated across a wide geographic range, we were also able to examine general ecological characteristics associated with the occurrence of *A. pumila*. These ecological characteristics included surrounding plant cover (both natives and non-natives), proximity to water source, topography, soil nutrients, soil moisture and soil temperature.

## MATERIALS AND METHODS

*Study Sites*—This study was replicated among three sites in Riverside and San Diego Counties (Fig. 1, Table 1). Skunk Hollow Preserve (SH) is located in the unincorporated area of French Valley, Riverside County, and consists of 138 acres of annual grassland, coastal sage scrub, and a vernal pool (Fig.2). Mission Trails (MT) is a 5,800 acres regional park located only eight miles northeast of downtown San Diego and is largely dominated by chaparral and sage scrub plant communities (Fig. 3). San Diego National Wildlife Refuge (SDNWR) is characterized by coastal sage and chaparral plant communities, and represents the southern most site in this study (Fig. 4).

*Experimental Design*—In February 2008, five replicated blocks were established at each of the three sites. At both MT and SDNWR, each replicated block consisted of 20, 1-$m^2$ plots with four treatments replicated five times. Treatments included hand-pulling of non-native species, application of Fusilade ©II, mowing, and a control (Fig. 5). At SH, we used pre-established blocks that were originally established in 2005 as part of a pilot study. Because of the proximity of the Skunk Hollow vernal pool and the unknown effect of Fusilade ©II on the endangered Riverside fairy shrimp, which is known to occur in the pool, Fusilade ©II was not applied as a treatment at this site. Therefore, replicated blocks at SH consisted of 15, 1-$m^2$ plots. The hand-pulling treatment consisted of removing all non-native plant species and was applied in late February/early March of 2008 and 2009 when plants were large enough to be identified and prior to them setting seed.

Fusilade ©II is a grass specific herbicide and was applied to the entire plot along with a non-ionic surfactant at a rateaccording to the labels in late February of 2008 and 2009. The mowing treatments were cut using hand shears to a height of approximately five cm in early March of 2008 and 2009 at which time non-native grasses had begun to flower, but not set seed. The timing of the mowing treatment was intended to prevent non-natives from setting seed. Control plots were left untouched during the course of this two-year study.

Pre-treatment vegetation data was collected at the plot level before the application of treatments in February 2008. Data was collected within 0.25 $m^2$ frames centered in the middle of each 1-$m^2$ plots so as to limit any effects from adjacent treatments (i.e. edge effects). Measurements included percent cover of each plant species, including percent cover of *A. pumila*, the number of *A. pumila* stems, and the number of *A. pumila* stems with flowering stalks. Although we understand that stems are not a true indicator of the number of genetically distinct individuals of *A. pumila* present in a given area, we assumed that increasing numbers of *A. pumila* stems directly relates to the health of the species. Additionally, previous studies and monitoring efforts for *A. pumila* have used stem counts as a measurement of a response to treatments (Kelly et al. 2007; Maher and Stanton 2006; Johnson et al. 1999). Vegetation measurements were repeated in May 2008, February 2009 (just prior to re-treatment), and May 2009. For analyses, plant species were grouped into "native" (grasses and forbs combined), non-native "exotic" species (grasses and forbs combined).

We also conducted a descriptive study of *A. pumila* habitat among the three sites. Certain habitat characteristics were described and other measurements taken, so as to: 1) determine the range of conditions over which the treatment response might be similar (i.e., to what extent these results could be applied to other occupied habitat); 2) help explain differences, if any, among sites in treatment response; and 3) more fully describe site conditions for extant *A. pumila* populations, as an indication of attributes of suitable habitat (e.g., for possible use in restoration and translocation). Measurements included soil chemistry, distance to surface water, slope, aspect, and elevation.  Distance to nearest surface water, aspect, and elevation of each replicated block was determined using digitized images from Google Earth. In mid-February 2008, we also deployed soil sensors to monitor soil temperature (N=2 per site) and soil moisture (N=1 per site) at 5 cm depth and photosynthetically-active-radiation (PAR) at the soil surface (N=1 per site). Environmental parameters were recorded every hour at each of the three sites using electronic datalogger (HOBO; Pocasset, Massachusetts). Over the summer of 2008, dataloggers at MT and SH were disturbed by rodents or coyotes. The datalogger at SH was repaired and redeployed in March 2008. However, the datalogger for MT could not be repaired. Thus, the growing season for 2008 is the only time period in which we have data for all three sites.

In April 2008, soil samples for chemical analyses were collected from each of the replicated blocks to a depth of 10 cm. Four samples were collected at each block and pooled together before chemical analyses (N= 5 per site). All soil analyses were performed at Servi-Tech Laboratories (Hasting, Nebraska).

*Statistical Analysis*—We evaluated treatment effects on the percent cover of exotic cover, native cover, and the number of *A. pumila* stems among sites using a two-way repeated measures ANOVA. We treated time as our repeated effect and evaluated treatment and the interactions between site and treatment to determine the effect of the treatment on the dependent variables and if these effects differed as a function of the site. For statistical analyses we used the averaged values for each treatment within a block, giving us a sample size of five per treatment per site. We followed these analyses with post-hoc tests using Bonferroni corrections to determine statistical differences between treatments by sites. All statistical analyses were performed using SPSS statistical software (SPSS Inc., v16.0, 2007).

## RESULTS

### Range-wide affects of treatments on vegetation

*Percent Exotic Cover* — When measuring pre-treatment conditions in February 2008, percent exotic cover was significantly lower at SH compared to MT and SDNWR in all treatments ($P < 0.05$, Fig. 6). In the control treatment, percent exotic cover at both MT and SDNWR did not significantly change during the study ($P > 0.05$), whereas percent exotic cover at SH was significantly higher in May 2008 and May 2009 compared to measurements taken in February 2008 ($P < 0.05$), but not in February 2009 ($P > 0.05$, Fig. 6A). The hand-pulling treatment elicited significantly different responses in percent exotic cover among the sites ($P < 0.05$, Fig. 6B). At both MT and SDNWR, percent exotic cover was reduced after the first treatment in 2008 by roughly 70% ($P < 0.05$), whereas there was no significant change at SH. However, percent exotic cover at all sites was significantly reduced in May 2009 compared to February 2008 and February 2009 ($P < 0.05$, Fig. 6B). The mow treatment affected percent exotic cover differently among sites ($P < 0.05$, Fig. 6C). At both MT and SDNWR, percent exotic cover did not significantly change until the last sampling date ($P < 0.05$), whereas exotic cover at SH significantly increased between February

2008 and May 2008 and then decreased between February 2009 and May 2009 ($P < 0.05$, Fig. 6C). In the Fusilade ©II treatment, percent exotic cover at both MT and SDNWR was reduced by roughly 55% between February 2008 and May 2008 ($P < 0.05$, Fig. 6D). At SDNWR, percent exotic cover was significantly higher in May 2009 compared to May 2008 ($P < 0.05$) and was not different than the measurement taken in February 2009 ($P < 0.05$, Fig. 6D). In contrast, percent exotic cover at MT remained significantly lower in both sampling dates in 2009 compared to February 2008 ($P < 0.05$).

*Percent Native Cover*— Prior to any treatments being applied in February 2008, percent native cover was significantly higher at SH compared to MT and SDNWR in all treatments ($P < 0.05$, Fig. 7). In the control treatment, percent native cover at both MT and SDNWR did not significantly change during the study ($P > 0.05$), whereas native cover at SH was significantly lower in May 2009 compared to measurements taken in 2008 ($P < 0.05$, Fig. 7A). In the hand-pulling treatment, percent native cover at MT and SDNWR did not significantly change during the study ($P > 0.05$); yet native cover at SH decrease roughly 20% in May 2009 compared to all other sampling dates ($P < 0.05$, Fig. 7B). In the mow treatment, percent native cover at SH was roughly 30% lower in May 2009 compared to measurements taken in February 2008 ($P < 0.05$), whereas there was no significant change at MT and SDNWR ($P > 0.05$, Fig. 7C). In the Fusilade ©II treatment, percent native cover did not significantly change at MT or SDNWR ($P > 0.05$, Fig. 7D).

*Ambrosia pumila Stems*— *A. pumila* stems counted prior to treatment application in February 2008 were significantly lower at MT compared to SDNWR in both the control and hand-pulling treatments ($P < 0.05$, Fig. 8). In the control treatment, the number of *A. pumila* stems did not significantly change during the study at any of the three sites ($P > 0.05$, Fig. 8A). In the hand-pulling treatment, the number of *A. pumila* stems differed significantly among sites during the study ($P < 0.05$). At SH there was no significantly change in the number of *A. pumila* stems during the study, whereas the number of *A. pumila* stems increased by an average of 30 individuals at MT and an average of 90 individuals at SDNWR between February 2008 and May 2009 ($P < 0.05$, Fig. 8B). In the mow treatment, the number of *A. pumila* stems did not significantly change during the study at any of the three sites ($P > 0.05$, Fig. 8C). In the Fusilade ©II treatment, the number of *A. pumila* stems at MT did not significantly change during the study. In contrast, the number of *A. pumila* stems at SDNWR increased by an average of 60 individuals between February 2008 and May 2009 ($P < 0.05$, Fig. 8D).

**Effects of treatments at the different sites**

*Mission Trails*—At the beginning of the experiment in February 2008, there were no significant differences in percent exotic plant cover among treatments at MT ($P > 0.05$, Fig. 9A). However, after treatments were applied percent exotic cover differed significantly among the treatments. In the control treatment, percent exotic cover did not significantly change throughout the study ($P > 0.05$), whereas in the mow treatment exotic cover did not significantly change until the last sampling date, where it was reduced by roughly 50% ($P< 0.05$, Fig. 9A). For both Fusilade ©II and hand-pulling treatments, percent exotic cover was significantly reduced after treatments were applied in 2008, and remained reduced compared to the control and pre-treatment conditions throughout the two-year study ($P < 0.05$). It is interesting to note that although there was an initial decrease in exotic cover after the first application of Fusilade ©II, there was a gradual, although statistically insignificant, increase in exotic cover over the remainder of the study (Fig. 9A). At the end of the experiment in May 2009, there were significant differences in percent exotic cover among the different treatments, with hand-pulling treatments having the lowest exotic cover compared to the other treatments ($P < 0.05$, Fig. 9A). There were no significant differences in percent native cover among treatments at the beginning of the experiment ($P > 0.05$). However, at the end of the experiment in May 2009, there were significant differences in percent native cover among the treatments ($P < 0.05$, Fig. 9B). Native cover in the hand-pulling treatment was significantly higher than both the mow and control treatments, but was not statistically higher than the Fusilade ©II treatment (Fig. 9B). The number of *A. pumila* stems was not significantly different among the treatments in February 2008 ($P> 0.05$); but after treatments were applied, the number of *A. pumila* stems differed significantly among treatments (Fig. 9C). In the hand-pulling treatment, the number of *A. pumila* stems significantly increased after the first application of the treatment in 2008 and remained significantly higher throughout the study ($P < 0.05$, Fig. 9C). In contrast, there were no statistically significant changes in the number of *A. pumila* stems in the Fusilade ©II, mow, and control treatments throughout the study ($P > 0.05$). At the end of the experiment in May 2009, there were no significant differences in the number of *A. pumila* stems among the different treatments.

*SDNWR*—At the beginning of the experiment in February 2008, there were no significant differences in percent exotic cover among treatments at SDNWR ($P > 0.05$, Fig. 10A). However, after treatments were applied, percent exotic cover differed significantly among the treatments throughout the study. In the control treatment, percent exotic cover did not significantly change throughout the study ($P > 0.05$), whereas in the mowing treatment exotic cover did not significantly change until the last sampling date, where it was reduced by roughly 30% ($P < 0.05$, Fig. 10A). For both the Fusilade ©II and hand-pulling treatments, percent exotic cover was significantly reduced following the first application of treatments in 2008 ($P < 0.05$); yet both treatments returned to pre-treatment conditions by February 2009 (Fig. 10A). After the second treatments were applied in 2009, only percent exotic cover in the hand-pulling treatment was significantly reduced in May 2009 compared to February 2009, whereas there was no significant reduction in exotic cover with the second application of the Fusilade ©II treatment in 2009 (Fig. 10A). At the end of the experiment in May 2009 there were significant differences in percent exotic cover among the different treatments ($P < 0.05$). Hand-pulling reduced exotic cover the most, while Fusilade ©II and mowing were not as effective, but still had some effect compared to the control, which did not change from pre-treatment conditions. (Fig. 10A). There were no significant differences in native cover among treatments at the beginning of the experiment ($P > 0.05$), nor was there any significant change in percent native cover among the treatments throughout the study (Fig. 10B). The number of *A. pumila* stems was not significantly different among treatments in February 2008 ($P > 0.05$). However, after treatments were applied the number of *A. pumila* stems differed significantly among treatments ($P < 0.05$, Fig. 10C). There were no significant changes in the number of *A. pumila* stems in the mow and control treatments throughout the study ($P > 0.05$), but the number of *A. pumila* stems in the hand-pulling and Fusilade ©II treatments significantly increased after the application of the first treatment in 2008, and remained significantly higher throughout the study ($P < 0.05$, Fig. 10C). At the end of the experiment there were significant differences in the number of *A. pumila* stems among the treatments ($P < 0.05$), where the hand-pulling treatment had the highest number of *A. pumila* stems. Fusilade ©II treatment had fewer stems than the hand-pulling treatment, but still more than the mow treatment, which did not have any more stems that the control (Fig. 10C).

*Skunk Hollow*—In February 2008 there were no significant differences in percent exotic cover among treatments. However, after treatments were applied percent exotic cover differed significantly among the treatments during the study ($P < 0.05$, Fig. 11A). In the control treatment, there was no significant change in percent exotic cover throughout the study, whereas exotic cover was reduced by roughly 45% in the hand-pulling treatment between February 2008 and May 2009. In the mow treatment, percent exotic cover was significantly higher in May 2008 compared to February 2008 and May 2009. At the end of the experiment there were significant differences in percent exotic cover among treatments ($P < 0.05$). Hand-pulling reduced exotic cover the most, while mowing was not as effective, but still had some effect compared to the control (Fig. 11A). There were no significant differences in native cover among treatments at the beginning of the experiment ($P > 0.05$). Interestingly, there was a gradual, although insignificant, trend of reduced native cover in all treatments, including the control, throughout the study. By May 2009 percent native cover was significantly reduced by roughly 15% in all treatments compared to measurements taken in February 2008 ($P < 0.05$, Fig. 11B). There were no significant differences in the number of *A. pumila* stems at the beginning of the experiment ($P > 0.05$, Fig. 11C). After the application of the first treatment in 2008 and continuing throughout the study, the number of *A. pumila* stems in the hand-pulling treatment was significantly higher than the control treatment ($P < 0.05$), but did not differ from the mow treatment. At the end of the experiment there were significant differences in the number of *A. pumila* stems among the treatments ($P < 0.05$), where hand-pulling had a higher number of *A. pumila* stems compared to the control, but the mowing treatment was not significantly different from either the hand-pulling treatment or the control (Fig. 11C).

**Cost of treatments**

We also determined the time it took to apply treatments as well as the cost of materials or equipment used when applying treatments. Travel time to and from the field sites was not included in this analysis as this could be highly variable depending on where workers are headquartered. Hand-pulling was by far the most expensive treatment, costing an average of $26.60/m$^2$, given a conservative hourly wage of $20/hour (Table 2). This cost was almost entirely attributable to the time it took to pull non-natives from the plot, whereas only $0.04/m$^2$ was attributable to equipment costs (hand weeder). Additionally, it took on average 1.33 hours to remove all of the non-native plants from one square meter area. Mowing was the next most expensive treatment to apply, with an average cost of $5.80/m$^2$ (Table 2). The cost of mowing was again largely attributable to the time it took to mow the plots, whereas only $0.02/m$^2$ was attributable to equipment costs (hand tools). Application of Fusilade ©II was the least expensive treatment option, taking only 0.02 hours to treat one square meter and costing only $0.017/m$^2$ in materials (Table 2). We only factored in the cost of the herbicide and surfactant into this analysis, not the spray or safety equipment, nor the overhead costs associated with extra insurance and licensing associated with applying pesticides.

**Descriptive Characteristics of *Ambrosia pumila* habitat**

*Surrounding Plant Cover* – Species lists were generated from data collection efforts within experimental plots (Tables 3-6). The occurrence/presence of each plant species encountered in the plots was generated for data collected in 2009. In the control plots at MT, *Bromus hordeacous* and *Vulpia myuros* were found in 100% of plots, while various species of *Erodium* were found in 96% of plots (Table 3). The next most common species found in these plots was *Distichlis spicata*, a native grass, which was found in 68% of plots at MT. At SDNWR, the most dominant species in the control plots were various species of *Erodium*, which were found in 96% of plots (Table 4). *Vulpia myuros* was found in 92% of the control plots, while the next two most commonly encountered species were *Bromus madtritensis* ssp. *rubens* and *Bromus hordeacous* (found in 84% and 64% of plots, respectively). At SH, the top four species occurring in the control plots were also exotic (Table 5). The most commonly occurring species was *Vulpia myuros* (found in 84% of plots), followed by *Bromus madtritensis* ssp. *rubens*, *Avena* spp, and various species of *Erodium* (found in 76%, 76%, and 64%of plots, respectively).

*Soil Chemistry*—Macronutrients (such as nitrogen, phosphorus, or potassium) differed significantly among sites, whereas only a few micronutrients (such as zinc and cooper) differed among sites (Table 6).  Nitrate nitrogen was roughly six times greater at SDNWR compared to both MT and SH ($P = 0.03$). Potassium was also significantly greater at SDNWR compared to the other two sites ($P = 0.01$), whereas phosphorus was significantly greater at SH and SDNWR compared to MT ($P = 0.01$). The majority of the micronutrients, with the exception of zinc and copper, were similar among the three sites. Interestingly, *A. pumila* at all three sites occurred in slightly alkaline soils where values ranged between 6.12 and 6.54 (Table 6). Soil samples were taken at the block level and were not taken within individual treatments.Therefore, soil chemistry data cannot be used to explain differences among management treatments.

*Abiotic and Site Conditions*—Soil temperature was slightly greater at SDNWR compared to MT and SH (Fig. 12A). Soil moisture, on the other hand, was significantly greater at SH compared to the other two sites ($P < 0.001$; Fig. 12B). We observed no significant differences in PAR among the sites, and values ranged between 0 μE at night to approximately 2000 μE at mid-day. SH, at 1350 ft, was higher in elevation than either SDNWR or MT (361 ft and 317 ft, respectively). At SH, replicated blocks were located around a vernal pool with four blocks situated on a slight slope facing westward and the remaining plot on an eastward slope (Fig. 2). Each replicated block represented a distinct patch of *A. pumila*, and therefore the proximity of *A. pumila* to a water source was determined as the distance of each block to the nearest water source. Because of the presence of the ephemeral vernal pool, populations of *A. pumila* were much closer to the nearest water source at SH ($P = 0.08$; average distance = 58.64 m). In contrast, at Mission Trials, there is a small lake within 100 m of the replicated blocks (Fig. 3). The average distance to the nearest water source was greatest at SDNWR (177.52 m), where the water source is a severely manipulated stream that often runs dry during the summer months (Fig. 4). All replicated blocks at both SDNWR and MT were situated on the north side of a small drainage.

## DISCUSSION

At all three sites, there was a general increase in the number of *A. pumila* stems after the treatments were applied in both March 2008 and 2009 (Fig. 8). However, the increase in *A. pumila* stems differed significantly among treatments. Hand-pulling and Fusilade ©II treatments had the greatest increase in the number of *A. pumila* stems compared to the mow and control treatments. At the same time, the percent cover of exotic species was significantly reduced in both the hand-pulling and Fusilade ©II treatments compared to the other two treatments (Fig. 6), suggesting that exotic species may be directly competing with *A. pumila*.

At both MT and SDNWR, the increase in *A. pumila* stems was significantly greater in the hand-pulling treatment compared to the Fusilade ©II treatment (Figs. 9 and10). One possible explanation for this difference may be related to the fact that *A. pumila* is frequently observed in lightly disturbed areas such as horse corrals, road sides, and fire breaks (USFWS 2009, Beauchamp 1986, p. 94; Payne 1993, p. 194). Soil in the hand-pulling treatment was disturbed as a result of hand pulling non-native species and therefore we may have unintentionally created more favorable microclimates for *A. pumila*. Another explanation could be that while Fusilade ©II kills exotic grasses, the biomass of the dead grass continues to stay in place and “competes” with *A. pumila* for light and physical space. An interesting future experiment would be to apply Fusilade ©II and then rake out the dead biomass left behind after spraying to determine the effect of dead grass on *A. pumila*.

The number of *A. pumila* stems differed significantly among treatments at the different sites. At MT the number of *A. pumila* stems increased by ~5.5 times in the hand-pulling treatment during the course of this study, whereas there was no significant change in the number of *A. pumila* stems in the other three treatments (Fig. 9). At SDNWR, both the hand-pulling and Fusilade ©II treatments significantly increased the number of *A. pumila* stems, whereas there was no significant change in the mow and control treatments (Fig. 10). At SH, there were slightly more *A. pumila* stems in the hand-pulling treatment compared to both the mow and control treatments, yet there were no significant changes in the number of *A. pumila* stems throughout the study (Fig. 11). One possible explanation for differences between MT and SDNWR may be related to the differences in the dominant exotic species at these two sites. At MT, the dominant exotic species are non-native grasses (e.g. *Bromus spp*. *Avena spp*. *Vulpia myuros*), whereas the dominant exotic species at SDNWR are *Erodium spp* (Tables 3 and 4).

In this study, we found that Fusilade ©II effectively killed *Erodium* species along with most non-native grasses without adversely affecting *A. pumila*. Fusilade ©II did not seem to affect any other broad leaf forbs and did not affect cover of native plants (Fig. 7D), but more analysis should be done to determine if some native species are more susceptible to Fusilade ©II than others (Tables 3 and 4). Traditionally, Fusilade ©II is thought to be a grass-specific herbicide, with little to no effect on broad leaf forbs. The effect of Fusilade ©II on species of *Erodium* in this study was so strong that the Fusilade ©II treatments dominated by species of *Erodium* often looked and responded similarly as the hand-pulling treatments. Fusilade ©II was also reported to kill *Erodium spp* at MT in a study by Kelly et al. (2007) and in a separate study by Steers and Allen (2008). The only notable exception between hand-pulling and Fusilade ©II treatments was the presence of dead biomass in Fusilade ©II plots compared to hand-pulling plots, in which aboveground biomass was removed from the plots. Build-up of dead biomass in the Fusilade ©II plots at SDNWR was minimal because of the smaller size of the most common species *Erodium botrys*. In contrast, the most common species at MT were larger grasses (i.e. *Bromus spp.* and *Vulpia myuros*), which lead to greater amounts of dead biomass. After being sprayed with Fusilade ©II, *E. botrys* dried and its leaves disintegrated within a few weeks, whereas the grasses treated with Fusilade ©II at MT dried, but did not disintegrate for at least one year (Fig 13). This may help explain why Fusilade ©II and hand-pulling treatments responded similarly at SDNWR, but not at MT.

Although Fusilade ©II is thought be a grass-specific herbicide, results from this study also suggest that some grass species are not affected by Fusilade ©II application. For example, *Vulpia myuros* (rattail fescue) was seemingly not affected by the application of Fusilade ©II. In fact, percent cover of *V. myuros* significantly increased after the application of Fusilade ©II at MT (Table 3). Previous studies have also shown minimal effect of Fusilade ©II on *Vulpia spp.* (Dowling and Nicol 1993, Mackereth et al 1993, Bowran and Wallace 1996, and Kelly et al 2007). It is unclear why *Vulpia spp* is resistant to Fusilade, but is susceptible to other herbicides such as Round-up. The increase in *V. myuros* along with dead biomass at MT may, in part, help explain why the Fusilade ©II and hand-pulling treatments responded differently at MT than at SDNWR. Although Fusilade ©II eliminated many of the non-native grasses (namely *Bromus spp*.), *V. myuros* quickly took its place and limited the increase in *A. pumila* stems (Tables 3 and 4). .

There was considerable variation in soil macronutrients among sites (Table 6). Therefore, it is difficult to identify specific combinations of soil nutrients that would be considered “ideal” *A. pumila* habitat. However, soil pH was relatively consistent among the sites, ranging from 6.12 to 6.54. Soil pH affects a wide-range of soil properties including chemical, biological, and indirectly even physical properties. For example, soil pH greatly influences the ability of roots to uptake many nutrients (Brady and Weil 2002). Because soil pH varied little among the three sites it may be a good indicator for identifying suitable *A. pumila* habitat in future translocation or other management activities.

*A. pumila* had the highest stems per $m^2$ at SDNWR and the lowest density of stems at MT, with SH falling in between. Water availability does not appear to influence the abundance of *A. pumila* among the sites because differences in soil moisture are not reflected in the abundance of *A. pumila* (Fig. 12). Nutrients like nitrogen and phosphorus are often the most limiting nutrients for plant productivity. Therefore, differences in macronutrients may, in part, explain the different abundances of *A. pumila* among the three sites. Significantly higher nitrate concentration at SDNWR may be responsible for the high abundance of *A. pumila* at this site. In contrast, the difference in abundance of *A. pumila* between MT and SH may be related to phosphorus availability. Significantly higher phosphorus at SH compared to MT may be responsible for higher abundance of *A. pumila* at SH compared to MT. In general, the soil characteristics measured in this study may help explain why there are generally more or less *A. pumila* or non-native plants at a given site, but does not explain why a treatment was more or less effective at any one site. Further studies are needed to determine whether or not nutrient concentrations truly affect the abundance of *A. pumila* stems (i.e. nutrient addition study).

It is important to point out that when we call a treatment "mowing" or "hand-pulling" we are referring to the specific combination of the treatment and the timing of the application of the treatment. Our treatments could have different results if applied at different times of year or multiple times per year. For example, if we mowed twice in one season, once early to remove competition and then again before seed set, we may have had different results with our "mowing" treatment.

## RECOMMENDATIONS

Results from this study suggests that the effective management for *A. pumila* is strongly site dependent, and is largely a function of the population or patch size of *A. pumila* as well as the dominant exotic competitors. For smaller patches of *A. pumila*, less than 5-$m^2$, hand-pulling of non-native, exotic, plants is likely the best management tool to encourage the recovery of *A. pumila*, especially if there is access to well trained, low cost labor or volunteers. However, hand-pulling is very labor intensive and may not be feasible at larger scales. Thus, for larger patches of *A. pumila,* application of Fusilade ©II may be an effective management tool to encourage the recovery of *A. pumila*. However, results presented here suggests that managers should use a combination of management tools because the widespread application of Fusilade ©II could simply shift the dominant exotic species from *Bromus spp*. to *Vulpia myuros* or an exotic forb not affected by Fusilade ©II. Therefore, a combination of Fusilade ©II and mowing would be best for larger patches of *A. pumila*. An example of a combination of treatments that could be used on a large scale would be spraying Fusilade ©II early in the season, when grasses and *Erodium* have recently germinated, and mowing later in the season, when grasses have begun flowering but have not yet set seed. Raking or collecting dead biomass after treatments are applied would likely also improve conditions for *A. pumila* recovery.

In the end, the most appropriate treatment will also be affected by the local costs for these treatments. Managers will have to choose the treatment that is right for their *A. pumila* population based on access to equipment (mowers or spray equipment), herbicides, a Qualified Applicator, cost, public support for use of pesticides, etc.

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**Table 1**. Description of study locations.

| Preserve Name | Preserve Owner | Preserve Manager | County | Total Preserve Area (acres) |
|---|---|---|---|---|
| Mission Trails Regional Park | City of San Diego | City of San Diego and Mission Trails Regional Park Foundation | San Diego | 5,900 |
| San Diego National Wildlife Refuge | U.S. Fish and Wildlife Service | U.S. Fish and Wildlife Service | San Diego | 44,000 |
| Skunk Hollow | Center for Natural Lands Management | Center for Natural Lands Management | Riverside | 138 |

**Table 2.** Summary of costs associated with each treatment.

| **Treatment** (1x per Season) | ***Average Time** (hours/m$^2$) | **Average Materials** (\$/m$^2$) | ****Estimated Cost** (\$/m$^2$) |
|---|---|---|---|
| Hand-pull | 1.33 | $0.04<br>includes hand tools | $26.60 |
| Fusilade ©II | 0.02 | $0.02<br>herbicide + surfactant, not insurance, spray or safety equipment, training, etc. | $0.42 |
| Mow | 0.29 | $0.07<br>includes hand tools | $5.87 |

*Does not include travel time to and from site

**Assumes wage of $20/hr

**Table 3.** List of species found in experimental plots at Mission Trails in 2009. Percent of plots in which each species occurred are also listed for February 2009 (pre-treatment) and May 2009 (post-treatment).

| | | | | | % of 1-m2 plots with the species present BEFORE Treatments | | | | % of 1-m2 plots with the species present AFTER Treatments | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Family | Genus | Species | Common Name | Native/Exotic | Control | Fusilade | Hand-pull | Mow | Control | Fusilade | Hand-pull | Mow |
| Apiaceae | *Daucus* | *pusillus* | American wild carrot | Native | 68% | 64% | 48% | 52% | 44% | 60% | 56% | 20% |
| Asteraceae | *Centaurea* | *melitensis* | star thistle, tocolote | Exotic | 12% | 24% | 12% | 32% | 8% | 40% | 8% | 20% |
| Asteraceae | *Conyza* | *sp* | Horseweed | Exotic | 0% | 0% | 0% | 0% | 0% | 4% | 0% | 0% |
| Asteraceae | *Corethrogyne* | *filaginifolia* | cudweed aster | Native | 0% | 0% | 4% | 0% | 0% | 0% | 4% | 0% |
| Asteraceae | *Deinandra* | *spp* | tarplant | Native | 8% | 16% | 12% | 8% | 36% | 28% | 24% | 20% |
| Asteraceae | *Filago* | *gallica* | narrow-leaved filago | Exotic | 20% | 36% | 36% | 20% | 8% | 36% | 32% | 12% |
| Asteraceae | *Hypochoeris* | *glabra* | smooth cats-ear | Exotic | 48% | 68% | 76% | 40% | 36% | 68% | 24% | 36% |
| Asteraceae | *Isocoma* | *menziesii* | coastal goldenbush | Native | 0% | 4% | 0% | 4% | 0% | 4% | 0% | 4% |
| Asteraceae | *Lactuca* | *serriola* | prickly lettuce | Exotic | 0% | 0% | 0% | 0% | 0% | 0% | 4% | 0% |
| Boraginaceae | *Cryptantha* | *spp.* | cryptantha | Native | 12% | 0% | 28% | 16% | 0% | 0% | 0% | 0% |
| Brassicaceae | *Brassica* | *geniculata* | short pod mustard | Exotic | 0% | 0% | 12% | 0% | 0% | 4% | 4% | 0% |
| Bryophyta | Moss | | moss | Native | 32% | 36% | 40% | 32% | 0% | 20% | 12% | 20% |
| Caryophyllaceae | *Silene* | *gallica* | windmill pink | Exotic | 4% | 4% | 12% | 4% | 8% | 20% | 20% | 12% |
| Crassulaceae | *Crassula* | *spp* | pygmy-stonecrop | Native | 20% | 32% | 60% | 24% | 4% | 28% | 60% | 12% |
| Cyperaceae | *Eleocharis* | *spp* | spike rush | Native | 28% | 56% | 56% | 16% | 0% | 0% | 0% | 0% |
| Euphorbiaceae | *Croton* | *setigerus* | doveweed | Native | 0% | 0% | 0% | 0% | 0% | 36% | 48% | 20% |
| Fabaceae | *Lotus* | *hamatus* | fish hook lotus | Native | 40% | 0% | 60% | 44% | 8% | 40% | 52% | 20% |
| Fabaceae | *Lotus* | *strigosus* | strigose lotus | Native | 0% | 52% | 0% | 0% | 0% | 0% | 0% | 0% |
| Fabaceae | *Lotus* | *unifoliatus* | Spanish clover | Native | 12% | 16% | 4% | 4% | 8% | 8% | 8% | 0% |
| Fabaceae | *Lupinus* | *bicolor* | miniature lupine | Native | 4% | 0% | 8% | 4% | 0% | 0% | 0% | 0% |
| Fabaceae | *Trifolium* | *spp* | clover | Native | 0% | 0% | 20% | 0% | 0% | 4% | 8% | 0% |
| Gentianaceae | *Centaurium* | *venustum* | canchalagua | Native | 0% | 0% | 0% | 0% | 0% | 8% | 16% | 0% |
| Geraniaceae | *Erodium* | *spp.* | filaree | Exotic | 88% | 96% | 100% | 92% | 96% | 92% | 24% | 92% |
| Liliaceae | *Calochortus* | *spp.* | mariposa lily | Native | 0% | 0% | 0% | 0% | 0% | 0% | 4% | 0% |
| Onagraceae | *Clarkia* | *purpurea* | four-spot clarkia | Native | 0% | 0% | 0% | 0% | 4% | 4% | 4% | 0% |
| Poaceae | *Avena* | *spp.* | wild oats* | Exotic | 0% | 0% | 0% | 0% | 12% | 0% | 4% | 0% |
| Poaceae | *Bromus* | *diandrus* | ripgut grass* | Exotic | 0% | 0% | 0% | 0% | 60% | 0% | 4% | 36% |
| Poaceae | *Bromus* | *hordeaceus* | soft chess* | Exotic | 0% | 0% | 0% | 0% | 100% | 4% | 100% | 100% |
| Poaceae | *Bromus* | *madritensis* | red brome* | Exotic | 100% | 84% | 100% | 100% | 56% | 0% | 32% | 32% |
| Poaceae | *Dichelostemma* | *capitatum* | blue dicks | Native | 0% | 0% | 0% | 4% | 0% | 0% | 0% | 0% |
| Poaceae | *Distichlis* | *spicata* | salt grass | Native | 28% | 36% | 24% | 32% | 68% | 16% | 40% | 48% |
| Poaceae | *Nassella* | *pulchera* | purple needlegrass | Native | 16% | 12% | 20% | 20% | 28% | 8% | 28% | 44% |
| Poaceae | *Vulpia* | *myuros* | rattail fescue | Exotic | 84% | 96% | 100% | 88% | 100% | 100% | 68% | 72% |
| Portulacaceae | *Calandrinia* | *ciliata* | red maids | Native | 4% | 32% | 40% | 8% | 8% | 20% | 36% | 0% |
| Primulaceae | *Anagalis* | *arvensis* | scarlet pimpernel | Exotic | 12% | 12% | 12% | 8% | 0% | 0% | 8% | 0% |
| Scrophulariaceae | *Linaria* | *canadensis* | smaller blue toad flax | Native | 32% | 20% | 56% | 24% | 8% | 16% | 60% | 0% |
| Violaceae | *Viola* | *pedunculata* | Johnny jump-up | Native | 4% | 4% | 0% | 0% | 0% | 0% | 0% | 0% |

* These broader-leaved grasses were difficult to identify in February, when pre-treatment data were collected. Thus, most of the grass species were inadvertently grouped in with *Bromus madritensis*. Data collected in May is more reliable because fruit and/or flowers were present at this time.

**Table 4**. List of species found in experimental plots at SDNWR in 2009. Percent of plots in which each species occurred are also listed for February 2009 (pre-treatment) and May 2009 (post-treatment).

| | | | | | % of 1-m2 plots with the species present BEFORE Treatments | | | | % of 1-m2 plots with the species present AFTER Treatments | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Family | Genus | Species | Common Name | Native/Exotic | Control | Fusilade | Hand-pull | Mow | Control | Fusilade | Hand-pull | Mow |
| Apiaceae | *Daucus* | *pusillus* | American wild carrot | Native | 12% | 24% | 20% | 0% | 4% | 8% | 20% | 0% |
| Asteraceae | *Corethrogyne* | *filaginifolia* | cudweed aster | Native | 0% | 0% | 0% | 0% | 0% | 0% | 4% | 0% |
| Asteraceae | *Deinandra* | *spp.* | tarplant | Native | 0% | 0% | 0% | 0% | 0% | 4% | 0% | 0% |
| Asteraceae | *Filago* | *gallica* | narrow-leaved filago | Exotic | 8% | 44% | 56% | 4% | 0% | 40% | 80% | 4% |
| Asteraceae | *Hypochoeris* | *glabra* | smooth cats-ear | Exotic | 40% | 72% | 72% | 48% | 8% | 68% | 28% | 32% |
| Asteraceae | *Lactuca* | *serriola* | prickly lettuce | Exotic | 0% | 4% | 0% | 0% | 4% | 4% | 8% | 8% |
| Boraginaceae | *Cryptantha* | *spp.* | cryptantha | Native | 28% | 20% | 36% | 16% | 12% | 20% | 28% | 8% |
| Brassicaceae | *Brassica* | *geniculata* | short pod mustard | Exotic | 12% | 40% | 32% | 24% | 12% | 40% | 24% | 8% |
| Brassicaceae | *Sisymbrium* | *orientale* | Oriental hedge mustard | Exotic | 0% | 0% | 0% | 0% | 0% | 8% | 4% | 4% |
| Bryophyta | Moss | | moss | Native | 48% | 12% | 64% | 28% | 4% | 20% | 16% | 0% |
| Caryophyllaceae | *Silene* | *gallica* | windmill pink | Exotic | 44% | 72% | 68% | 40% | 40% | 84% | 52% | 28% |
| Chenopodiaceae | *Salsola* | *tragus* | Russian thistle | Exotic | 0% | 0% | 0% | 0% | 0% | 0% | 4% | 0% |
| Crassulaceae | *Crassula* | *spp.* | pygmy-stonecrop | Native | 32% | 60% | 84% | 28% | 0% | 32% | 60% | 0% |
| Euphorbiaceae | *Croton* | *setigerus* | doveweed | Native | 0% | 0% | 0% | 0% | 20% | 16% | 56% | 24% |
| Fabaceae | *Lotus* | *hamatus* | fish hook lotus | Native | 12% | 0% | 28% | 8% | 4% | 12% | 36% | 4% |
| Fabaceae | *Lupinus* | *bicolor* | miniature lupine | Native | 16% | 36% | 32% | 28% | 4% | 24% | 36% | 4% |
| Fabaceae | *Medicago* | *polymorpha* | bur-clover | Exotic | 0% | 0% | 0% | 0% | 0% | 4% | 0% | 0% |
| Fabaceae | *Trifolium* | *spp.* | clover | Native | 12% | 20% | 32% | 8% | 4% | 12% | 20% | 4% |
| Gentianaceae | *Centaurium* | *venustum* | canchalagua | Native | 0% | 0% | 0% | 0% | 0% | 0% | 4% | 0% |
| Geraniaceae | *Erodium* | *spp.* | filaree | Exotic | 100% | 100% | 100% | 100% | 96% | 100% | 84% | 100% |
| Juncaceae | *Juncus* | *spp.* | toad rush | Native | 0% | 0% | 0% | 0% | 0% | 0% | 16% | 0% |
| Poaceae | *Avena* | *spp.* | wild oats* | Exotic | 0% | 0% | 0% | 0% | 4% | 4% | 0% | 0% |
| Poaceae | *Bromus* | *diandrus* | ripgut grass* | Exotic | 0% | 0% | 0% | 0% | 12% | 0% | 8% | 4% |
| Poaceae | *Bromus* | *hordeaceus* | soft chess* | Exotic | 0% | 0% | 0% | 0% | 64% | 4% | 64% | 56% |
| Poaceae | *Bromus* | *madritensis* | red brome* | Exotic | 100% | 64% | 100% | 100% | 84% | 4% | 40% | 60% |
| Poaceae | *Distichlis* | *spicata* | salt grass | Native | 0% | 0% | 0% | 4% | 4% | 0% | 4% | 4% |
| Poaceae | *Hordeum* | *spp.* | barley | Exotic | 0% | 0% | 0% | 0% | 8% | 0% | 0% | 0% |
| Poaceae | *Nassella* | *pulchera* | purple needlegrass | Native | 0% | 0% | 0% | 0% | 0% | 20% | 0% | 0% |
| Poaceae | *Vulpia* | *myuros* | rattail fescue | Exotic | 84% | 92% | 88% | 80% | 92% | 96% | 56% | 56% |
| Polygonaceae | *Eriogonum* | *fasciculatum* | California buckwheat | Native | 4% | 0% | 0% | 0% | 4% | 0% | 0% | 0% |
| Portulacaceae | *Calandrinia* | *ciliata* | red maids | Native | 8% | 24% | 36% | 12% | 0% | 16% | 20% | 0% |
| Primulaceae | *Anagalis* | *arvensis* | scarlet pimpernel | Exotic | 12% | 28% | 4% | 4% | 4% | 4% | 16% | 0% |
| Scrophulariaceae | *Linaria* | *canadensis* | smaller blue toad flax | Native | 40% | 28% | 24% | 48% | 12% | 4% | 24% | 0% |

* These broader-leaved grasses were difficult to identify in February, when pre-treatment data were collected. Thus, most of the grass species were inadvertently grouped in with *Bromus madritensis*. Data collected in May is more reliable because fruit and/or flowers were present at this time.

**Table 5.** List of species found in experimental plots at Skunk Hollow in 2009. Percent of plots in which each species occurred are also listed for February 2009 (pre-treatment) and May 2009 (post-treatment).

| | | | | | % of 1-m2 plots with the species present BEFORE Treatments | | | % of 1-m2 plots with the species present AFTER Treatments | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Family | Genus | Species | Common Name | Native/Exotic | Control | Hand-pull | Mow | Control | Hand-pull | Mow |
| Portulacaceae | *Calandrinia* | *ciliata* | red maids | Native | 20% | 32% | 28% | 0% | 0% | 0% |
| Euphorbiaceae | *Croton* | *setigerus* | doveweed | Native | 0% | 0% | 0% | 0% | 32% | 8% |
| Boraginaceae | *Cryptantha* | *spp.* | cryptantha | Native | 28% | 32% | 24% | 0% | 0% | 0% |
| Polygonaceae | *Eriogonum* | *gracile* | slender buckwheat | Native | 0% | 0% | 4% | 0% | 0% | 4% |
| Euphorbiaceae | *Euphorbia* | *albomarginata* | rattlesnake spurge | Native | 0% | 0% | 0% | 0% | 4% | 0% |
| Asteraceae | *Lactuca* | *serriola* | prickly lettuce | Exotic | 0% | 0% | 4% | 0% | 0% | 0% |
| Bryophyta | *Moss* | | moss | Native | 44% | 44% | 48% | 0% | 8% | 0% |
| Asteraceae | *Stephanomeria* | *exigua* | wreath-plant | Native | 0% | 0% | 0% | 0% | 4% | 0% |
| Lamiaceae | *Trichostema* | *lanceolatum* | vinegar weed | Native | 0% | 0% | 0% | 0% | 0% | 4% |
| Fabaceae | *Trifolium* | *spp.* | clover | Native | 0% | 4% | 4% | 0% | 4% | 0% |
| Primulaceae | *Anagalis* | *arvensis* | scarlet pimpernel | Exotic | 40% | 44% | 56% | 4% | 12% | 4% |
| Liliaceae | *Calochortus* | *spp.* | mariposa lily | Native | 0% | 0% | 0% | 4% | 0% | 0% |
| Apiaceae | *Daucus* | *pusillus* | American wild carrot | Native | 28% | 48% | 32% | 4% | 20% | 20% |
| Fabaceae | *Lotus* | *hamatus* | fish hook lotus | Native | 4% | 12% | 12% | 4% | 8% | 12% |
| Fabaceae | *Lotus* | *unifoliatus* | Spanish clover | Native | 4% | 0% | 4% | 4% | 0% | 0% |
| Fabaceae | *Lupinus* | *succulentus* | arroyo lupine | Native | 4% | 0% | 4% | 4% | 0% | 0% |
| Malvaceae | *Malvella* | *leprosa* | alkali mallow | Native | 0% | 0% | 0% | 4% | 4% | 4% |
| Fabaceae | *Medicago* | *polymorpha* | bur-clover | Exotic | 0% | 0% | 0% | 4% | 4% | 0% |
| Poaceae | *Nassella* | *pulchera* | purple needlegrass | Native | 4% | 0% | 4% | 4% | 4% | 4% |
| Scrophulariaceae | *Castilleja* | *excerta* | purple owl's clover | Native | 0% | 4% | 4% | 8% | 4% | 8% |
| Asteraceae | *Hypochoeris* | *glabra* | smooth cats-ear | Exotic | 40% | 52% | 20% | 8% | 8% | 8% |
| Caryophyllaceae | *Silene* | *gallica* | windmill pink | Exotic | 16% | 48% | 48% | 8% | 40% | 48% |
| Brassicaceae | *Brassica* | *geniculata* | short pod mustard | Exotic | 8% | 16% | 8% | 12% | 20% | 4% |
| Crassulaceae | *Crassula* | *spp.* | pygmy-stonecrop | Native | 36% | 24% | 36% | 12% | 12% | 24% |
| Polygonaceae | *Eriogonum* | *fasciculatum* | California buckwheat | Native | 20% | 12% | 24% | 16% | 20% | 24% |
| Boraginaceae | *Plagiobothrys* | *spp.* | popcorn flower | Native | 20% | 32% | 44% | 20% | 40% | 20% |
| Plantain | *Plantago* | *erecta* | California plantain | Native | 20% | 20% | 16% | 20% | 20% | 20% |
| Asteraceae | *Centaurea* | *melitensis* | star thistle, tocolote | Exotic | 24% | 24% | 28% | 24% | 8% | 20% |
| Asteraceae | *Filago* | *gallica* | narrow-leaved filago | Exotic | 52% | 76% | 72% | 24% | 80% | 52% |
| Poaceae | *Bromus* | *hordeaceus* | soft chess* | Exotic | 0% | 0% | 0% | 32% | 28% | 28% |
| Boraginaceae | *Amsinckia* | *menziesii* | common fiddleneck | Native | 32% | 44% | 32% | 36% | 32% | 12% |
| Poaceae | *Bromus* | *diandrus* | ripgut grass* | Exotic | 32% | 24% | 32% | 44% | 8% | 12% |
| Asteraceae | *Deinandra* | *spp.* | tarplant | Native | 44% | 80% | 76% | 48% | 76% | 88% |
| Fabaceae | *Lupinus* | *bicolor* | miniature lupine | Native | 72% | 64% | 64% | 48% | 36% | 48% |
| Geraniaceae | *Erodium* | *spp.* | filaree | Exotic | 100% | 96% | 100% | 64% | 80% | 92% |
| Poaceae | *Avena* | *spp.* | wild oats* | Exotic | 56% | 52% | 56% | 76% | 32% | 64% |
| Poaceae | *Bromus* | *madritensis* | red brome* | Exotic | 88% | 68% | 84% | 76% | 64% | 68% |
| Poaceae | *Vulpia* | *myuros* | rattail fescue | Exotic | 80% | 100% | 96% | 84% | 60% | 76% |

**Table 6.** Mean (± 1 SE) values of soil properties among the three different sites: San Diego National Wildlife Refuge, Mission Trails Regional Park, and Skunk Hollow Preserve. Each mean is the average of five soil samples. Soil property means followed by different letters denote significant differences among sites ($\alpha = 0.05$).

| | LOCATION | | | |
|---|---|---|---|---|
| Soil Properties | SDNWR | Mission Trails | Skunk Hollow | P-values |
| % Organic matter | 1.98 ± 0.16[a] | 1.94 ± 0.11[a] | 1.28 ± 0.20[b] | P = 0.02 |
| pH | 6.34 ± 0.06 | 6.12 ± 0.12 | 6.54 ± 0.14 | P = 0.07 |
| Soluble Salts (mmho/cm) | 0.13 ± 0.02 | 0.096 ± 0.002 | 0.14 ± 0.03 | P = 0.74 |
| Nitrate-N (ppm) | 3.2 ± 1.38[a] | 0.5 ± 0.00[b] | 0.5 ± 0.00[b] | P = 0.03 |
| Ammonium-N (ppm) | 9.2 ± 1.16 | 6.2 ± 0.58 | 8.0 ± 1.05 | P = 0.13 |
| Phosphorus (ppm) | 21.4 ± 7.83[a] | 6.0 ± 0.00[b] | 37.6 ± 7.71[a] | P = 0.01 |
| Potassium (ppm) | 298.8 ± 58.82[a] | 134.6 ± 18.15[b] | 113.4 ± 15.56[b] | P = 0.01 |
| Sulfur (ppm) | 8.0 ± 0.89 | 6.2 ± 0.20 | 6.4 ± 0.24 | P = 0.10 |
| Calcium (ppm) | 940.0 ± 38.42 | 1035.20 ± 31.26 | 1309.6 ± 270.47 | P = 0.47 |
| Magnesium (ppm) | 139.6 ± 9.09 | 228.8 ± 21.05 | 271.2 ± 70.16 | P = 0.11 |
| Sodium (ppm) | 21.80 ± 2.06 | 26.00 ± 2.19 | 20.20 ± 1.32 | P = 0.12 |
| Zinc (ppm) | 3.4 ± 0.30[a] | 2.16 ± 0.12[b] | 0.96 ± 0.12[c] | P < 0.01 |
| Iron (ppm) | 47.52 ± 8.90 | 41.16 ± 4.42 | 26.68 ± 5.00 | P = 0.10 |
| Manganese (ppm) | 37.48 ± 6.86 | 29.72 ± 1.94 | 21.04 ± 2.17 | P = 0.06 |
| Copper (ppm) | 1.64 ± 0.12[a] | 1.80 ± 0.46[a] | 0.68 ± 0.45[b] | P = 0.01 |
| Cation Exchange Capacity | 6.8 ± 0.50 | 7.8 ± 0.58 | 9.0 ± 2.02 | P = 0.48 |


**Figure 1**. Google Earth image of our three sites in southern California: Skunk Hollow Preserve, Mission Trails Regional Park, and San Diego National Wildlife Refuge (SDNWR). Both MT and SDNWR are located in San Diego County close to the US/ Mexico boarder, whereas SH is in western Riverside County.

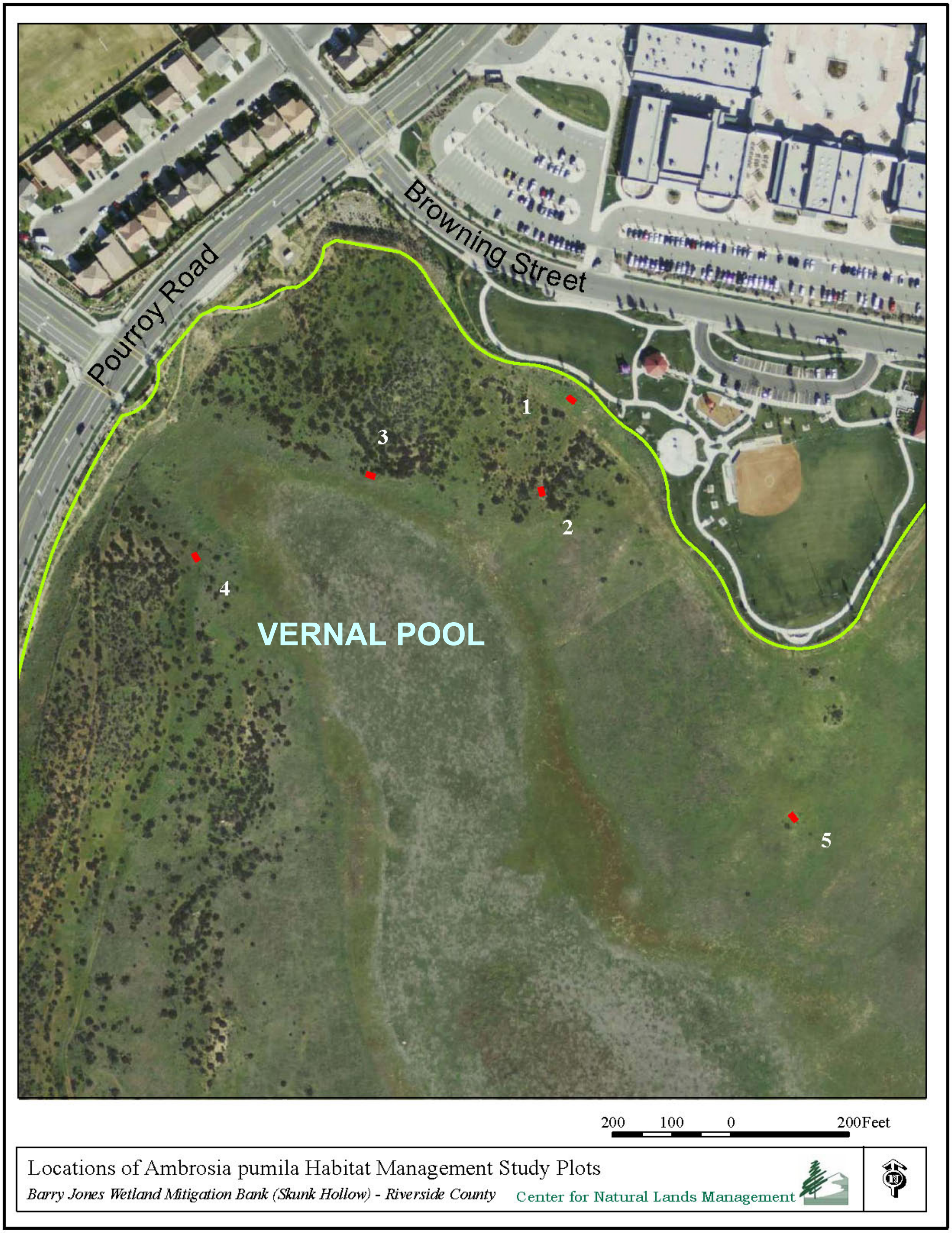
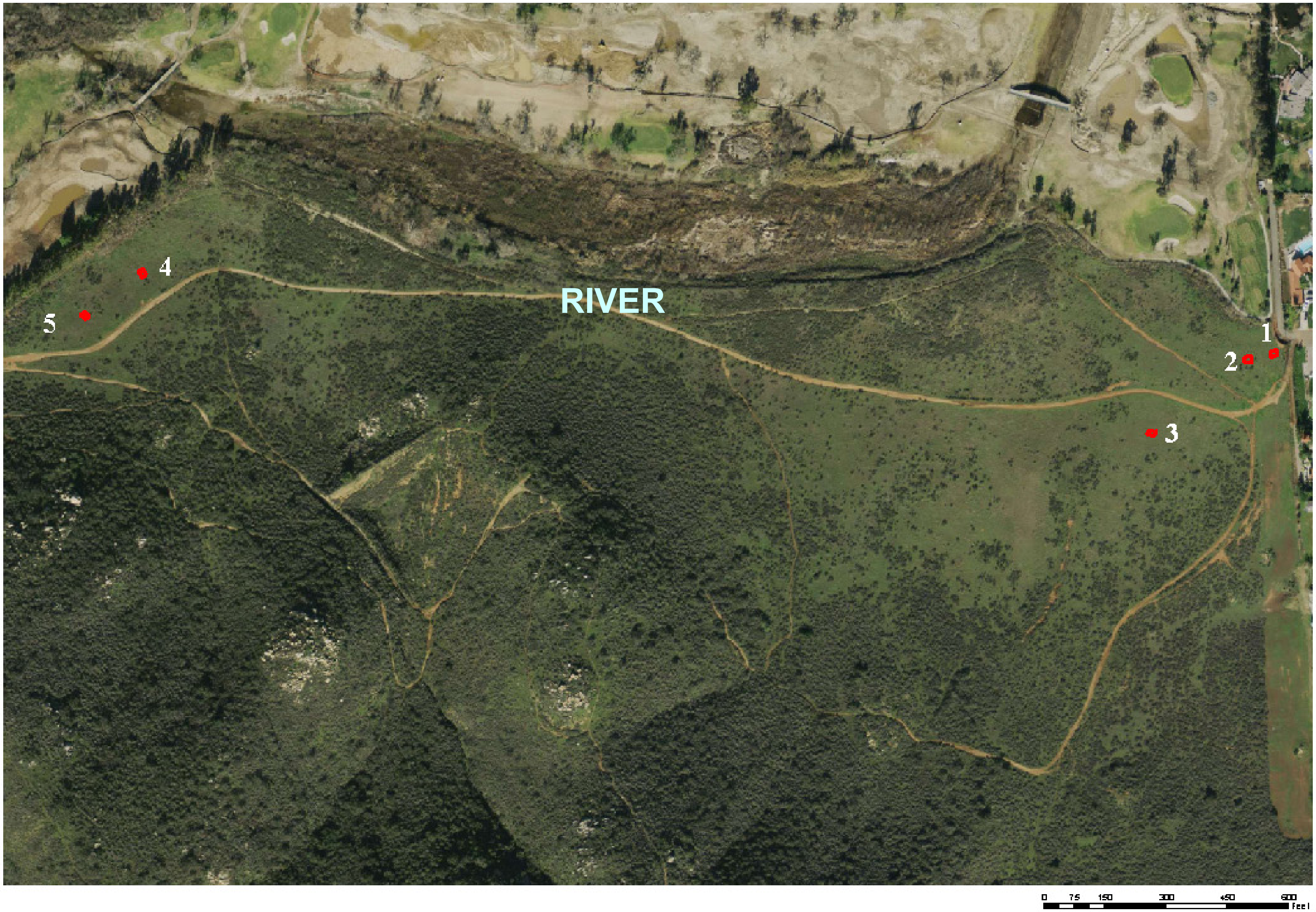



**Figure 2.** Aerial photograph with experimental plot locations at Skunk Hollow Preserve.


**Figure 3.** Aerial photograph with experimental plot locations at Mission Trails Regional Park.




**Locations of *Ambrosia pumila* Habitat Management Study Plots**
San Diego National Wildlife Refuge, San Diego County

Center for Natural Lands Management

**Figure 4.** Aerial photograph with experimental plot locations at San Diego National Wildlife Refuge.

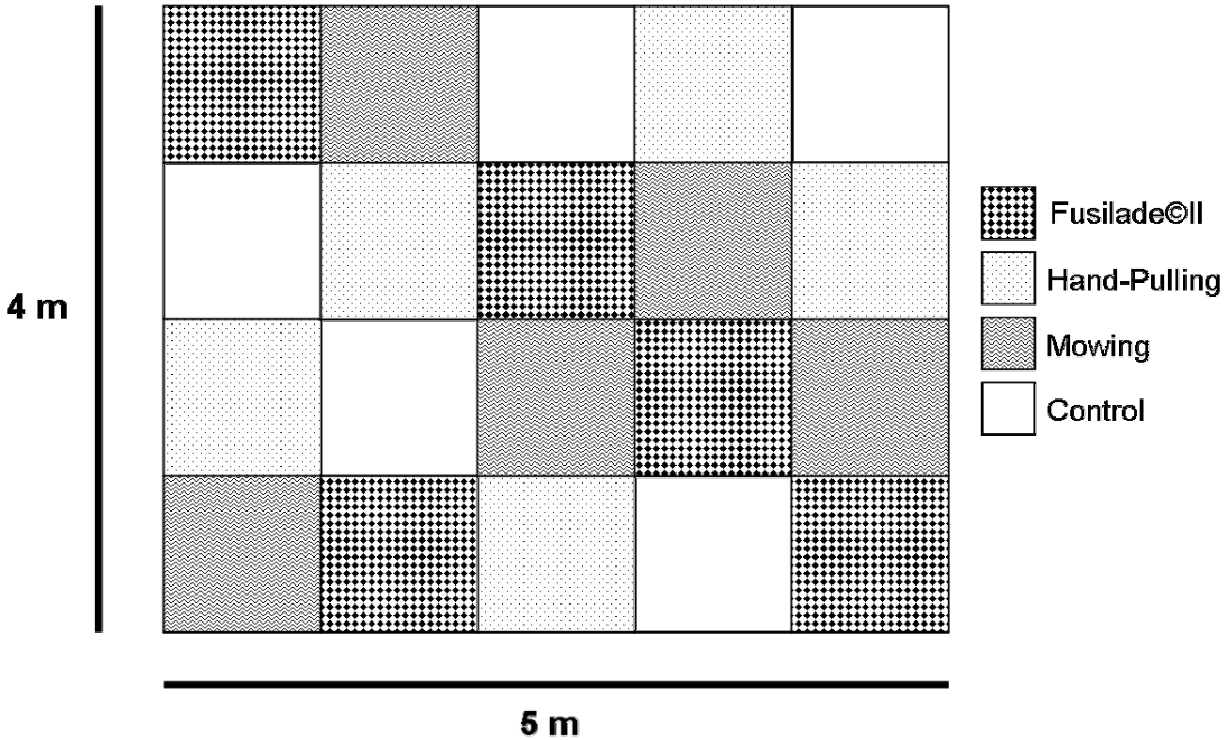



**Figure 5**. Diagram of one of the replicated blocks used at MT and SDNWR. Each block consisted of 20, 1-m$^2$ plots with four treatments replicated five times. Treatments included hand-pulling, application of Fusilade ©II, mowing, and a control. At SH, Fusilade ©II was not applied and therefore replicated blocks there consisted of 15, 1-m$^2$ plots. There were a total of five replicated blocks at each site.

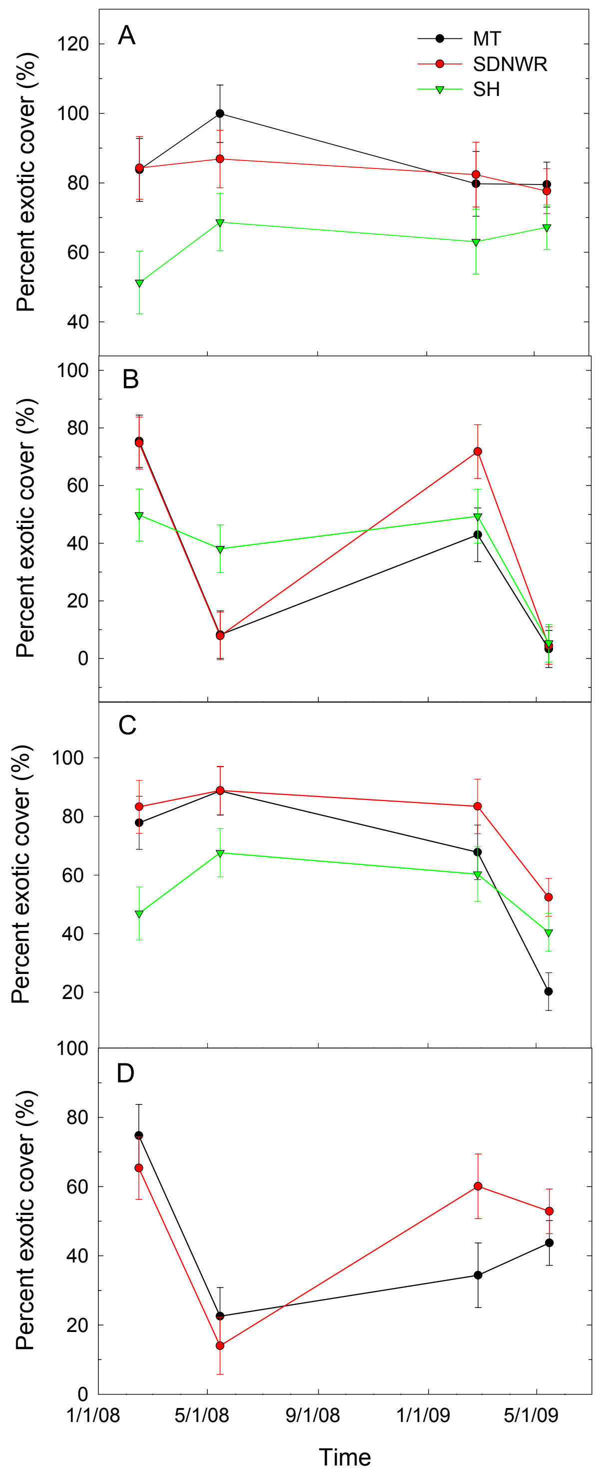



**Figure 6**. Percent exotic cover at MT, SDNWR, and SH from February 2008 to May 2009. Treatments included (A) control, (B) hand-pulling, (C) mow, and (D) Fusilade ©II. Treatments were applied in late February/early March of 2008 and 2009. Values represent mean and 95% confidence intervals (N = 5 per sampling date); thus, if confidence intervals overlap, values are not significantly different (α = 0.05).

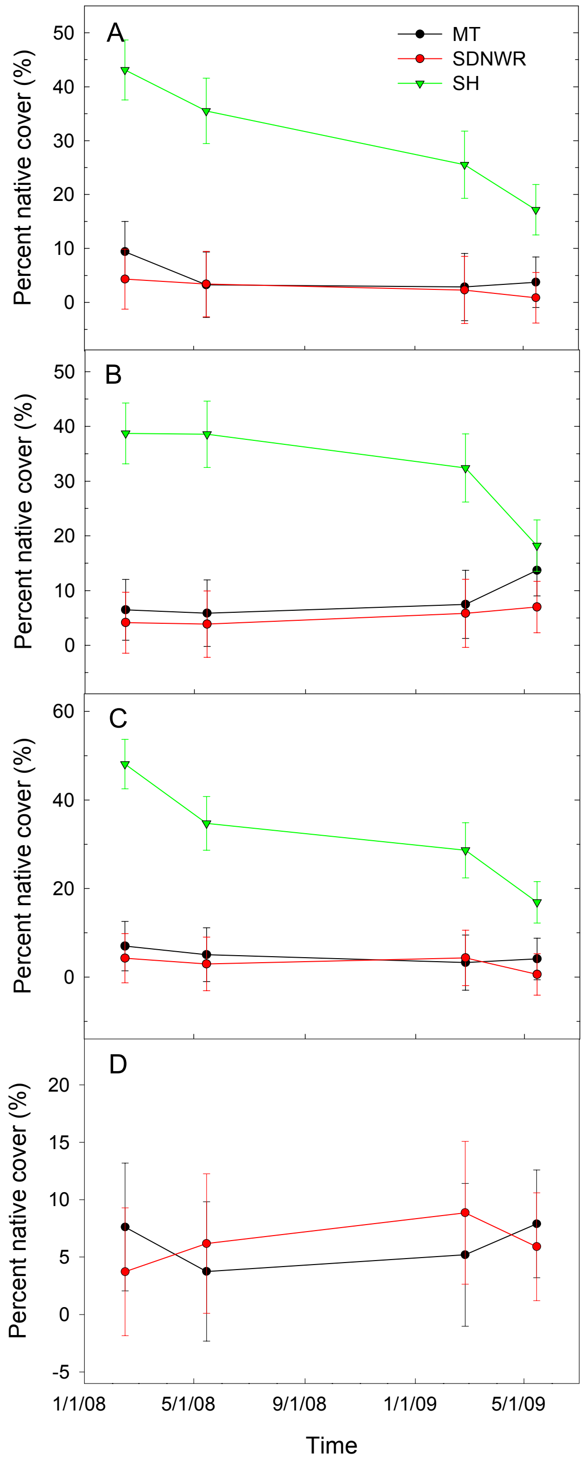



**Figure 7**. Percent native cover at MT, SDNWR, and SH from February 2008 to May 2009. Treatments included (A) control, (B) hand-pulling, (C) mow, and (D) Fusilade ©II. Treatments were applied in late February/early March of 2008 and 2009. Values represent mean and 95% confidence intervals (N = 5 per sampling date) ; thus, if confidence intervals overlap, values are not significantly different (α = 0.05).

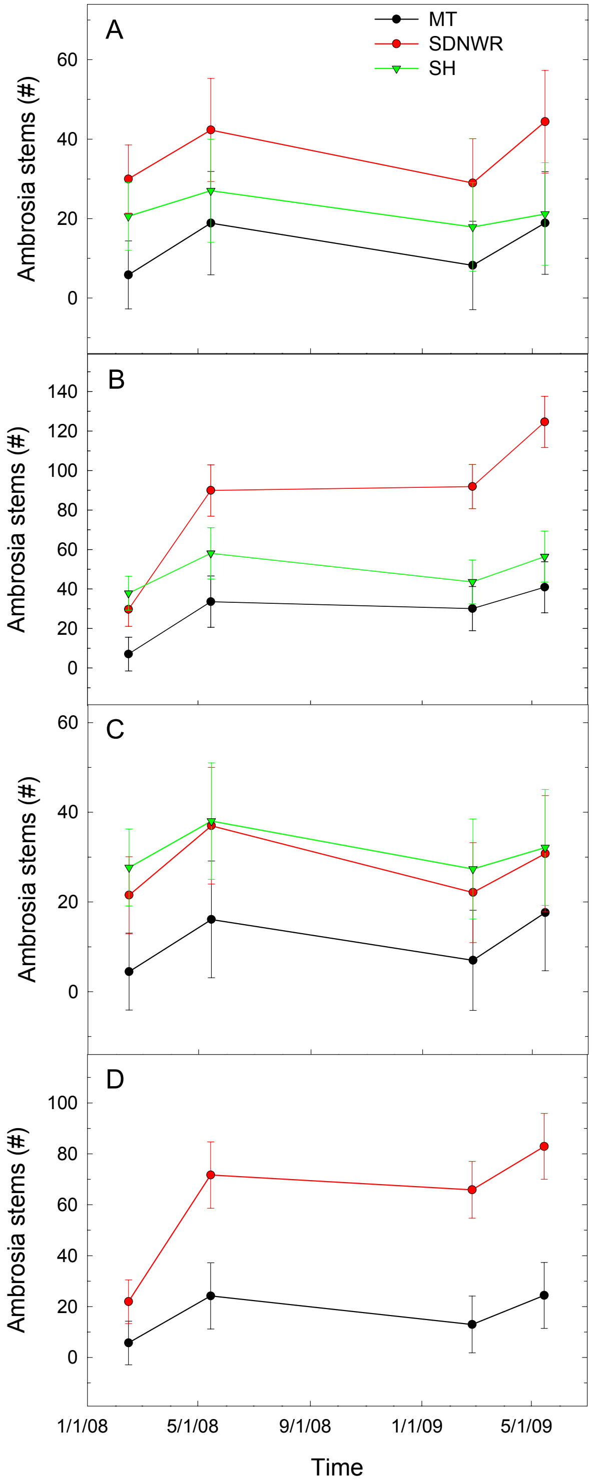



**Figure 8**. The number of *Ambrosia pumila* stems at MT, SDNWR, and SH from February 2008 to May 2009. Treatments included (A) control, (B) hand-pulling, (C) mow, and (D) Fusilade ©II. Treatments were applied in late February/early March of 2008 and 2009. Values represent mean and 95% confidence intervals (N = 5 per sampling date); thus, if confidence intervals overlap, values are not significantly different (α = 0.05).

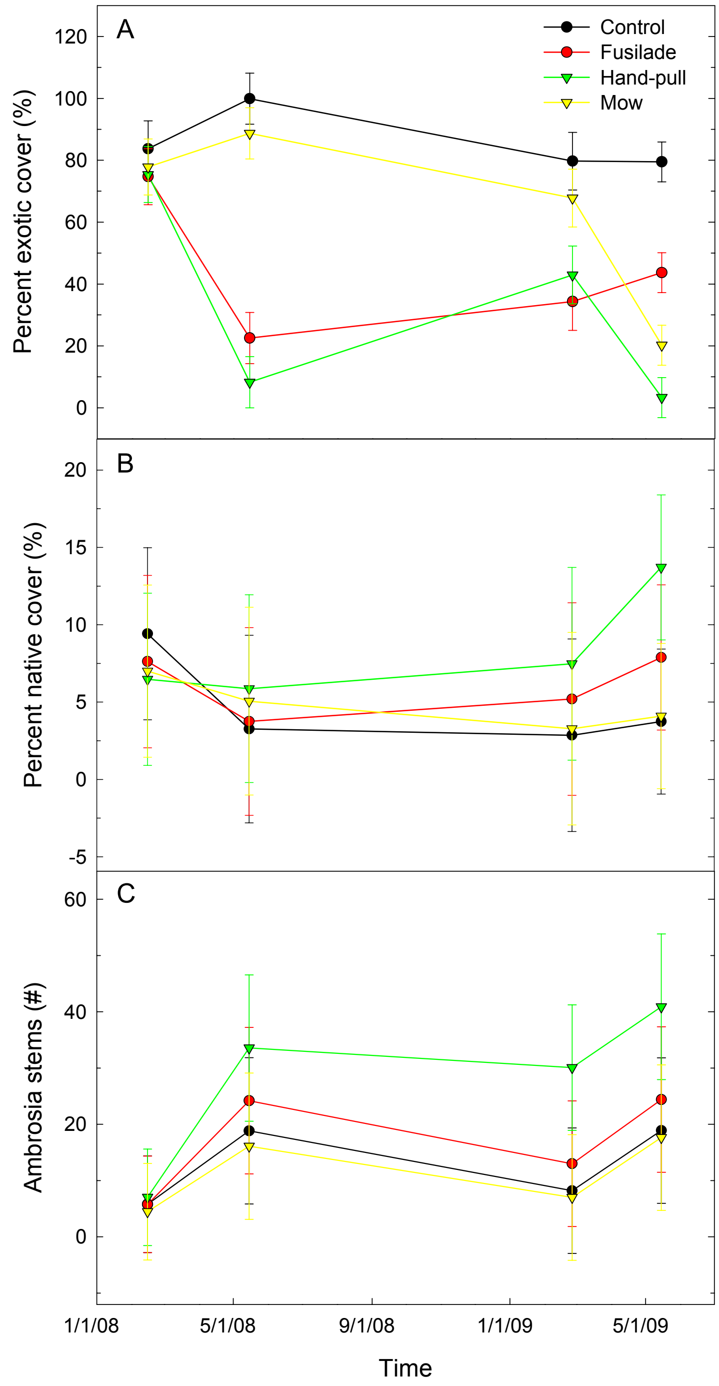



**Figure 9**. Change in (A) percent exotic cover, (B) percent native cover, and (C) the number of *A. pumila* stems at Mission Trails. Treatments included a control, application of Fusilade ©II, hand-pulling of exotic species, and mowing. Treatments were applied in late February/early March of 2008 and 2009. Values represent mean and 95% confidence intervals (N = 5 per sampling date); thus, if confidence intervals overlap, values are not significantly different (α = 0.05).

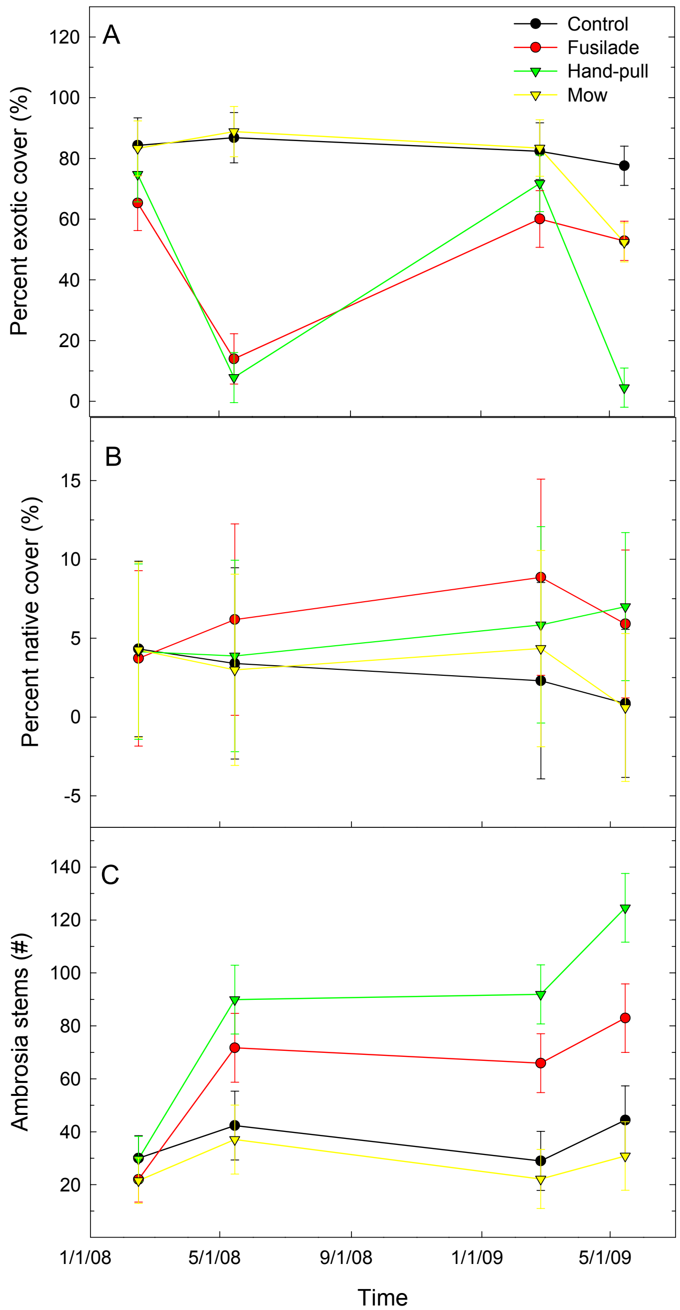



**Figure 10**. Change in (A) percent exotic cover, (B) percent native cover, and (C) the number of *A. pumila* stems at San Diego National Wildlife Refuge. Treatments included a control, application of Fusilade ©II, hand-pulling of exotic species, and mowing. Treatments were applied in late February/early March of 2008 and 2009. Values represent mean and 95% confidence intervals (N = 5 per sampling date); thus, if confidence intervals overlap, values are not significantly different (α = 0.05).

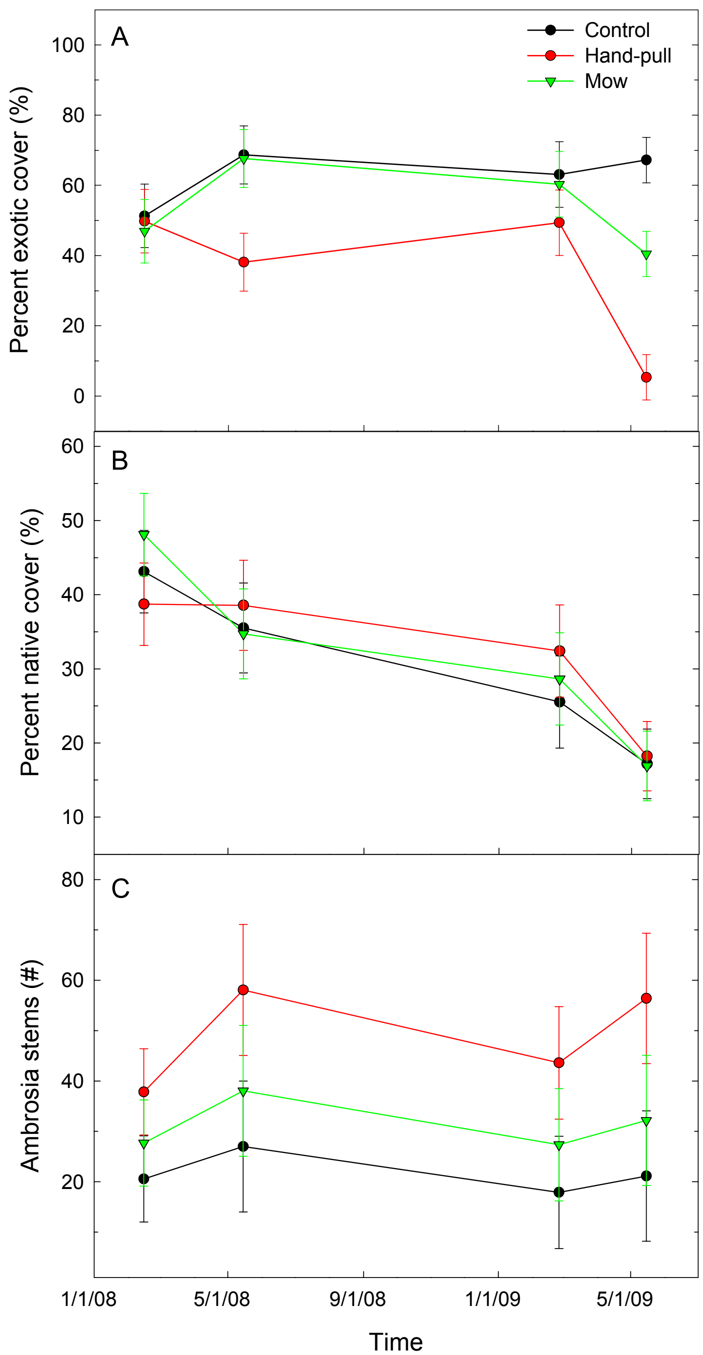



**Figure 11**. Change in (A) percent exotic cover, (B) percent native cover, and (C) the number of *A. pumila* stems at Skunk Hollow. Treatments included a control, hand-pulling of exotic species, and mowing. Treatments were applied in late February/early March of 2008 and 2009. Values represent mean and 95% confidence intervals (N = 5 per sampling date); thus, if confidence intervals overlap, values are not significantly different ($\alpha = 0.05$).

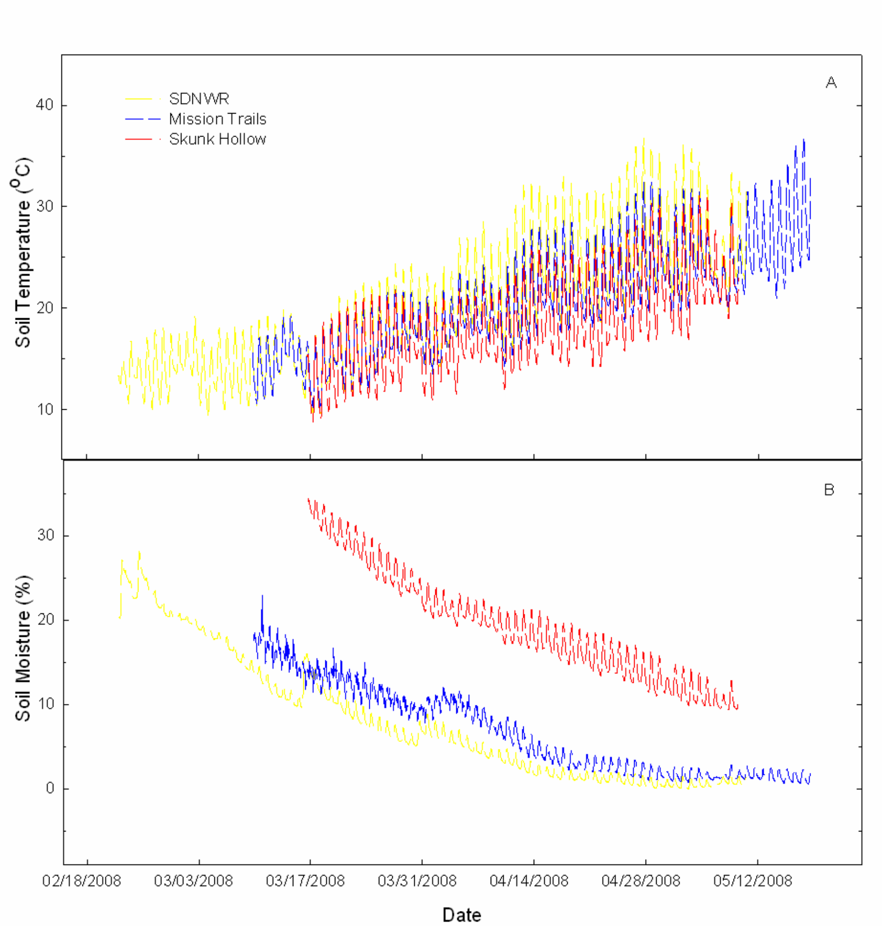



**Figure 12**. Mean soil temperature (A) and soil moisture (B) among the three sites; San Diego National Wildlife Refuge (SDNWR), Mission Trails Regional Park, and Skunk Hollow Preserve. Both temperature and moisture were continuously monitored at a soil depth of 5 cm.


**Figure 13.** A close-up photograph of two 1-$m^2$ treatment plots at Mission Trails. The plot outlined in yellow was treated with Fusilade ©II, while the plot outlined in red had all of the non-native plants hand-pulled and all treated biomass was removed from the plot. Note the dead biomass remaining in the plot treated with Fusilade ©II.