The Feasibility of Chaparral Restoration on Type-Converted Slopes[1]

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Abstract

Increased fire frequency, livestock grazing, and other disturbances have converted many chaparral stands in southern California to non-native annual grassland. Competition from annual grasses interferes with the establishment of chaparral shrubs, presenting a challenge to restoring chaparral in type-converted areas.

In this study we examined the feasibility of restoring chaparral by exploring several methods of restoration on type-converted slopes in San Timoteo Canyon, Riverside County, California. We assessed the effectiveness of a broad-spectrum herbicide (glyphosate) and a grass-specific herbicide (fluazifop-p-butyl) in facilitating shrub establishment. In addition, we compared the success of seeding and planting containerized shrub seedlings as methods of restoration and examined the soil seed bank to see if there was a relict seed bank that could be manipulated to promote restoration. The broad-spectrum herbicide application significantly increased soil moisture and the successful establishment of transplanted seedlings. The grass-specific herbicide, applied later in the season, was less effective. Seeding was unsuccessful, most likely due to low rainfall during the study, and few germinable seeds of native chaparral species were detected in the grassland soil.

Keywords: chaparral, restoration, type-conversion, glyphosate, fluazifop, grass competition, seed bank.

Introduction

In southern California, type conversion of chaparral to non-native annual grassland has occurred on many landscapes due to disturbances such as frequent fire and livestock grazing. Deliberate conversion of chaparral to grassland for purposes such as improving grazing land and wildlife habitat is a long-standing practice that may pre-date European settlement (e.g., Keeley 2002). The USDA Forest Service pursued type-conversion beginning in the late 1950s for these and other purposes (e.g., providing fuel breaks; Bentley 1967, Tyrrel 1982). Fire frequency increased during the 20th century due to increases in human-caused ignitions, especially at the wildland-urban interface (Keeley et al. 1999, Rundel and King 2001, Keeley and Fotheringham 2003). Short fire-return intervals can extirpate chaparral shrub species

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by killing obligate seeders before they mature, and extremely short fire-return intervals reduce the ability of resprouters to recover (Zedler et al. 1983, Halsey 2005 and references therein). Colonization of burned or disturbed areas by non-native annual grasses consequently leads to a positive feedback cycle that further increases fire frequency, increases competitive suppression of natives, and alters ecosystem structure and function (Zedler et al. 1983, D'Antonio and Vitousek 1992, Minnich and Dezzani 1998, Stylinski and Allen 1999, DiTomaso 2000, Cione et al. 2002, Syphard et al. 2006).

It has been recognized that converting chaparral to non-native grassland may incur costs. On steep slopes, grasses are less effective than shrubs at preventing land slips after heavy rains (Corbett and Rice 1966). Chaparral shrubs vary in rooting habit (Helmers et al. 1955), but because they are generally much more deeply rooted, they are more effective at preventing slope failure than the annual grasses (Rice et al. 1969). From a different perspective, increasing recognition of threats to global biodiversity and of the unique native flora of California has led to many attempts to restore native systems. Restoring slow-growing shrubs in areas dominated by fast-growing annual grasses, however, can be challenging

In California, non-native annual vegetation often outcompetes shrub and tree seedlings for limited summer soil moisture, thereby preventing woody plant establishment (e.g., Gordon et al. 1989, Williams and Hobbs 1989, Eliason and Allen 1997). As a result, research into restoring shrublands, such as coastal sage scrub, has often incorporated tests of methods for reducing grass competition. These methods have included weeding, mowing, disking, soil solarization, and employing grass-specific herbicides (Allen et al. 2000, Cione et al. 2002, Cox and Allen 2008, Marushia and Allen 2011). Grass-specific herbicides offer attractive options in restoration because their specificity allows managers to treat areas without threatening most restoration plantings. They do not control invasive broad-leaf weeds, however, which may also suppress restoration plantings. In contrast, common broad-spectrum herbicides, such as glyphosate, cannot be applied easily after desirable shrubs or forbs emerge or are planted. We explored a combined approach to suppressing non-native competitors by using a broad-spectrum herbicide prior to planting and a grass-specific herbicide after planting to control late-germinating grass cohorts.

The overall goal of this study was to explore the feasibility of restoring chaparral on type-converted slopes by (1) comparing the effectiveness of a grass-specific herbicide (fluazifop) to that of a broad-spectrum herbicide (glyphosate) with a fluazifop follow-up in facilitating chaparral restoration, (2) comparing the effectiveness of seeding and planting containerized seedlings as methods of restoration, and (3) determining whether a relict chaparral seed bank existed on the site that could be manipulated for restoration.

Study Area

Research was conducted on an ecological preserve owned by the Riverside Land Conservancy in San Timoteo Canyon, Riverside County, California (33° 58.252' N, -117° 3.986' W). Historic land use of the San Timoteo Canyon has dramatically altered the natural habitats in the canyon and the preserve. Prior to European colonization, the Cahuilla tribe occupied areas of the canyon (Christian 2002). Early settlers, in the 1850s, used the canyon for raising and grazing livestock, grain and hay farming, dairy operations, beekeeping, and citrus groves. The grazing and agricultural practices led to type-conversion from native shrubs to non-native annual grasslands and cropland. Historic aerial photographs show that many hillsides in the canyon were once covered by chaparral; now they are covered primarily by non-native annual grasses. Agricultural operations continued late into the 20th century, until the land was purchased and subdivided into residential development projects, state parks, and county parks (Knecht 1971, Christian 2002).

On the preserve where this study was conducted, agricultural practices began in approximately 1875 and ceased in 2003 when the Riverside Land Conservancy obtained the property (Jack Easton, Riverside Land Conservancy, pers. comm. 18 Nov. 2013). The study site supports remnant chaparral stands on ridge tops that are dominated by *Adenostoma fasciculatum* Hook. & Arn., *Eriogonum fasciculatum* Benth., *Artemisia californica* Less., *Rhus aromatic* Aiton, *Rhamnus crocea* Nutt., *Rhus ovata* S. Watson, and *Quercus berberidifolia* Liebm. Our experiments were conducted on west-facing grass-dominated hillsides with slopes of 35-60 percent, at an elevation of approximately 650 m.

Methods

Effectiveness of various manipulations on chaparral shrub establishment was investigated in a factorial experiment. Treatments consisted of four restoration methods (no restoration treatment, smoke-water application, applying seeds of chaparral shrubs, and planting container stock) across three herbicide applications (no herbicide, glyphosate with a follow-up fluazifop application [glyphosate + fluazifop follow-up], and only fluazifop). The smoke-water treatment was applied in an attempt to stimulate the germination of smoke-responsive seeds in the soil seed bank at the site (Roche et al. 1997). The resulting 12 treatments were replicated three times in a randomized block design. Treatments were applied in plots measuring 2 x 2 m, except for plots in which containerized seedlings were planted, which measured 2 x 5 m.

Herbicide Application

Glyphosate plots were treated with Ranger® PRO[1] (Monsanto Co.) at a rate of 2.34 L ha^{-1} (1.123 kg glyphosate ha^{-1}). For plots seeded in mid-December, glyphosate was applied within 24 hours of seeding; for other plots glyphosate was applied on 23 Jan 2013. The fluazifop-only and the glyphosate + fluazifop follow-up plots were treated with Fusilade®II (Syngenta, Inc.) after restoration treatments were applied (below) and when grasses were more active, on 6 Mar 2013, at a rate of 1.32 L ha^{-1} (316 g fluazifop-P-butyl ha^{-1}) with 0.5% surfactant (Activator 90). Herbicide was applied via backpack sprayer with an 8004 vs nozzle.

Seed Application

Seeds of chaparral shrubs (*Adenostoma fasciculatum* Hook. & Arn., *Gutierrezia sarothrae* (Pursh) Britton & Rusby, *Quercus berberidifolia* Liebm., *Rhus aromatica* Aiton, and *Rhus ovata* S. Watson) were purchased from Wild California, a local

[1] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

wholesale nursery. Additionally, seeds of two shrub species more characteristic of coastal sage scrub or early successional environments (*Artemisia californica* Less. and *Eriogonum fasciculatum* Benth.) were purchased and included in the seed mix for comparison. Four of these species were pre-treated by Wild California staff. *Adenostoma* seed received 24 hour soak in liquid chamise smoke, which was prepared by Wild California staff. *Quercus* received cold stratification, and both *Rhus* species received an acid wash.

Eight acorns were planted in each seeded plot, with other species being sown at 4-9 kg seed ha^{-1} to yield an overall rate of 35 kg pure seed ha^{-1}. Seeding rates from 2.2-33 kg ha^{-1} have been used in restoration: the seeding rate is dependent on species, size of seed, and the number of species being used (e.g. DeSimone 2011; CalTrans 2012). Seeds were sown on 14 Dec 2012. Seeds of the two *Rhus* species and the oak were distributed into a shallow ditch and then tamped down. Soil "packing," or tamping, guarantees good seed-soil contact and maintains soil moisture (Morgan 1997). The other, smaller seeds were broadcast over the plot by hand.

Containerized Seedling Installation

Containerized seedlings of *Adenostoma fasciculatum, Eriogonum fasciculatum, Quercus berberidifolia,* and *Rhus ovata* were purchased from Wild California, Recon Native Plants, Rancho Santa Ana Botanic Garden, and Riverside-Corona Resource Conservation District. Plants were in 1-gallon pots except for *Rhus ovata* seedlings, which were only available in 2-gallon pots, and the *Quercus* seedlings, which were only available in deep bullet pots.

There were two planting dates due to the timing of herbicide application. Plots scheduled to receive fluazifop only (a grass-specific herbicide) were planted as early in the season as the onset of winter rains allowed. Plots scheduled to be treated with glyphosate (a broad-spectrum herbicide) were not planted until after glyphosate application. The fluazifop and no-herbicide plots were planted on 20 Dec 2012. The glyphosate + fluazifop follow-up plots were planted on 30 Jan 2013. Each 2 x 5 m plot was planted with three *Adenostoma* seedlings (aside from one plot that was planted with 2 due to limited seedling availability), five *Eriogonum* seedlings, five *Quercus* seedlings and five *Rhus ovata* seedlings. Shallow basins were dug adjacent to each seedling to facilitate subsequent watering. The plots that received seedlings were watered once or twice a month as needed, at a rate of 1 L per plant, throughout the remaining winter and spring season.

Plots were surveyed every 2-3 weeks for seedling survival. At the same time, the height and width of each plant was measured. Live plant canopy volume was then calculated as the volume of a spheroid from the height and width measurements.

Effects of Herbicide and Planting on Soil Moisture

To assess the effect of herbicide treatments on soil water status, soil samples were collected in April 2013 from all three herbicide treatments in plots with no restoration treatment and in plots planted with containerized seedlings. The latter plots had received supplemental water due to periodic irrigation of seedlings and had last been watered nine days prior to soil sampling. Within each plot, duplicate samples were collected from each of three depths: 0-5 cm, 5-15 cm, and 15-30 cm. Each sample was homogenized separately, then a 117 cm^3 aliquot was taken from the homogenized sample and placed in an air-tight soil tin. Each sample was weighed prior to drying at 105°C for 8 days and immediately after drying.

Seed Bank Assessment

To determine whether a relict chaparral seed bank remained on the site, soil samples were collected from the research site in November 2012, prior to any winter rains. A soil core tool (6 cm in diameter) was used to obtain the samples to a depth of 4 cm. Soil samples were collected at 1-meter intervals along transects between plots. The samples from each block of plots were homogenized and passed through a 4 mm sieve to remove large rocks and pebbles.

To stimulate the germination of as many species as possible, soil was subjected to four treatments. One quarter of the soil from each block was exposed to heat (105°C for 5 minutes) then smoke water, one quarter was treated with smoke water only (no heat), one quarter was treated with 500 ppm gibberellic acid, and one quarter received deionized water (no treatment). Smoke water was generated by bubbling smoke through 20-liter jugs of water for one hour (Roche et al. 1997). Aliquots of approximately 120 cm^3 of soil were spread to a depth of 3 mm in flats on top of a 50:50 mixture of sand and seed starting mix and watered with either 55 mL of 10% smoke water, 55 mL of 500 ppm gibberellic acid, or 55 mL of deionized water. After 24 hours, flats were placed under an automatic mist system, receiving a mist of deionized water for 3 minutes every 8 hours.

As seedlings germinated, representatives of each species were transplanted into 4-inch pots for further growth and identification. Unknown species were identified using *T*he *Jepson Manual, Vascular Plants of California, Second Edition* (Baldwin et al. 2012).

In the field, smoke water was applied to the soil in an attempt to stimulate the germination of smoke-responsive seeds from any relict chaparral seed bank. Smoke water was applied to the soil at a rate of 1 L m^{-2} (Roche et al. 1997) on 17 Dec 2012.

Statistical Analyses

Differences in seedling survival among herbicide treatments were tested with a series of pairwise comparisons using Fisher's Exact Test. Species were analyzed separately. Due to low sample sizes, data from all three blocks were combined for this analysis.

Effects of block and herbicide treatment on plant size of survivors were analyzed with a two-way ANOVA (GLM ANOVA, MiniTab® 16 Statistical Software). Species were analyzed separately. To better test for herbicide effects on growth, we then compared sizes of only the ten largest plants of each species in each treatment. This approach eliminates the potential bias introduced by differential survival of individuals of different sizes (i.e., the tendency of smaller plants to die in more stressful environments and survive in more benign environments). Because this approach limits sample size, data from all three blocks were combined for each species and subjected to one-way ANOVAs followed by Tukey's tests (MiniTab® 16 Statistical Software).

Differences in soil water content across blocks, across herbicide treatments, and between restoration treatments (planted vs. no restoration treatment) were analyzed with three-way nested ANOVAs (GLM ANOVA, MiniTab® 16 Statistical Software).

Depth increments were analyzed separately, and duplicate samples were nested within plots.

Results

Impacts of Herbicide Treatment on Seeding Success

Seed application was not effective. Casual observation of animal disturbance indicated that some seeds, especially of *Quercus*, were lost to seed predation. The one seedling that was observed (an oak) died within a month of emergence. This seedling emerged in a fluazifop-only plot. No other seedling emergence was observed for any of the other species during the spring after seeding.

Impacts of Herbicide Treatment on Containerized Seedling Success

By mid-May 2013, mortality of *Adenostoma* and *Quercus* was lower in the glyphosate + fluazifop follow-up treatment than in the control or in the fluazifop-only treatments (fig. 1). Mortality among seedlings of *Rhus ovata* and *Eriogonum* was still quite low by mid-May, but effects of the glyphosate + fluazifop follow-up treatment were apparent in the growth of *Eriogonum* (fig. 2).

Because so few individuals of *Adenostoma* and *Quercus* survived in the control treatment, their growth was not analyzed. For all survivors of *Eriogonum* and *R. ovata*, two-way ANOVAs revealed no effect of block on plant size and no interaction between block and herbicide treatment. Comparison of the ten largest plants of *R. ovata* in each treatment revealed no significant effect of herbicide treatment on plant size ($p=0.421$, $df= 2$, $F= 0.89$; fig. 2). However, for *Eriogonum*, live canopy volume was much larger for the ten largest plants in the glyphosate + fluazifop follow-up treatment than for the ten largest plants in any other treatment ($p= 0.00$, $df= 2$, $F= 49.31$; fig. 2).

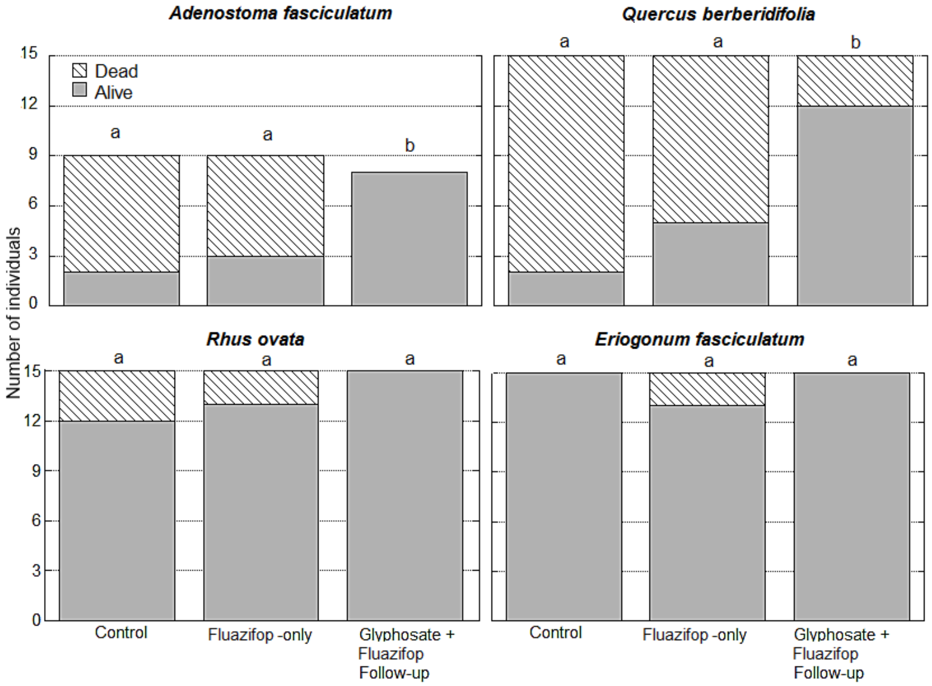

Figure 1–Survival of containerized seedlings in the different herbicide treatments. For each species bars sharing the same letter are not significantly different at p<0.05 according to Fisher's exact test.

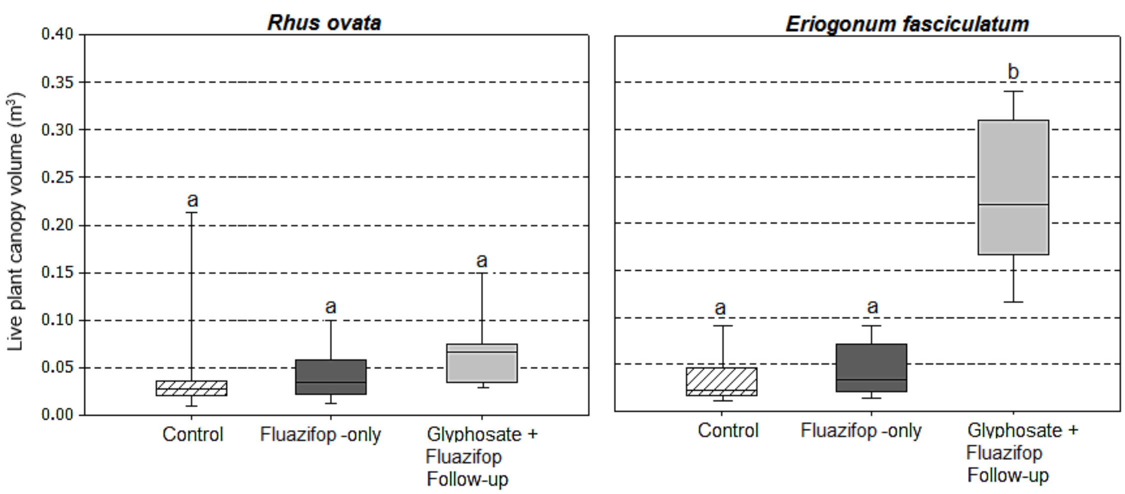

Figure 2–Live plant canopy volume (m^3) in mid-May of the 10 largest individuals from each treatment for *Rhus ovata* and *Eriogonum.* The medians, upper and lower quartiles, and ranges are shown. For each species bars sharing the same letter are not significantly different at p<0.05 according to Tukey's test.

Impacts of Herbicide on Gravimetric Soil Water Content

Gravimetric soil water content in the glyphosate + fluazifop follow-up treatment was significantly higher than in the control and in the fluazifop-only treatments (p<0.01; fig. 3, table 1). There were no significant differences in soil water content between control and fluazifop-only plots at any soil depth ($p < 0.05$, Tukey's test). There was no significant difference in gravimetric soil water content between control plots and those that were planted and given supplemental water at any soil depth (table 1).

Table 1—Three-way nested ANOVA results for gravimetric soil water content. Depth increments were analyzed separately

		0-5 cm		5-15 cm		15-30 cm	
Source	**df**	**F**	**P**	**F**	**P**	**F**	**P**
Block (B)	2	3.34	0.06	18.22	0.00	27.65	0.00
Planting (P)	1	0.00	0.99	0.27	0.61	0.00	0.95
Herbicide (H)	2	17.99	0.00	145.89	0.00	166.43	0.00
B x P	2	0.40	0.68	1.26	0.31	0.91	0.42
P x H	2	0.10	0.90	0.86	0.44	4.01	0.04
B x H	4	3.22	0.04	1.02	0.43	3.42	0.03
B x P x H	4	0.38	0.82	1.70	0.19	3.08	0.04
Error	17						
Total	34						

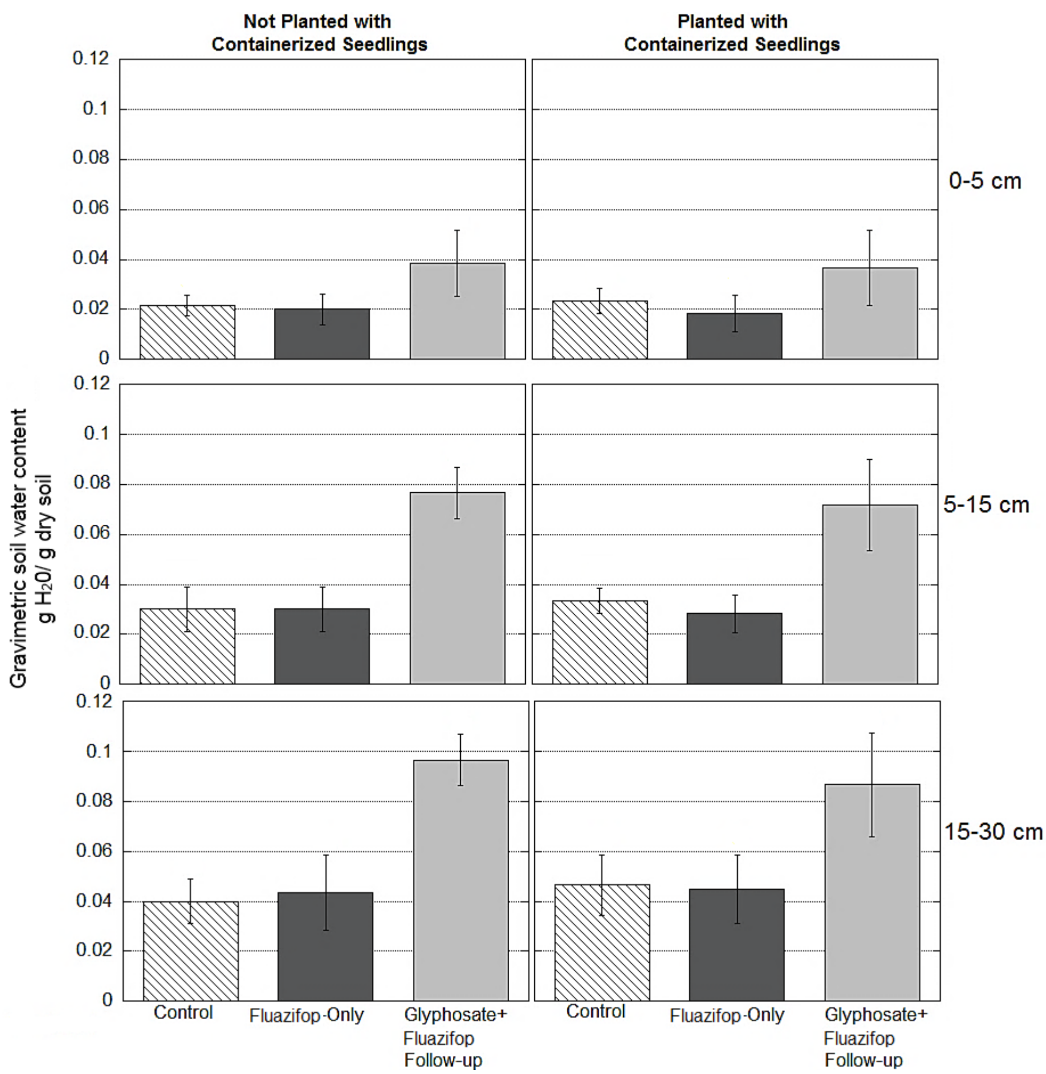

Figure 3–Gravimetric soil water content from soil samples collected in April 2013. Means and standard deviations are shown.

Seed Bank Assessment

The seed bank was dominated by non-native species (fig. 4). Those present were *Bromus diandrus* Roth*, Schismus barbatus* (L.) Thell., *Hirschfeldia incana (L.)* Lagr.-Fossat*, Erodium cicutarium* (L.) Aiton. and *Centaurea melitensis L*. Ruderal native species such as *Croton setigerus* Hook*, Amsinckia menziesii* (Lehm.) Nelson & J.F. Macbr. and *Gnaphalium* sp. were also present in the seed bank. Only two native shrubs, *Artemisia californica* Less. and *Eriogonum fasciculatum* Benth. were present in the seed bank. The weedy non-natives made up 58 percent of the assay. The ruderal natives comprised 24 percent, and other native herbs comprised 15 percent. Native shrubs comprised only 3 percent of the assay.

Germination of some species clearly benefited from soil treatments (smoke water, heat and smoke water, gibberellic acid), but no single treatment benefited all species (fig. 4). Application of smoke water to soil in the field did not result in the emergence of chaparral shrub seedlings or change the composition of the plant community appreciably.

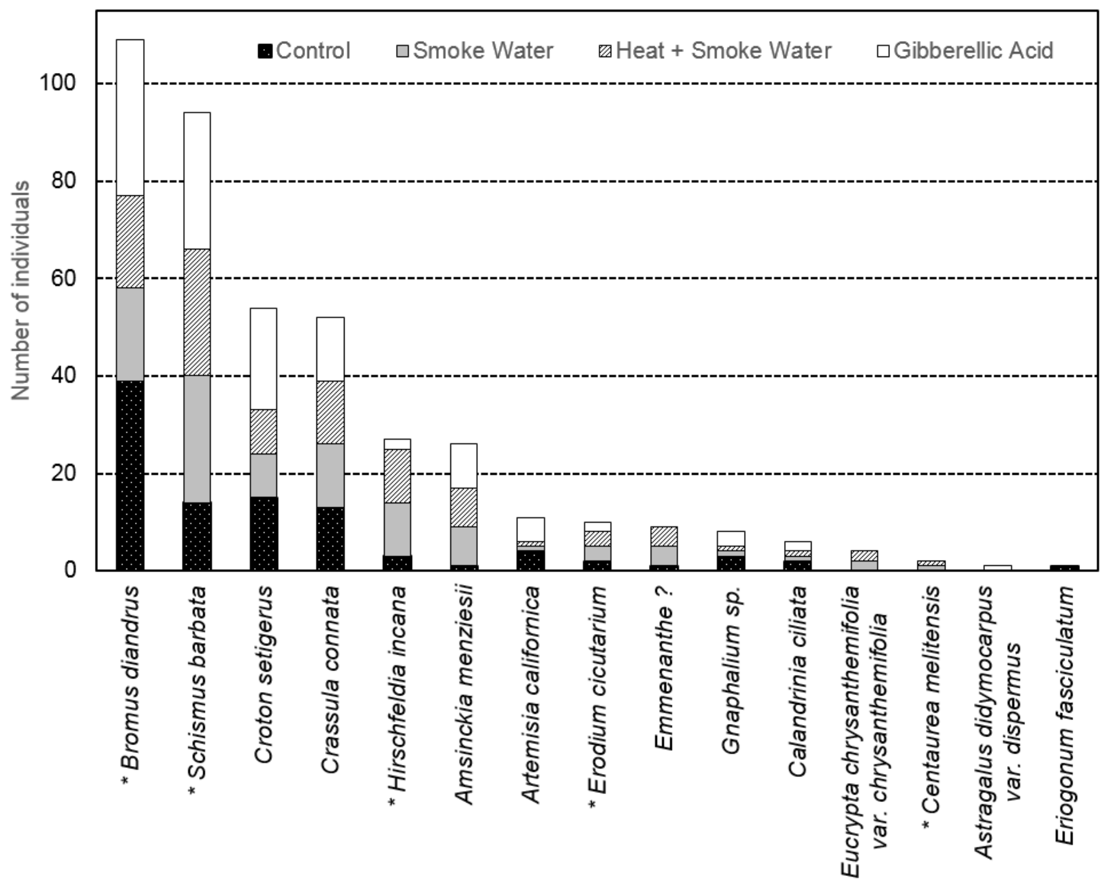

Figure 4–Seedling emergence from seed bank assay. Asterisk (*) indicates a non-native species.

Discussion

For chaparral restoration to be successful, weed populations must be controlled relatively early in the season. Glyphosate applications, applied early in the growing season, had many beneficial effects that fluazifop, applied later in the season, did not exhibit. Glyphosate-treated plots had higher soil moisture, which probably contributed to the higher survival and/or growth exhibited by shrub seedlings transplanted into these plots. Fluazifop alone, which was applied later in the year (March rather than December) did not result in higher springtime soil moisture content or transplant performance over control levels. Whether earlier fluazifop application would have increased soil water content or simply allowed broad-leaf weeds to use soil moisture is unknown. However, the timing of this study’s fluazifop application was similar to that employed in previous studies in coastal sage scrub systems (Cox and Allen 2008, Marushia and Allen 2011), and this study’s glyphosate treatment followed by a fluazifop treatment was more effective than the fluazifop-only treatment at promoting transplant success.

Although the glyphosate treatment increased the growth and/or survival of *Eriogonum*, *Quercus*, and *Adenostoma*, early-season growth and survival of *Rhus ovata* were uniformly high across all treatments. Whether the higher success of *Rhus ovata* is characteristic of the species or was due to the fact that transplants were from 2-gallon pots, rather than smaller 1-gallon pots, is unknown. However, some research has shown that survival of outplanted seedlings from deeper pots with longer roots is higher than that of seedlings from smaller pots (Burkhart 2006). Production of container stock of larger seedlings requires more time, effort, and advance planning however, so the effect of size on transplant success in restoration practice merits further investigation.

Seeding was highly unsuccessful compared to container transplants. Several factors may have contributed to that failure. Rainfall was limited: from the time of seed sowing to mid-May, precipitation was 41 percent of normal. Additionally, the presence of grass thatch may have contributed to the failure of the seeding treatment. Eliason et al. (1997) recommended that, for coastal sage scrub restoration, seeding should be accompanied by reduction in grass cover and thatch removal. In our study, thatch was not removed; its presence could have prevented seeds from making good contact with the soil or decreased light levels needed for germination. Whether seeding success would have been higher in a wetter year or with different site treatment is unknown. However, in this study, applying seed was much less successful than transplanting seedlings, a result that has previously been found in coastal sage scrub restoration (Eliason et al. 1997).

The relict native seed bank appeared to be insufficient for restoration of chaparral shrubs at our study site. As a result, attempts to manipulate that seed bank (e.g., with the application of smoke water to the soil in the field) were futile. This finding is consistent with previous work in coastal sage scrub that has shown that seed banks can be depleted rapidly by frequent fire, disturbance, and proximity to non-native annual grasslands (Cione et al. 2002, Cox and Allen 2008). Our study area had been degraded for a long period of time (estimated at 70+ years), and relict chaparral seed banks may be more intact in areas that have not been type-converted for as long. Geophytes present in the grassland at our study site (e.g., *Calochortus plummerae* E. Greene, *Dichelostemma capitatum* Alph. Wood, data not shown) merit preservation as understory components of chaparral. While their presence could constrain site treatments and the timing of herbicide application, early-season grass control (before geophytes emerge) may prove beneficial as it did for the chaparral shrub transplants in this study.

Conclusions

Chaparral restoration of type-converted areas may be feasible if the non-native annual grass competition is eliminated early in the season. Although it is too early to tell if transplanted seedlings will become fully established once supplemental water ceases, initial results suggest that transplanting shrub seedlings into herbicide-treated areas is more successful than seeding or attempting to manipulate a residual chaparral seed bank under the conditions of our study. Our study site had been occupied by non-native grasses for a substantial length of time, a factor that likely contributed to the paucity of a native soil seed bank. The year of our study was exceptionally dry, a factor that may have contributed to seeding failure and exacerbated early-spring grass competition. Under these conditions, a winter glyphosate application with a springtime fluazifop follow-up was more effective at eliminating non-native annual grasses and promoting transplant success than springtime fluazifop application alone. This combination of herbicide treatments, followed by planting of containerized seedlings, appears to be a promising approach to re-establishing chaparral shrubs on type-converted slopes.

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