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Efficacy of Exotic Control Strategies for Restoring Coastal Prairie Grasses

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Restoration in Mediterranean-climate grasslands is strongly impeded by lack of native propagules and competition with exotic grasses and forbs. We report on a study testing several methods for exotic plant control combined with planting native grasses to restore prairies in former agricultural land in coastal California. Specifically we compared tarping (shading out recently germinated seedlings with black plastic) once, tarping twice, topsoil removal, herbicide (glyphosate), and a control treatment in factorial combinations with or without wood mulch. Into each treatment we planted three native grass species (*Elymus glaucus, Hordeum brachyantherum,* and *Stipa pulchra*) and monitored plant survival and cover for three growing seasons. Survival of native grass species was high in all treatments, but was slightly lower in unmulched soil removal and control treatments in the first 2 yr. Mulching, tarping, and herbicide were all effective in reducing exotic grass cover and enhancing native grass cover for the first 2 yr, but by the third growing season cover of the plant guilds and bare ground had mostly converged, primarily because of the declining effects of the initial treatments. Mulching and tarping were both considerably more expensive than herbicide treatment. Topsoil removal was less effective in increasing native grass cover likely because soil removal altered the surface hydrology in this system. Our results show that several treatments were effective in enhancing native grass establishment, but that longer term monitoring is needed to evaluate the efficacy of restoration efforts. The most appropriate approach to controlling exotics to restore specific grassland sites will depend not only on the effectiveness, but also on relative costs and site constraints.

Nomenclature: Glyphosate; blue wild rye, *Elymus glaucus* Buckley; meadow barley, *Hordeum brachyantherum* Nevski; purple needlegrass, *Stipa pulchra* Hitchc.

Key words: Cost of restoration, grassland, herbicide, mulch, solarization, tarping, topsoil removal.

Temperate and Mediterranean grasslands worldwide, and in California in particular, are highly threatened ecosystems that are the focus of extensive restoration efforts (Hoekstra et al. 2005; Stromberg et al. 2007). Recovery of Mediterranean grasslands is limited both by competition from numerous exotic grasses and forbs and a lack of native propagules (Corbin et al. 2004; Gaertner et al. 2009; Seabloom et al. 2003). Therefore, restoration strategies typically include efforts to both reduce exotic plant cover and reintroduce native species (Corbin et al. 2004; Stromberg et al. 2007). While many different strategies are used to control exotic species and tip the balance toward natives, some are not feasible in the remaining habitat fragments bordered by human developments that characterize most coastal systems. For example, burning often is highly restricted because of concerns regarding air quality and risk to nearby properties (Keeley 2002), and cattle grazing may not be economically profitable (Huntsinger et al. 2010). Land managers commonly use herbicides for exotic control given their cost effectiveness, but their use may be limited because of concerns about their effects on nearby human populations and ecosystems (Cornish and Burgin 2005), which have resulted in some local ordinances constraining their use (e.g., City of Sebastopol 2000).

Therefore, research is needed on non-chemical exotic management strategies, among which are mulching, tarping, and topsoil removal. Wood mulch is commonly used in restoration to reduce germination of and competition with exotic plants, as well as to ameliorate temperature extremes, enhance soil moisture retention, and increase the accumulation of organic matter (Biederman

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Management Implications

Restoring California grasslands requires extensive efforts to reduce competition with exotic grasses and forbs and reintroduction of native species. Herbicides are frequently used to control exotic species, but given various concerns about their negative effects, cost-effective non-chemical strategies are needed. We compared five strategies for controlling exotic species in former agricultural lands to restore California coastal prairie species: tarping (shading out recently germinated seedlings with black plastic) once, tarping twice, topsoil removal, glyphosate herbicide, and wood mulch. Into each treatment we planted three native perennial grass species (blue wild rye, meadow barley, and purple needlegrass) and monitored plant survival and cover for three growing seasons. Our results show that using black plastic tarps to shade out recently germinated seedlings and applying wood mulch are both effective non-herbicide methods for reducing exotic grass cover and enhancing native grass cover in the initial stage of grassland restoration. Both approaches, however, are considerably more expensive than using herbicides unless they can be done with volunteer labor. Overall, tarping twice was no more effective than tarping once, so we do not recommend a second tarping. Removing topsoil resulted in a sufficient change in hydrology that the sites experienced extended flooding in the first year which reducing native grass survival, but this approach may be more effective in sites with different topography. The effectiveness of our restoration treatments declined substantially by the third year, highlighting the importance of ongoing monitoring to compare the efficacy of restoration strategies, combined with continued exotic control. Herbicide, tarping, and mulch were all effective in reducing exotic grasses for the first 2 yr of restoration. The most cost-effective strategy for reducing exotic cover and restoring native grasses will depend on project-specific factors, including cost of labor and supplies, as well as local herbicide use constraints.

and Whisenant 2009; Chalker-Scott 2007; Concilio 2013). Solarization is another potential exotic control strategy in which a clear or black plastic tarp is placed on bare ground to sterilize the soil. This strategy is primarily used in hot, arid conditions which result in sufficiently high soil temperatures that kill the seed bank and/or recently germinated seedlings (Concilio 2013; El-Keblawy and Al-Hamadi 2009; Lambrecht and D'Amore 2010; Moyes et al. 2005), but may be less effective close to the coast where summer temperatures are moderated by the ocean and fog (Stapleton 2000). A related, but less commonly used, alternative is to cover the soil with black plastic tarps to shade out recently-germinated exotic seedlings (hereafter referred to as tarping); this method has been successful in less extreme climatic conditions (Marushia and Allen 2011; Stapleton 2000). Another possible, non-chemical approach to controlling exotic plants is removing the top layer (5 to 10 cm (2 to 4 in) of soil which can serve to reduce the exotic seed bank and decrease soil nitrogen (Buisson et al. 2008; Buisson et al. 2006; Olsson and Ödman 2014).

We report on an experiment testing the efficacy of several methods to both reduce cover of exotic grasses and forbs and enhance the survival and cover of native grasses planted into former agricultural lands to restore California coastal prairie. We compared tarping once, tarping twice, herbicide, topsoil removal, and mulching through three growing seasons, as past research shows that while restoration treatments may have distinct differences in the first year or two following implementation, the effects often diminish over time (e.g., Rein et al. 2007; Rinella et al. 2012; Seabloom 2011).

Materials and Methods

Site Description. The research was conducted on a post-agricultural marine terrace at the University of California, Santa Cruz (UCSC) Younger Lagoon Reserve adjacent to the Long Marine Laboratory (36°57′11.59″N, 122°3′55.46″W). The land was used for over 50 yr for a mixture of dairy cattle followed by growing Brussels sprouts until agricultural activities ceased in the 1980s. The land transferred to the UCSC in 1999 and was later mandated for restoration of the original habitat types, a mixture of coastal prairie, scrub, and freshwater wet meadow, as part of mitigation for campus development.

The land has $<2°$ slope and the soils are mix of poorly drained loams and sandy loams which experience hydric conditions following normal to heavy rainfall periods. The climate is Mediterranean with rainfall falling during the winter mo (primarily November through April) and an extended dry season (May–October) during which temperatures are moderated by coastal fog (maximum daily temperatures rarely are >22 C (71 F), as the site is located <100 m (109 yd) from the Pacific Ocean. Average annual rainfall between 1993 and 2013 was 434.7 mm (17.1 in); the first year of the study (2010 to 2011) had above-average rainfall (720.2 mm (28.3 in)), whereas the subsequent 2 yr received less than average rainfall: 367.5 mm (14.5 in) (2011 to 2012) and 288.60 mm (11.4 in) (2012 to 2013).

California coastal prairies were probably once dominated by native bunch grasses and often host a high diversity of annual and perennial forbs (Ford and Hayes 2007; Stromberg et al. 2001). However, prior to the start of the experiment the above-ground vegetation in the study area consisted entirely of a mixture of exotic grasses and forbs.

Experimental Design. In late August 2010, the entire site was mowed and fenced to exclude large herbivores, primarily rabbits. Five 5 by 5-m plots in each of five randomized blocks were randomly assigned to one of five treatments: tarping once (1×), tarping twice (2×), topsoil removal, herbicide, and control (no treatment except mowing immediately prior to planting). The blocks run perpendicular to the coastal bluff edge to control for microclimatic variation because of this gradient. A 0.5-m buffer separates adjacent plots.

Treatments were initiated at different times so that they would be completed by the same planting date. In mid-August 2010, 2× tarping plots were irrigated for 10 min d^{-1} for 18 d. After allowing seeds to germinate, 10-mil black, polyethylene tarps were laid over each plot with corners weighed down by sandbags to prevent winds from disrupting the experiment. The tarps were removed after 6.5 wk immediately prior to the onset of fall rains. Both 1× and 2× tarping plots were left uncovered after the first rains in the third week of October to allow seed germination. In early November 1× and 2× tarping plots were covered with black tarps for 8 wk, and tarps were removed in early January, prior to planting.

In soil removal plots, a bulldozer scraped off the top 5 cm (2 in) of soil in October 2010. In herbicide plots, a solution of glyphosate (Round-up Pro®), water, and blue dye was sprayed in mid-November 2010 and again in early January 2011. Approximately 3,785 ml (1 gal) of water, 89 ml (3 oz) of glyphosate, and 47 ml (1.6 oz) of blue dye were manually sprayed on each plot. The second treatment was timed to allow the solution to immobilize before planting natives.

Immediately prior to planting, all plots (including controls) were clipped to ground level with a mechanical trimmer to facilitate planting seedlings. Plots were divided into two halves (2.5 by 5 m) and ~3 cm of wood mulch was applied to half of each plot. The mulch was a mixture of *Sequoia sempervirens* (D. Don) Endl. (coast redwood), *Quercus agrifolia* Née (coast live oak), and *Umbellularia californica* (Hook & Arn.) Nutt. (California bay laurel). Nomenclature throughout follows Baldwin et al. (2012).

Plant Materials and Planting. We planted three species of native, perennial coastal prairie grasses: *Elymus glaucus* Buckley (blue wild rye), *Hordeum brachyantherum* Nevski (meadow barley), and *Stipa pulchra* Hitchc. (purple needlegrass; *Nassella pulchra* (Hitchc.) Barkworth). Seeds were collected from within Younger Lagoon Natural Reserve or from Franklin Point in Año Nuevo State Park, approximately 40 km (25 mi) from the Reserve. *S. pulchra* and *E. glaucus* seeds were germinated and grown in greenhouses at the main UCSC campus (approximately 6 km from the study site) beginning in early September 2010. Seedlings were transferred into Ray Leach SC7 Stubby Conetainers (3.8 by 14 cm) to promote root-growth. Because of experimental difficulties, *H. brachyantherum* seeds were germinated in mid-November, approximately 10 wk after the other species. *E. glaucus* and *S. pulchra* seedlings were moved to the research site in early January 2011 to allow acclimation prior to planting. *H. brachyantherum* seedlings were moved to the site in early February and were only acclimated for 1 to 3 d prior to planting.

Elymus glaucus, S. pulchra, and *H. brachyantherum* seedlings were planted on January 14, January 21, and February 6, 2011, respectively. In each sub-plot there was an 8 by 15 grid of plants, each separated by 30 cm: seedlings were planted in five alternating rows of 8 seedlings of each species.

Data Collection. At the peak of the growing season (late-April/early-May) in 2011 (first growing season) and 2012 (second growing season), we recorded survival and estimated cover (to the nearest 0.25 square decimeter ($dm^2 = 100\ cm^2$)) of all planted grass seedlings. By 2013 (third growing season) it was impossible to distinguish separate grass seedlings, so we estimated relative cover of each species as part of guild cover measurements. To quantify overall vegetation composition, in late-April/early-May of 2011, 2012, and 2013, we estimated the percent cover of native grasses, exotic grasses, exotic forbs, and bare ground (including bare soil and mulch) in 5% cover classes (i.e. 0 to 5%, 5 to 10%, 10 to 15%) in four 0.25 by 1.0-m quadrats in each sub-plot. There were no native forbs recorded in experimental plots.

Data Analysis. Prior to analysis, measurements from individual plants or quadrats within a given sub-plot were averaged to obtain a single value. We used a mixed effects model (using the lme function in the lmer package in R) to analyze the effect of the whole-plot treatment (control, topsoil removal, herbicide, 1× tarping, or 2× tarping), mulch (the sub-plot treatment), and their interaction on survival and cover of each species of grass seedlings and cover of the different vegetation guilds (native grasses, exotic forbs, exotic grasses) and bare ground. Block was included as a random factor. We used Tukey's multiple comparison procedure to test for differences between whole-plot treatments when there was a significant treatment effect but not a significant treatment by mulch interaction. We conducted separate Tukey's multiple comparison procedures for mulched and unmulched sub-plots of the whole-plot treatments when there was a significant treatment by mulch interaction.

We present results of individual native grass plant survival and cover in April 2012, second growing season. Results from April 2011 (first growing season) were similar but less pronounced as measurements were taken only 3 mo after planting. We calculated relative cover of the vegetation guilds as the percentage cover of the target guild divided by total live vegetation cover. We report relative vegetation cover given that our goal was to test the effects of the different restoration strategies on increasing the relative cover of native compared to exotic guilds and total cover varied strongly interannually, largely in response to rainfall differences (Hobbs et al. 2007). Initial repeated measures analyses of cover guilds showed that there were strong treatment by time interactions so we report the results of the 3 yr separately. Percentage values were arcsine transformed and individual seedling cover values logtransformed when necessary to meet assumptions of normality and homogeneity of variance.

Cost Comparison. We estimated costs of both labor and supplies for the three most promising methods for exotic control: tarping 1×, herbicide, and mulching. We calculated labor time from work time logs maintained by UC Natural Reserves staff and supplies based on bulk prices in our region.

Results and Discussion

Survival and Individual Cover of Native Grasses. Overall seedling survival was high: 95% and 88% for all species across all treatments in the first (April 2011) and second (April 2012) growing seasons respectively, showing their promise for restoration in this system. Survival values were similar for all species in the second year (*E. glaucus*: 91%, *H. brachyantherum*: 87%, *S. pulchra*: 86%), whereas cover of individual plants of *E. glaucus* (1.5 dm^2) was greater than *H. brachyantherum* (1.0 dm^2) or *S. pulchra* (0.9 dm^2).

Seedling establishment and survival in Mediterranean systems is notoriously variable largely in response to large interannual differences in rainfall (Hobbs et al. 2007; Seabloom 2011), and the first year of our study coincided with an above-average rainfall year, which likely positively affected our high native grass seedling survival rates. Corbin and D'Antonio (2004) reported similarly high survival rates in mesic California coastal prairies, but others have reported lower survival in drier years with high variation across species (Buisson et al. 2006; Farrell et al. 2007; Tang 2013).

Second-year seedling survival was ≥84% in all mulched treatments, but was more variable across treatments in unmulched plots (Figure 1). The interaction between treatment and mulching was significant for *H. brachyantherum* and marginally significant for *S. pulchra*, as survival was lower in unmulched control and soil removal plots (Figure 1, Table 1). There was also a significant interaction term for *E. glaucus* for which survival was lowest in the unmulched herbicide treatment.

Cover of individual grass seedlings showed a similar, but stronger, pattern (Figure 1). For *S. pulchra*, cover was higher in mulched plots across all treatments with no significant interaction term (Table 1); cover was lower in control and soil removal compared to the other treatments. For both *E. glaucus* and *H. brachyantherum,* there was a significant treatment by mulch interaction; cover was lower in unmulched control and soil removal plots for both species, whereas mulching did not have as strong an effect in tarping 1× or 2× plots (Figure 1, Table 1).

Overall Vegetation Composition. In the first growing season, relative native grass cover was greater in mulched than unmulched plots and was greater in herbicide and both tarping treatments than in control and soil removal plots (Figure 2, Table 1), consistent with patterns of survival and cover of individual species. Results from the second year were identical except that cover in the tarping 1× treatment did not differ significantly from any other whole-plot treatments. By the third growing season, treatment differences had decreased; the positive effect of mulching was observed only in control, soil removal, and herbicide plots (treatment by mulching effect) and the treatment effect was only significant in unmulched plots (Figure 2, Table 1). Experiment-wide native grass cover in the third year was comprised of approximately half *E. glaucus* and a quarter each of *H. brachyantherum* and *S. pulchra*. No recruitment of native grasses was observed, so all the cover was comprised of planted individuals.

Relative exotic grass cover (mostly *Bromus diandrus* Roth (ripgut brome), *Festuca myuros* L. (rattail fescue), *Festuca perennis* (L.) Columbus & J.P. Sm. (Italian rye grass)) showed the opposite pattern as native grasses, with higher cover in unmulched plots in the first 2 yr and no effect by the third year (Figure 2, Table 1). Exotic grass cover was lowest in herbicide treatments in the first year, but did not vary across whole-plot treatments thereafter (Table 1).

Relative exotic forb cover was dominated by *Raphanus sativus* L. (radish), *Carduus pycnocephalus* L. (Italian thistle), *Cirsium vulgare* (Savi) Ten. (bull thistle), *Helminthotheca echioides* (L.) Holub (bristly ox-tongue) and *Medicago polymorpha* L. (California burclover) and did not differ across treatments in the first growing season (Figure 2). In the second year, there was a significant treatment by mulch interaction with greater cover in unmulched control, soil removal and herbicide plots (Table 1). There was greater cover in the control and soil removal treatments, primarily in unmulched plots, in the third year.

Bare ground (both bare soil and wood mulch) was much higher in all mulched plots and unmulched herbicide plots in the first year (Figure 3). Bare ground in mulched plots dropped substantially (<10% in all treatments) in the second year, but the mulching effect remained significant (Table 1). By the third year, there was no significant effect of the mulching treatment on bare ground (Table 1), although overall bare ground was higher than the preceding year likely because of dry conditions. By this time, wood mulch only covered 0.9% of mulched plots.

Cost Comparison. Costs for mulching and tarping were an order of magnitude higher than herbiciding (complete cost estimates are detailed in Table S1). At our site, herbiciding twice prior to planting cost US\$1,440 ha^{-1} (\$600 for herbicides and \$840 for labor). Tarping once would cost US\$14,040 ha^{-1} (\$5,400 for plastic and \$8,640 for labor) if all labor were paid, although we were

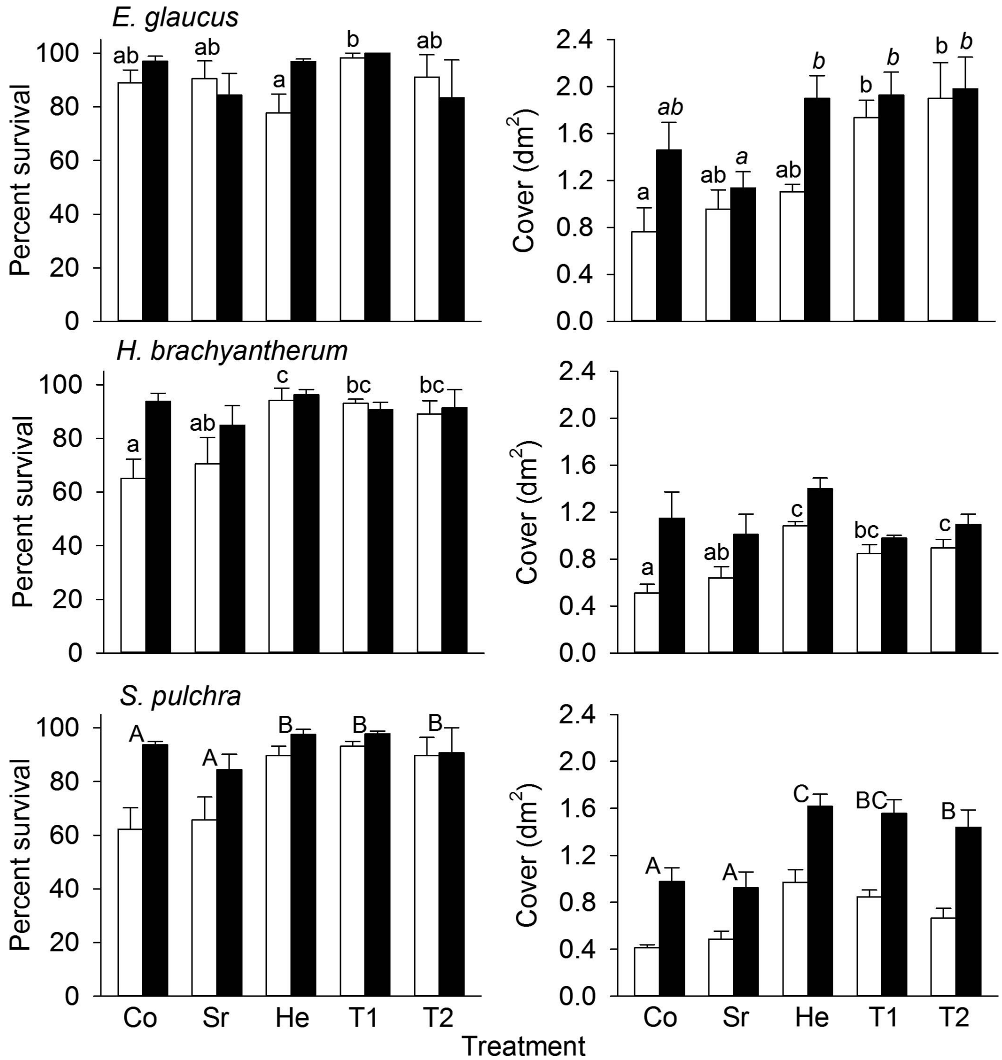

Figure 1. Percent survival and cover of individual grass seedlings in control (Co), soil removal (Sr), herbicide (He), tarping 1× (T1) and tarping 2× (T2) treatments crossed with no mulch (white bars) and mulching (black bars) in second growing season (April 2012). Error bars indicate 1 SE. When ANOVA (Table 1) indicated a significant treatment effect ($P < 0.05$) but no treatment by mulch interaction, differences in whole-plot treatment means using Tukey's mean separation procedure are indicated with capital letters. When ANOVA (Table 1) showed a significant treatment by mulch interaction, differences across sub-plot treatment means are illustrated with lower case letters separately for unmulched (nonitalic) and mulched (italic) sub-plots. No letters are shown when no treatments differed significantly.

able to utilize some volunteer labor to reduce costs. The cost of mulching is highly variable depending on whether a free source of mulch is available and whether it is spread manually or with machinery; a considerable amount of mulch is needed (300 m^3 ha^{-1}) resulting in an estimated total cost of US$18,190 ha^{-1} ($11,790 for mulch and $6,400 for labor).

Evaluation of Short-Term Treatment Efficacy. Our results are consistent with many previous studies showing that both herbicides and mulch are effective in reducing exotic grass competition and favoring native grasses (e.g., Cox and Allen 2008; Huddleston and Young 2005; Irvine et al. 2013; Kettenring and Adams 2011; Nyamai et al. 2011). Exotic control treatments had much weaker and less consistent effects on cover of exotic forbs, which likely reflects the fact that cover of exotics forbs, many of which are low-stature and/or have basal rosettes, is strongly influenced by competition with taller-stature grasses, both native and exotic (Cox and Allen 2011; Hayes and Holl 2011).

While herbicides are commonly the most effective exotic control strategy and much cheaper than alternatives (Kephart 2001; Kettenring and Adams 2011), they are

Table 1. Results of mixed effects models of treatment, mulch and treatment by mulch interaction on vegetation variables.

Variable	Growing season	Treatment *F*	Treatment P	Mulch *F*	Mulch P	Treat. × Mulch *F*	Treat. × Mulch P
Individual plants (Figure 1)							
E. glaucus survival	2	2.4	0.0956	2.2	0.1559	4.0	0.0149
E. glaucus cover	2	4.3	0.0148	56.9	<0.0001	8.2	0.0004
H. brachyantherum survival	2	3.8	0.0238	20.9	0.0002	6.5	0.0016
H. brachyantherum cover	2	5.6	0.0051	81.3	<0.0001	7.9	0.0005
S. pulchra survival	2	7.0	0.0018	46.7	<0.0001	2.4	0.0878
S. pulchra cover	2	18.1	<0.0001	166.4	<0.0001	1.2	0.3366
Guild cover (Figure 2)							
Native grass	1	14.8	<0.0001	102.0	<0.0001	0.8	0.5666
	2	6.2	0.0034	79.2	<0.0001	1.4	0.2850
	3	2.3	0.1024	16.1	0.0007	4.0	0.0160
Exotic grass	1	15.4	<0.0001	132.3	<0.0001	1.3	0.3034
	2	3.3	0.0686	29.5	<0.0001	0.9	0.4849
	3	0.8	0.5292	0.5	0.4965	0.8	0.5601
Exotic forb	1	1.7	0.2049	<0.0	0.9247	0.8	0.5328
	2	3.4	0.0328	4.4	0.0479	3.8	0.0191
	3	3.5	0.0318	3.9	0.0612	2.0	0.1294
Bare ground (Figure 3)	1	10.5	0.0002	84.5	<0.0001	2.0	0.1363
	2	0.9	0.4622	35.4	<0.0001	0.4	0.8191
	3	9.2	0.0005	0.1	0.7714	1.4	0.2676

increasingly difficult to use because of popular sentiment. Herbicides may have negative effects on native species (Cornish and Burgin 2005; Rinella et al. 2009; Rodriguez and Jacobo 2013), but in systems such as California grasslands, where exotic species exert a strong competitive effect on native survival, the net effect of herbicides is usually positive (Corbin et al. 2004).

Mulching reduces exotic cover, which in part may be because of increased microbial activity reducing high N availability, which is especially important in former agricultural soils (Zink and Allen 1998) or in areas with high atmospheric N deposition (Weiss 1999). Mulch also increases soil moisture, which can enhance seed germination and seedling survival in arid systems (Biederman and Whisenant 2009; Nyamai et al. 2011). The vast majority of wood mulch breaks down within 2 yr in our study system, so in turn these effects are expected to decrease. A major obstacle to using mulch is the high cost if a free or low cost source is not available.

There has been much less study of using tarps to shade out exotic seedlings prior to seedling planting. Results from our study and others (Marushia and Allen 2011) suggest that a single tarping immediately after the first rainfall in a Mediterranean region can be similarly effective to herbicides in reducing exotic cover. Hutchinson and Viers (2011) found that tarping once, along with tilling to break up roots, was effective for control of a perennial invasive herb. Our results showed that a second tarping following irrigation during the Mediterranean dry season had minimal additional benefits for exotic control. Moreover, this approach requires irrigation, which adds costs and is not feasible in systems far from water sources. Tarping is used at a large scale in agriculture, suggesting it could be used in restoration settings. We estimate, however, that tarping is an order of magnitude more expensive than two herbicide applications, although these costs will vary depending on local supply and labor costs. Moreover, tarping can be challenging when there are existing woody plants interspersed throughout the grasslands.

Past research suggests that topsoil removal can be effective to reduce exotic competition and restore grassland habitats in upland conditions or to restore wet meadows in combination with introduction of native wetland plant propagules (Buisson et al. 2006; Farrell et al. 2007; Klimkowska et al. 2010; Pfeifer-Meister et al. 2012). Topsoil removal, however, causes extensive damage to the ecosystem, including removing the native seed bank and microbial communities (Diaz et al. 2008; Pfeifer-Meister et al. 2012), and requires somewhere to dispose of the soil. In our experiment, removing the top layer of soil was not effective in reducing exotic cover at our study site, which is flat, deep soiled, and includes small patches of herbaceous freshwater wetlands. Removing 5 cm of soil appeared to change the hydrological conditions; we

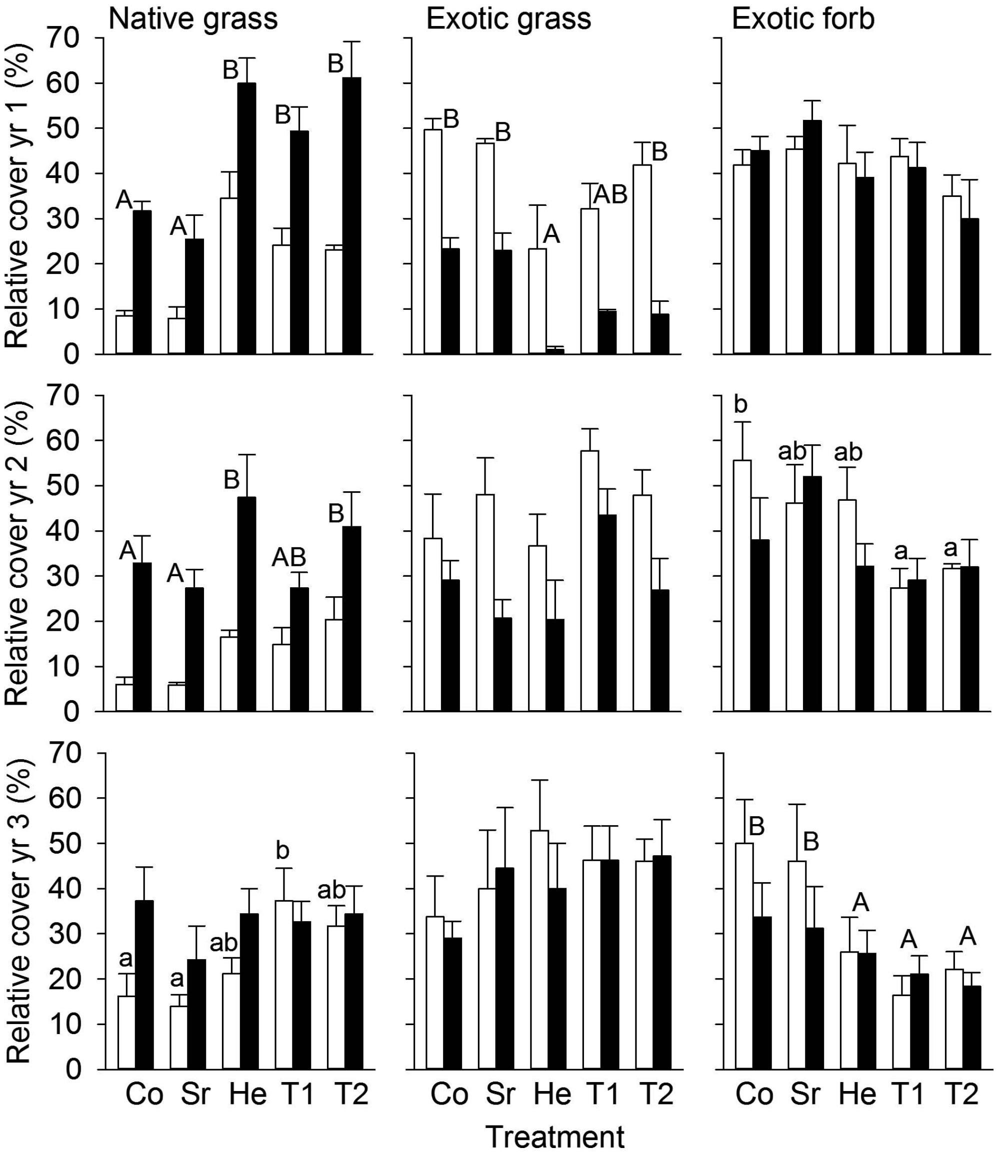

Figure 2. Relative cover of vegetation guilds in control (Co), soil removal (Sr), herbicide (He), tarping 1× (T1) and tarping 2× (T2) treatments crossed with no mulch (white bars) and mulching (black bars) over the 3 yr of the study. Error bars indicate 1 SE. When ANOVA (Table 1) indicated a significant treatment effect ($p < 0.05$) but no treatment by mulch interaction, differences in whole-plot treatment means using Tukey's mean separation procedure are indicated with capital letters. When ANOVA (Table 1) showed a significant treatment by mulch interaction, differences across sub-plot treatment means are illustrated with lower case letters separately for unmulched (non-italic) and mulched (italic) sub-plots. No letters are shown when no treatments differed significantly.

observed that soil removal plots had standing water for a longer time period than the other treatments following high rainfall events in the first year, which likely facilitated the recolonization of exotic seeds and reduced seedling survival of the planted native grasses. Interestingly, we also observed establishment of *Juncus bufonius* L. (toad rush), a native, annual rush commonly associated with freshwater wetlands (Lichvar 2013), primarily in soil removal plots, in the summer following the first sampling (Mann 2012), although the species was not recorded during our annual spring surveys perhaps because of its small size and late flowering period.

Convergence of Treatment Methods. Our results show that both mulching and tarping are non-chemical exotic control methods that reduce exotic grass cover and enhance the success of native grass planting efforts over the first 2 yr. The effects of the restoration methods, however, converged substantially within 3 yr after treatments congruent with a large body of past literature showing that the effect of

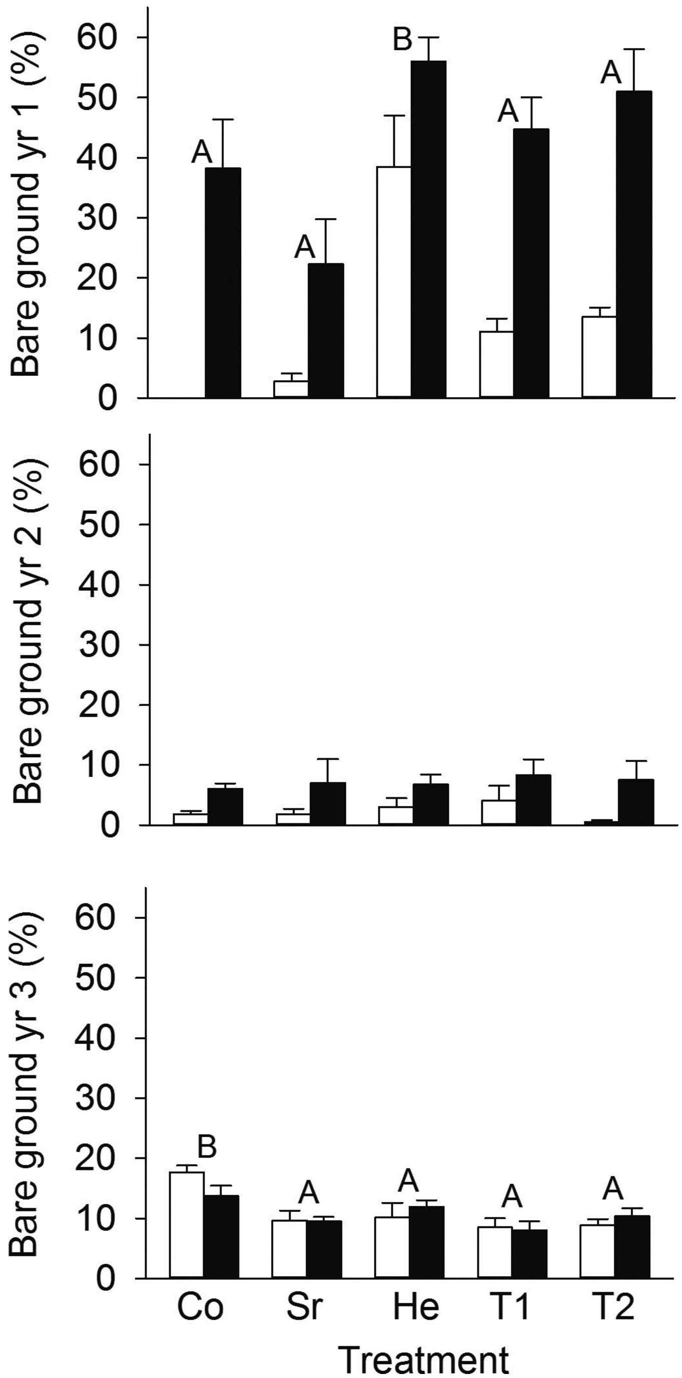

Figure 3. Bare ground in control (Co), soil removal (Sr), herbicide (He), tarping 1× (T1) and tarping 2× (T2) treatments crossed with no mulch (white bars) and mulching (black bars) over the 3 yr of the study. Error bars indicate 1 SE. Whole-plot treatment means with the same capital letters are not significantly different ($P < 0.05$) using Tukey's mean separation procedure. See Table 1 for ANOVA statistics.

restoration actions may be short-lived (Matthews and Spyreas 2010; Rinella et al. 2012; Seabloom 2011). By the third year, there were minimal effects of treatment on bare ground and exotic grasses, which raises the question of whether expensive exotic control techniques are justified. Treatment effects on native grasses declined although native cover remained lower in the control, soil removal, and herbicide plots that were unmulched.

Other studies have suggested that interannual climatic variation, which is beyond the control of practitioners, may be more important than the restoration method used (Cox and Allen 2011; Wilson et al. 2004), so that investing resources in multiple years of seeding or planting may enhance restoration success more than expensive efforts to control exotic competition. What is clear is that long-term monitoring is needed to evaluate the efficacy of different restoration treatments, a call that has been made repeatedly in the academic literature (Matthews and Spyreas 2010; Rinella et al. 2012), but is less commonly implemented (Kettenring and Adams 2011). Clearly, selecting among the options of no treatment, mulching, herbicide, and tarping will require balancing long-term efficacy with costs and logistical constraints at specific sites, as well as considering the effect of the treatments on any extant native vegetation and seed bank.

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