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RESEARCH ARTICLE

Development of Techniques to Improve Coastal Prairie Restoration on the Clatsop Plains, Oregon

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ABSTRACT: With the substantial losses of native prairie habitat over the last century, research focusing on the restoration of prairies has become imperative in order to conserve these imperiled ecosystems and the biodiversity they support. On the Clatsop Plains in northwestern Oregon, there are only a few remnant patches of coastal prairie, which are vital for many species including the federally threatened Oregon silverspot butterfly (*Speyeria zerene hippolyta*). Building upon previous work done on the Clatsop Plains, we implemented a study to develop techniques to improve coastal prairie restoration in this region. The objective of this study was to identify an effective site preparation/treatment that resulted in the greatest success of seeded forb and graminoid establishment, while also limiting introduced graminoid and forb species. We examined the effectiveness of four treatments (untreated control, herbicide, soil inversion, and soil removal) at three sites on the Clatsop Plains. After three seasons, the soil removal treatment enhanced native species abundance while maintaining low cover of introduced forbs and graminoids. However, cost of these methods is also an important consideration for land managers. Soil removal was the most effective treatment we tested, but it would be more expensive to implement on a large scale compared to the other treatments.

Index terms: coastal prairie, habitat restoration, soil removal

INTRODUCTION

Grasslands are a critically endangered ecosystem, with declines in native grassland ecosystems across North America as high as 99.9% (Noss et al. 1995). These declines have been driven mainly by human development and agriculture, since prairies often occupy area that is flat, fertile, and/or otherwise desirable. On the Clatsop Plains in northwestern Oregon, there are only a few remnant patches of coastal prairie, which are vital for many species including the federally threatened Oregon silverspot butterfly (*Speyeria zerene hippolyta* W.H. Edwards; USFWS 2001). Prior to European settlement, these grasslands were likely maintained by frequent fires set by Native Americans (Hammond and McCorkle 1983). With the substantial losses of native grassland habitat, research focusing on the restoration of grasslands has become imperative in order to conserve these imperiled ecosystems and the biodiversity they support.

Current established techniques for restoring grasslands have shown various results on a single-and multiple-treatment scale. Commonly employed restoration techniques generally aim either to reintroduce disturbance or to reduce nonnative grasses, other graminoids, forbs, shrubs, and nitrogen-fixing legumes—or a combination of both techniques. Management techniques such as prescribed fire (Hatch et al. 1999; Copeland et al. 2002; Bartolome et al. 2004), mowing (Collins et al. 1998; Willems 2001; Van Dyke et al. 2004), herbicide application (Masters et al. 1996; Bakker et al. 2003; Stanley et al. 2011), carbon addition (Alpert and Maron 2000; Paschke et al. 2000; Blumenthal et al. 2003), solarization (e.g., heating the weed seed bank to lethal temperatures using clear plastic ground cloth; Schultz 2001; Moyes et al. 2005), grazing (Collins et al. 1998; Hatch et al. 1999; Bartolome et al. 2004), topsoil removal (Hölzel and Otte 2003; Buisson et al. 2006; Klimkowska et al. 2010), and topsoil inversion (Pywell et al. 2002; Jones et al. 2010) have been used to mimic non-climatic natural disturbance processes, and to foster restoration of biodiversity of native plants and animals on managed sites. Inland prairie research in the Pacific Northwest found that native prairie species responded best to the most disturbance-intensive treatment combination (i.e., herbicide, burning, and post-fire herbicide applications), which also reduced the abundance of invasive grasses and forbs (Stanley et al. 2011). Studies conducted on coastal prairie habitat in central California and northwestern Wales, UK, have shown promise in reintroducing the historical natural disturbance regime of blowing sand. Plant growth and establishment of coastal prairie species increased when combined with topsoil inversion or topsoil removal (Buisson et al. 2006; Jones et al. 2010).

Previous but unpublished work in the region (2002–2007; Pickering, unpub. report) tested various combinations of treatments to evaluate the best approach for maintaining and enhancing coastal prairie communities. Primary treatments included mowing, prescribed fire, and grazing, with overlain treatments of heat (infrared weed burner), soil impoverishment, and applications of organic herbicide (Scythe, Gowan Co., Yuma, Arizona). While several of these treatments reduced the abundance of specific groups of invasive plants or increased the abundance of native species, none of the treatment combinations were successful in meeting all of the restoration objectives. The selected treatments were inadequate in sufficiently reducing introduced plant cover to allow for seeded native plant species to successfully establish (Pickering, unpub. report).

We implemented a study to identify an effective site preparation/treatment that would result in the greatest success of seeded forb and graminoid establishment, while also limiting introduced graminoid and forb species for coastal prairies within the Clatsop Plains in Oregon, USA. In this study we were testing the efficacy of three treatments: herbicide, soil removal, and soil inversion. We hypothesized that the soil removal treatment would have the greatest success in seeded forb and graminoid establishment as well as the lowest cover of introduced forbs and graminoids, due to removal of a portion of the existing seedbank and exposure of bare soil.

METHODS

Study Area

Our study sites consisted of three properties managed by the North Coast Land Conservancy (NCLC) as part of the Neacoxie Wildlife Corridor: Neacoxie Forest (Site A), Surf Pines (Site B), and Reed Ranch (Site C). These sites are located within the Clatsop Plains Habitat Conservation Area for the federally threatened Oregon silverspot butterfly, and were selected for restoration in order to provide habitat and increase nectar availability for the butterfly (USFWS 2001). Site A (46°02'37.0" N, 123°55'10.1" W) is a 15.9-ha (39.4-acre) site located within the city limits of Gearhart, Oregon, consisting of a wide swath of coastal prairie adjacent to a forested dune dominated by Sitka spruce (*Picea sitchensis* (Bong.) Carrière). Site B (46°03'31.8" N, 123°55'20.5" W) is a 1.9-ha (4.7-acre) site located in the community of Surf Pines, Oregon, bordered to the east by Neacoxie Creek. Site C (46°05'07.7" N, 123°55'26.3" W) is a 47.4-ha (117.1-acre) site located between the cities of Gearhart and Warrenton, Oregon, which was utilized for agriculture before being conserved by NCLC in 2008. The initial, pretreatment floristic composition of these sites was dominated by several invasive pasture grasses including *Agrostis stolonifera* L., *Anthoxanthum odoratum* L., and *Schedonorus arundinaceus* Schreb. A remnant coastal prairie documented at Camp Rilea (owned by the Oregon Military Department) was utilized as the reference condition for the floristic composition of coastal prairies on the Clatsop Plains.

The mean annual precipitation at our study sites is approximately 190 cm (75 inches), with the highest amount of precipitation occurring in the fall and winter; the minimum and maximum annual air temperature are approximately 7 °C (45 °F) and 14 °C (58 °F), respectively (PRISM Climate Group 2017). Site B was located on Waldport soils, a relatively young soil series (< 300 y) with a weakly developed A horizon of fine sand, while Sites A and C were located on Gearhart soils, an older soil series (500–1000 y) defined by a well-developed A horizon comprised of fine sandy loam. Soils at our study sites had little to no organic matter layer (NRCS 2018; Tomlinson and Limbird, unpub. report).

Experimental Design

At each site, there were four replicates of each of four treatments, including an untreated control. The treatments tested for this study include herbicide, soil removal, and soil inversion. Treatment plots measured 5 × 5 m and were randomly assigned at each site, with allowances for equipment. Soil inversion plots required a larger area to allow equipment to implement the technique, but only the internal 5 × 5 m were used for measurements.

Herbicide treatments included an initial application of imazapyr (28.7% active ingredient) in fall 2013, followed by application of glyphosate (53.8% active ingredient) in spring and fall 2014. Herbicides were applied with a backpack sprayer at a 1% concentration. Soil inversion and removal treatments were initiated in fall 2014. A moldboard plow and tractor combination were used to invert the top 0.15–0.2 m of soil, which was intended to bury high-nutrient organics while bringing to the surface less-developed, lower-nutrient soils. The goal of the removal treatment was similar to the soil inversion in removing the existing vegetation and exposing bare soil, but topsoil (5–15 cm of soil) was completely removed from the site(s); removing the topsoil exposed bare, nutrient-poor mineral sand at each site.

In the fall/winter of 2014, five species were seeded into the 5 × 5-m plots (Table 1). These species were selected because they were identified as part of the floristic composition of a remnant coastal prairie in this region, they are appropriate nectar sources for the Oregon silverspot butterfly, and there was a sufficient amount of genetically appropriate seed.

For each 5 × 5-m plot, we established four 1-m^2 sampling plots. Each meter square plot was set 1 m from the edges and 1 m from each other. Within each sampling plot, we estimated visual cover of each species present. Each species cover was estimated to the nearest 1%, except for those with <1%. Species with <1% cover were estimated at either 0.5%, or listed as "trace" to note occurrence and assigned 0.01% for use in analysis. All monitoring occurred in mid- to late May, with pre-treatment data collected in 2013 and post-treatment data collected in 2015–2017.

Data Analyses

We tested for treatment effects with a mixed-model ANOVA for a randomized block design (Kuehl 2000), with site as a random factor and each year of the study analyzed individually. We performed analyses in NCSS 2007 (Hintze 2008) to examine the effects of treatment on seeded native forb cover, seeded native graminoid cover, and native and nonnative forb and

Table 1. Species and amounts seeded into coastal prairie restoration research plots (Sites A, B, and C).

Species	Growth habit	Pure live seeds/ft^2	Pure live seeds/m^2	Seeds/lb	g/m^2	Purity	Germ
Festuca rubra	Graminoid	30	323	400,000	0.37	90	80
Achillea millefolium	Forb	50	538	2,000,000	0.12	70	70
Solidago canadensis	Forb	50	538	2,000,000	0.12	50	50
Aster subspicatus	Forb	20	215	1,000,000	0.09	40	40
Lupinus littoralis	Forb	2	22	70,000	0.14	100	90

graminoid cover. Post hoc Tukey's HSD tests were used to evaluate differences among treatments. All data presented are means ±1 SE.

RESULTS

Seeded native forb cover increased from 2015 to 2017 in all treatments, and cover ranged from 1% to 15% (Figure 1). Herbicide and soil removal plots had significantly higher seeded native forb cover than controls (2017: $F = 14.58$, $P = 0.004$). Soil inversion plots were similar to the controls after three growing seasons. After three seasons, introduced forb cover was highest in herbicide plots at all sites, and in 2017, ranged from 4% to 41% (Figure 2). Introduced forb cover in herbicide plots was significantly higher than controls and other treatments, and in soil removal plots was significantly lower than controls and other treatments ($F = 13.75$, $P = 0.004$).

The native seeded grass, *Festuca rubra* L., had cover ≤6% across all treatments after three growing seasons and was not significantly different from the controls (2017: $F = 1.78$, $P = 0.251$). Introduced graminoid cover was reduced from 2013 to 2016 in all treated plots, but in 2017 only the soil removal and herbicide plots had cover significantly lower than controls (2017: $F = 22.38$, $P = 0.001$; Figure 3). After three seasons, introduced graminoid cover was less than 5% in soil removal plots at all sites, and was significantly lower than all other treatments.

DISCUSSION

The main objective of this study was to identify an effective site preparation/treatment for the restoration of coastal prairies within the Clatsop Plains in Oregon, USA. Overall, herbicide treated plots and soil removal plots had the highest seeded native forb cover, with seeded native forb cover increasing each year. These plots also had lower introduced graminoid cover than the soil inversion plots and controls, which could have reduced competition and led to more successful establishment of the seeded forb species. Several studies have shown greater establishment (Masters et al. 1996; Huddleston and Young 2005) and higher survivorship (Bakker et al. 2003) of seedlings in herbicide treated areas due to competitive release from invasive species. Buisson et al. (2006) found that topsoil removal reduced exotic vegetation and thus reduced competition, leading to greater survival of native perennial grass transplants. Topsoil removal can serve to remove nitrogen (N) availability (Aerts et al. 1995; Tallowin and Smith 2001; Hölzel and Otte 2003; Buisson et al. 2006), which may favor slower-growing native species that are adapted to low-nutrient conditions (Tilman 1985; Wedin and Tilman 1993; Daehler 2003). Several studies have provided evidence that nutrient impoverishment, either by topsoil removal (Hölzel and Otte 2003; Buisson et al. 2006; Klimkowska et al. 2010), topsoil inversion/deep cultivation (Pywell et al. 2002; Jones et al. 2010), or carbon addition (Alpert and Maron 2000; Paschke et al. 2000; Blumenthal et al. 2003) can benefit the restoration of low-production grasslands by favoring the establishment of low-nutrient–adapted native species.

Several studies have found that native species may not always outperform invasive species under low nutrient conditions (Corbin and D'Antonio 2004; Thomsen

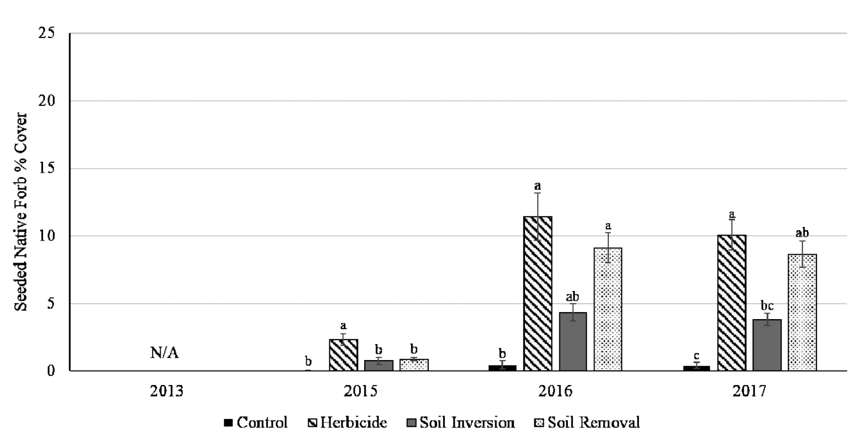

Figure 1. Mean percent (%) cover ±1 SE for native seeded forbs in 2013 (pre-treatment) and 2015–2017 (post-treatment). Letters represent significant differences between treatments using Tukey's HSD test (P < 0.05).

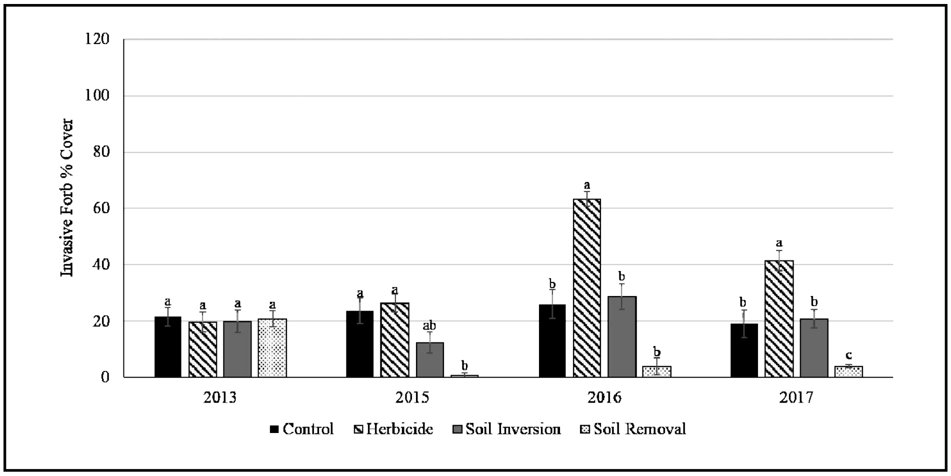

Figure 2. Mean percent (%) cover ±1 SE for introduced forbs in 2013 (pre-treatment) and 2015–2017 (post-treatment). Letters represent significant differences between treatments using Tukey's HSD test (*P* < 0.05).

et al. 2006; Funk and Vitousek 2007). At our study sites, the dominant introduced graminoids were perennial pasture grasses, which have been selected for optimal growth in a high-input agricultural system. While managing nutrient levels may not always be effective in controlling invasive species (Funk and Vitousek 2007), topsoil removal in our study had the desired effect of greater establishment by seeded native species than introduced graminoids.

Seeded native forb cover was composed mainly of *Achillea millefolium* L. and *Lupinus littoralis* (Douglas) at all sites. *Lupinus littoralis* is a pioneer species of dune systems (Kumler 1969), so its successful establishment on the sandy substrate left after topsoil removal would be expected. It was used for secondary dune stabilization in the late 1930s since it was shown to germinate readily, have strong seedling vigor, and would usually set seed in the first year. It also leaves a persistent mulch and fixes nitrogen, both of which help pave the way for the establishment of perennial grasses (Reckendorf et al. 1985). *Achillea millefolium* is dominant in protected edges of initial dune areas (Kumler 1969) and has been found to grow more rapidly at low nitrogen levels and acquire more nitrogen per plant from nitrogen-poor soils than late successional species (Tilman 1986). Additional native forb species, mainly *Ranunculus occidentalis* (Nutt.), were also recorded at the study sites, but contributed less than 5% cover.

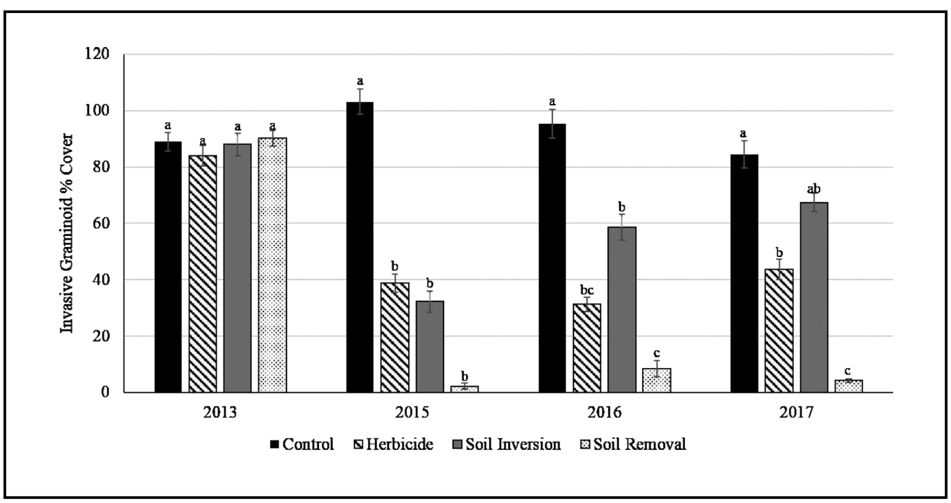

Figure 3. Mean percent (%) cover ±1 SE for introduced graminoids in 2013 (pre-treatment) and 2015–2017 (post-treatment). Letters represent significant differences between treatments using Tukey's HSD test (*P* < 0.05).

Festuca rubra cover remained ≤15% after three seasons, but we observed increases each year. We intentionally limited the amount of *F. rubra* seed in the mix due to concerns with it outcompeting the seeded native forb species, as has been recorded during other coastal prairie restoration efforts (Silvernail, unpub. report). However, if management objectives require higher cover, future efforts could include higher seeding rates of *F. rubra*. The limited amount of native forb seed available for the project is not uncommon (Ladouceur et al. 2017) and likely limited establishment of native species. We would recommend increasing forb seeding rates, if seed are available, to increase cover of native forb species.

After three seasons, invasive graminoids, predominantly *Agrostis stolonifera* L., *Anthoxanthum odoratum* L., and *Schedonorus arundinaceus* ((Schreb.) Dumort., nom. cons.), maintained cover values >16% in all treatments, except soil removal (<5%). The highest levels of introduced graminoid cover were recorded in the soil inversion plots. This treatment did not achieve the objective of completely "flipping" the soil to cover the existing vegetation and reveal bare soil. The soil inversion technique was envisioned to completely "flip" the soil so that the existing vegetation would be buried and the soil profile would be exposed. The plow/tractor combination used in our study was not adequate to completely turn the soil with existing vegetation, which resulted in incomplete soil turning and minimal harm to existing vegetation. If the technique were to be tested again, modification would have to be made to ensure proper equipment and potentially include some form of preparation of the existing vegetation (i.e., mowing, herbicide, rototilling).

The herbicides used during our study, imazapyr and glyphosate, are both broad-spectrum herbicides and would be expected to control introduced graminoid species. Although herbicide treated plots had less introduced graminoid cover than controls, there was still over 50% introduced graminoid cover at two of the sites (Sites A and C) after three seasons. Introduced forb cover, composed mainly of *Hypochaeris radicata* L. and *Rumex acetosella* L., was highest in the herbicide treated plots, and increased throughout the study period at all sites. This amount of cover ensured that these introduced species would continue to dominate the plots and limit establishment of seeded native species. The lack of thatch removal could have limited herbicide contact with actively growing plant material (Kyser et al. 2007; Wilson et al. 2008), and timing (i.e., cold weather limiting photosynthetic rate), and/or weather factors (i.e., rainfall too soon after application) could have reduced efficacy (Kudsk and Kristensen 1992). Although care was taken to avoid weather issues during application, high moisture levels are common and could have resulted in reduced control. Removal of thatch could potentially have provided better control by exposing more actively growing plant tissue to herbicide application (Hanlon and Langeland 2000; Kyser et al. 2007; Wilson et al. 2008).

The soil removal treatment was the most effective technique for reducing cover of both introduced graminoids and forbs. This result was expected since the existing vegetation was completely removed and likely portions of the existing seed bank as well, limiting reestablishment of nontarget species (Jensen 1998; Hölzel and Otte 2003; Kiehl et al. 2006).

The cover of seeded native forbs in the soil removal treatment was similar to herbicide treatments, but did not have the high introduced forb cover found in herbicide treatments. However, the soil removal plots had low cover of vegetation overall. Topsoil removal removes organic material, which was an intended goal of this treatment, but nevertheless can make germination of seeded species difficult. The substrate remaining after topsoil removal (in our case, bare sand) would have diminished soil moisture as well as soil nutrients, which could lead to seed and/or seedling desiccation. Klimkowska et al. (2010) found the addition of seed-containing hay immediately following topsoil removal to increase the cover of vascular species, increase species richness, and increase aboveground biomass. Although the addition of hay may lower germination and seedling survival through litter accumulation (Jensen 1998; Eckstein and Donath 2005), it could facilitate seedling establishment by conserving soil moisture (Cobbaert et al. 2004; Eckstein and Donath 2005) and providing "safe sites" for seedling recruitment on bare substrates (Kiehl et al. 2010). In addition, hay application could restrict unwanted colonization from the surrounding area and inhibit germination of nontarget species from the seed bank (Eckstein and Donath 2005; Klimkowska et al. 2010). Application of seed-containing hay was not included in our study but further studies could investigate if this treatment following topsoil removal could result in greater seedling establishment and cover of native vegetation for coastal prairie restoration sites.

Cost of these methods is also an important consideration for land managers. Although the soil removal treatment was the best of our tested methods, it would be expensive to implement on a large scale. Managers would also need to consider having to deal with the spoils removed from the site(s). Multiple applications of imazapyr herbicide would be a lower-cost option, although work is needed to understand the potential impacts to both target and nontarget species after repeated application. The soil inversion technique, although not successful in our study, could potentially be combined with herbicide application to provide a more cost-effective treatment to be tested.

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