Use of carbon addition in upland prairie restoration at Fern Ridge Natural Area

2013

Final Report to the US Army Corps of Engineers

Report prepared by Erin C Gray

Institute for Applied Ecology

PREFACE

This report is the result of a cooperative project between the Institute for Applied Ecology (IAE) and a federal agency. IAE is a non-profit organization dedicated to natural resource conservation, research, and education. Our aim is to provide a service to public and private agencies and individuals by developing and communicating information on ecosystems, species, and effective management strategies and by conducting research, monitoring, and experiments. IAE offers educational opportunities through internships. Our current activities are concentrated on rare and endangered plants and invasive species.

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Cover photograph: Carbon addition plots at Big Spires, Spring 2012.

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REPORT TO THE US ARMY CORPS OF ENGINEERS

INTRODUCTION

Prairies in the Willamette Valley are among the most endangered ecosystems in North America, and support many imperiled species (Noss et al. 1995; Dunn and Ewing 1997; Floberg et al. 2004), including the threatened plant *Lupinus oreganus* (Kincaid's lupine) and the endangered Fender's blue butterfly (*Icaricia icarioides fenderi*). These systems are increasingly threatened by invasion of exotic grasses and forbs, and many management activities are designed to increase native forb and grass diversity in these invaded systems. Approximately 100 acres of occupied or potential habitat for Fender's blue butterfly and *L. oreganus* is under management at Fern Ridge Natural Area. The Fern Ridge master plan provides these sites with wildlife habitat or environmentally sensitive land use designations. The current rare species management plan and Biological Opinion place primary emphasis on activities to benefit listed species; all sites except one are designated critical habitat for Fender's blue butterfly, *L. oreganus*, or both.

Figure 1. Big Spires, Fern Ridge Natural Area

One potential tool for decreasing invasion by exotic species is carbon addition. Carbon addition limits the amount of soil nutrients available for plant growth (particularly nitrogen and phosphorus) by stimulating microbial activity. Several studies have indicated that native species are more capable of tolerating low nutrient conditions than exotic species (Morgan 1994, Reever et al. 1999, Alpert and Maron 2000, Blumenthal et al. 2003, Kirkpatrick et al. *unpublished data*). Carbon addition is thought to reduce nitrogen availability, thereby altering the competitive dynamics of the treated area (Corbin and D'Antonio 2004). Effects of carbon addition for restoration purposes have been tested in various forms including sucrose, activated carbon, sawdust, leaf and bark mulch, and oat straw (Corbin and D'Antonio 2004, Mitchell and Bakker 2011). In prairies of the Puget Trough lowlands, sucrose addition resulted in the decline of invasive grasses and forbs in areas that were invaded by the nitrogen-fixing shrub *Cytisus scoparius*, however treatment effects were short-lived (Kirkpatrick and Lubetkin 2011). Another study testing the effects of sucrose and activated carbon on Pacific Northwest prairies found that these treatments affected functional groups differently, where forbs were more affected by treatment and sucrose was, overall, more effective than activated carbon (Mitchell and Bakker 2011).

In this experiment we tested if carbon addition, in the form of sucrose, would benefit native plant diversity in upland prairies at Fern Ridge Natural Area. Does carbon addition have long-term beneficial effects on native species abundance? Do treatment effects differ by site or by plant community composition prior to treatment? Is this an effective tool for managing for native plant diversity, particularly in areas where other treatments (herbicide, mowing) cannot be used? We chose sucrose as our carbon source because of its demonstrated positive effects on native species noted in other studies (Corbin and D'Antonio 2004); straw was not used because thatch has been found to be a limiting factor of native species growth and establishment in upland prairie systems (Maret and Wilson 2005). Plots were established at the Big Spires and West Shore sites in spring of 2012. Treatments occurred in spring 2012, fall 2012, and in spring 2013.

Study Sites

Restoration at Big Spires (Figure 1, Figure 2) was initiated in 2006. The site has undergone several years of herbicide treatments (including glyphosate and sethoxydim) and a controlled burn in fall 2011. *Festuca roemeri* has been drilled at the site every year since 2009. Three weeks post-burn, a native seed mix was spread over the entire site at approximately 48 seeds ft^{-1}. Twenty 5 x 80m plots were established to receive additional seed application to create islands of higher diversity and/or because seed of some species was limited (Thorpe 2010).

West Shore is a remnant upland prairie with a small population of *L. oreganus* throughout the southern half of the site (Figure 3). A challenge to managing this area is that exotic forbs are relatively abundant, but unlike grasses, cannot be treated with selective herbicides (as these would also kill the lupine and nectar plants). More detailed description of management history of both sites can be found in Thorpe 2010.

Figure 2. Locations of sugar addition macroplots at Big Spires, Fern Ridge Natural Area. Numbers are associated with GPS points (Table 1).

Figure 3. Locations of sugar addition macroplots at West Shore, Fern Ridge Natural Area. Numbers are associated with GPS points (Table 1).

METHODS

We established 5 experimental blocks per site. Blocks were composed of 4, 1m x 1m treatment units. The center of each block was marked with an 18" rebar capped with a yellow endcap. Rebar were inserted until only the cap was visible above ground. 12" nails were placed in the block corners, so that there was one nail in each corner. At Big Spires, blocks were established near the northwest corner of existing diversity plots (areas seeded in 2009 to create islands of high diversity; Thorpe 2010). At West Shore, macroplots were haphazardly placed throughout the half of the site occupied by *L. oreganus* and with a higher cover of forbs, however they did not contain *L. oreganus*.

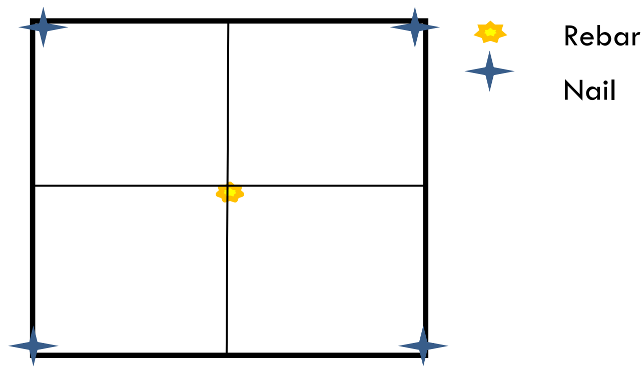

Figure 4. Block setup for carbon experiment. Treatment units (1 m^2) were randomly assigned and oriented North/South.

Treatments were randomly applied to the four treatment units within each block; sucrose was applied at a rate of 1.81 kg C ,$^{-1}$ per m^2 (Figure 4). Each unit received one of four levels of sucrose addition as follows:

1. Control
2. Carbon added spring 2012 only
3. Carbon added spring 2012 + fall 2012
4. Carbon added spring 2012 + fall 2012 + spring 2013

Monitoring occurred in all plots in June 2012 and 2013, one month after the spring carbon addition treatments. Percent cover of all species within each 1m^2 treatment plot was recorded, along with percent cover of bare ground, litter, and moss/lichen. Due to overlap of vegetation, total cover often exceeded 100%. Carbon was added to two randomly placed plots in fall 2012, and one more treatment occurred in spring 2013 (Table 1). Final monitoring occurred after the last treatment, in June 2013 to enable comparisons of the three treatment levels and the control.

We calculated total mean cover of native and exotic cover of the major functional groups (forbs, grasses, shrubs) for treated and untreated plots at each site. Due to differences in population characteristics and management history for both sites, we tested for treatment effects on each site separately. We used 2-factor ANOVA (R Development Core Team 2009) to test for the total cover, functional group cover by provenance, and cover of soil surface codes, using treatment unit and block as fixed factors. Data from treated areas were averaged to equal out sample size. When a significant main factor effect was found, we used a single factor ANOVA to test for differences in response for that factor.

Table 1. Carbon addition plot and treatment schedule, 2012-2013. For Big Spires, macroplot numbers are associated with diversity seeding plot numbers

Site	Macroplot #	Tag #	GPS Point	Corner of control	Carbon spring 2012 only	Carbon spring & fall 2012	Carbon Spring &fall 2012, spring 2013
Big Spires	18	157	151	NE	SW	NW	SE
Big Spires	16	158	152	SW	NW	NE	SE
Big Spires	8	159	153	SW	SE	NE	NW
Big Spires	5	161	154	NE	SW	SE	NW
Big Spires	2	160	155	NW	NE	SE	SW
West Shore	1	162	156	SW	NE	SE	NW
West Shore	2	166	157	NE	SE	NW	SW
West Shore	3	165	158	NE	NW	SW	SE
West Shore	4	164	159	NW	SW	SE	NE
West Shore	5	163	160	SW	SE	NW	NE

RESULTS AND DISCUSSION

West Shore

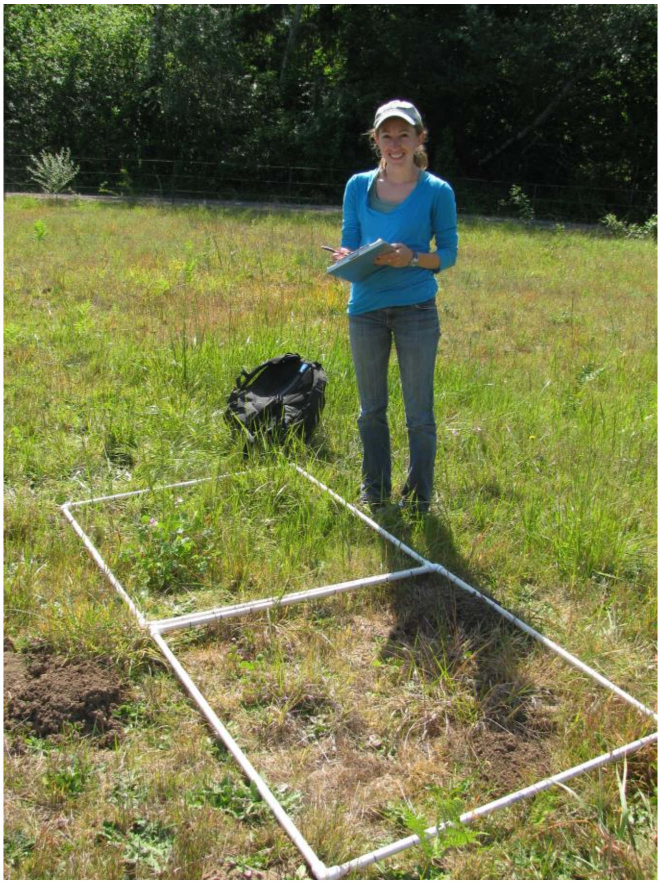

Figure 5. Monitoring carbon addition plots at West Shore in 2013. The plot in the foreground was treated with three carbon additions while the other was untreated.

West Shore was exotic graminoid dominated in 2010, but after a series of restoration treatments including mowing and spraying with Fluazifop, it is now primarily forb-dominated (Bois 2012). At West Shore, we observed 29 species in 2013, as compared to 20 species in 2012. Of those, 18 were exotic and 11 were native. Exotic species were more abundant than natives, composing 62% of cover, mostly graminoids. While native species didn't dominate the site (38% of total cover), there were high proportions of cover by native forbs, including many nectar species (Figure 6). Forbs included natives such as *Fragaria virginiana, Lotus unifoliatus,* and *Apocynum androsaemifolium,* also abundant were exotic forbs *Daucus carrota* and *Hypochaeris radicata*. Exotic grasses, including *Anthoxanthum ordoratum, Dactylis glomerata,* and *Schedonorus phoenix* were common and abundant.

Carbon addition decreased plant cover across both native and exotic species at West Shore. In general, total mean vegetative cover tended to decrease with increased levels of treatment (Figure 6; Appendix C, P =0.02). Additionally at West Shore, we observed treatment effects on total mean exotic cover (Appendix D, P >0.001) and total mean native cover (Appendix E, P= 0.03). In comparison to untreated plots, total mean exotic cover tended to decrease greatly with the first carbon treatment, and continued to decline with each additional treatment (Figure 6, above). Likewise, total mean native cover tended to increase slightly with the first carbon treatment, but decreased with each additional carbon treatment (Figure 6, above). When comparing those plots with three treatments to those in untreated plots, total native cover changed by -58%, total exotic cover changed by -48%, and total cover changed by -52%.

We observed some interesting trends in cover of functional groups (forbs, graminoids, and shrubs) relative to carbon treatments at West Shore (Figure 6). Though native cover tended to decrease more than exotic cover with three carbon treatments, the greatest decline occurred between the second and third carbon addition for native forbs (Figure 6, below). Native graminoids actually had a net increase in cover after one treatment when compared to untreated plots. This data suggests that at West Shore multiple carbon treatments might not be necessary to increase native species cover. For total exotic cover, the greatest decrease occurred after one carbon treatment, but continued with each consecutive treatment. While exotic forbs declined with each carbon addition, the difference between the second and third was the most dramatic. Exotic graminoids decreased with each consecutive carbon addition, while exotic shrubs were promoted between second and third carbon addition. These results suggest that if the final goal includes decreasing exotic species cover while promoting cover of natives, one or two carbon additions might be the most effective way to insure that native species are not disproportionally affected. Native species, primarily forbs, were already present and abundant at the site prior to treatment suggesting that the pre-treatment state might help determine the amount of carbon needed to impact it in a positive direction.

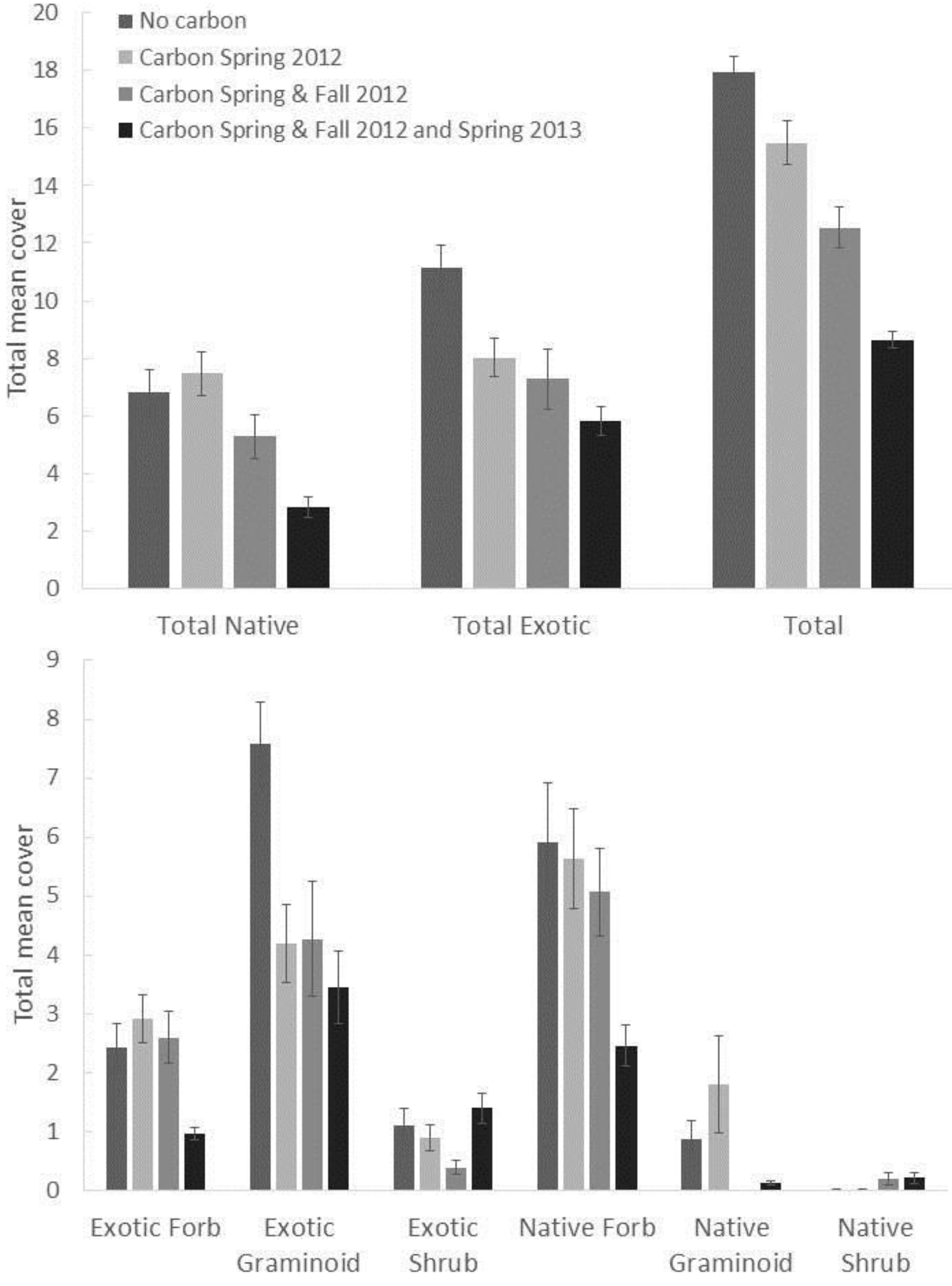

Figure 6. Total mean cover of functional groups at West Shore, 2013. Error bars represent 1 SE.

Big Spires

Big Spires was an extremely degraded site, but with restoration activities since 2008, community composition at the site has improved notably (Bois 2012). We observed 36 species in plots at Big Spires in 2013, which was an increase from the 19 observed in 2012. Of those, 26 were exotic and 11 were native. Plant communities at Big Spires were predominately composed of grasses. In 2013, exotic species composed 75% of cover while natives composed the remaining 25%. The most abundant species at Big Spires were exotic grasses *Anthoxanthum odoratum* and *Agrostis stolonifera*. *Festuca roemeri*, a native grass that had been seeded at the site, was also abundant across all treatment units.

We observed treatment effects on total mean exotic cover for Big Spires (Figure 7; Appendix F, P= 0.03), but not for total mean vegetative cover or total mean native cover (P = 0.4-1.0). At Big Spires, there was a slight decrease in exotic cover between the initial carbon treatment and untreated plots. The second treatment was associated with an increase in exotic cover to the level of the untreated plots. The final treatment resulted in a decrease in total mean cover, which was a -67% change from untreated plots (Figure 7, above). Though differences were not statistically significant, increased levels of carbon addition tended to increase total mean native cover, with a 119% increase with three carbon treatments in comparison to no treatment. Total cover tended to decrease with each consecutive carbon treatment though these differences were not statistically significant (Figure 7).

By looking at the data by functional group (forbs, graminoids, and shrubs), the data indicate some interesting trends that may be useful for restoration purposes. Exotic species cover was composed almost entirely by graminoids at Big Spires. Three treatments of carbon addition resulted in a very large decrease in cover for this functional group (-55%; Figure 7, below). Native cover was also composed primarily of graminoids which, while variable between one and two carbon treatments, increased in cover with the third treatment (Figure 7, below). These data suggest that at Big Spires, three carbon treatments were most effective at both decreasing exotic species cover and increasing cover of native species. In fact, with three carbon treatments, total mean cover of native graminoids tended to be greater than exotic graminoids (Figure 7).

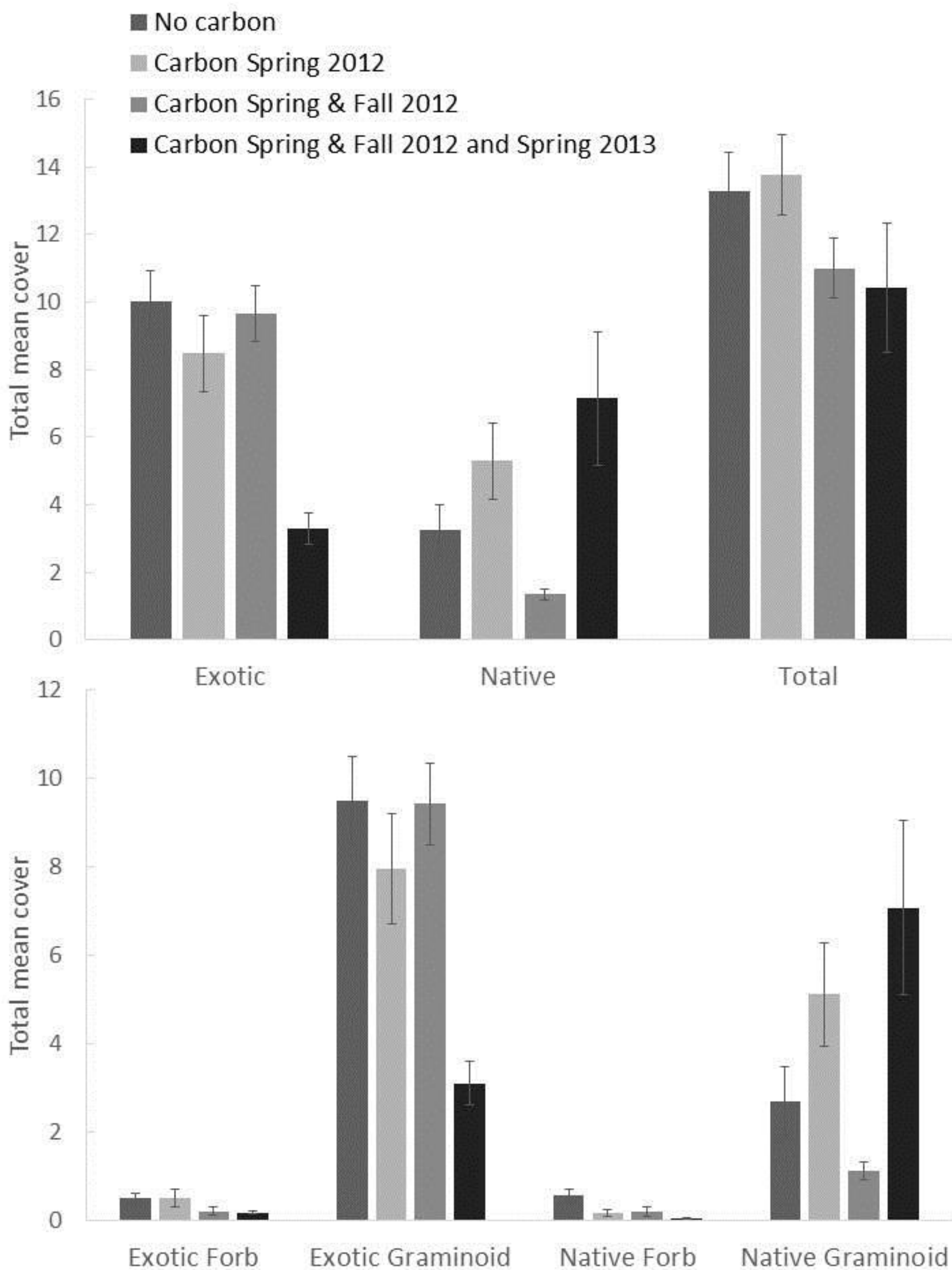

Figure 7. Total mean cover by functional group at Big Spires, 2013. Error bars represent 1 SE.

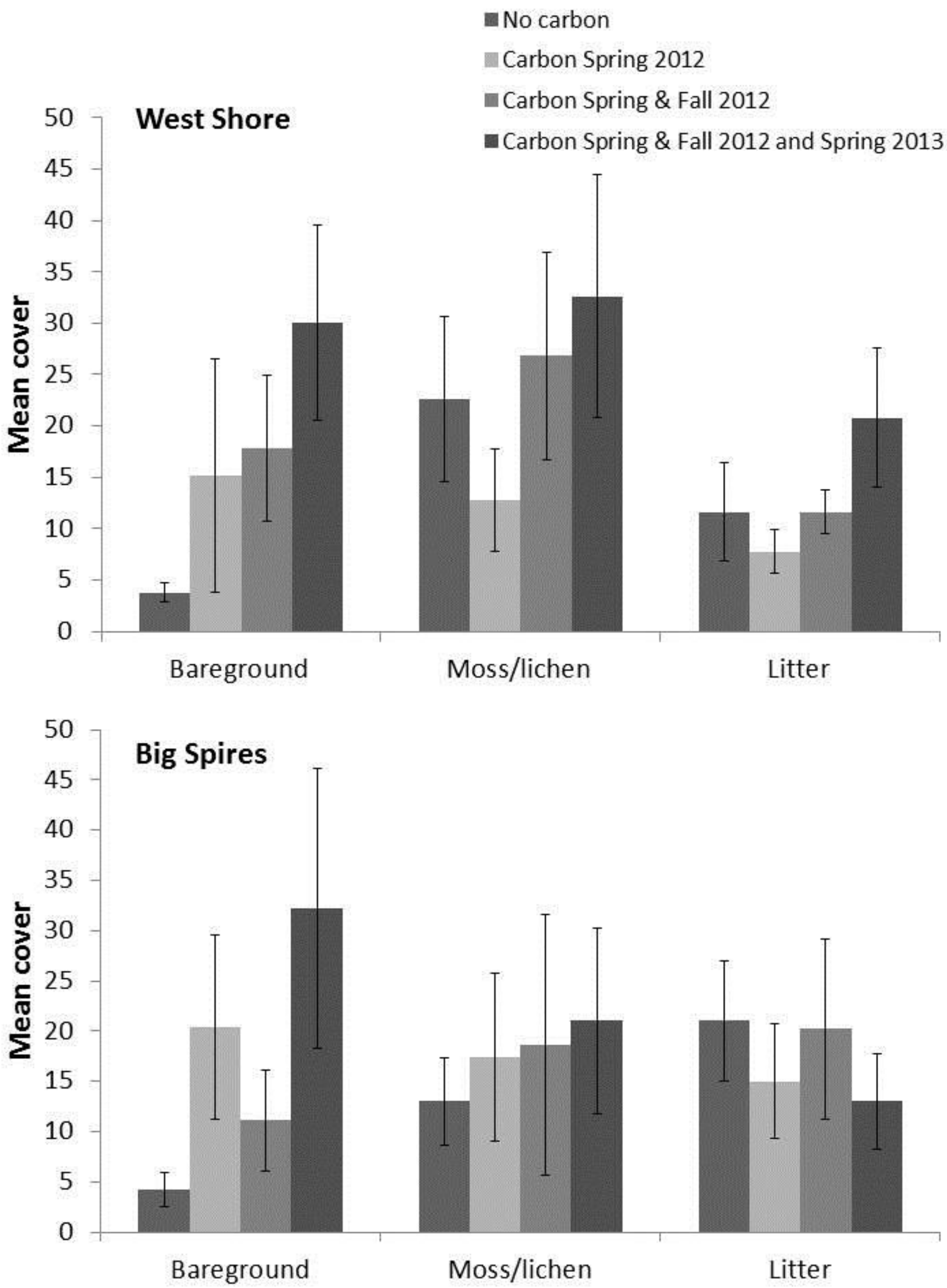

Figure 8. Mean percent cover of soil surface categories at West Shore (above) and Big Spires (below). Error bars represent 1 SE.

Soil surface categories also tended to be affected by carbon treatment. Bare ground tended to increase with each consecutive carbon treatment at West Shore (Figure 8, above). While bare ground was more variable at Big Spires, the third treatment yielded the most bare ground relative to untreated plots (Figure 8, below). Moss/lichen cover tended to increase slightly at Big Spires, and while West Shore experienced an overall increase in moss/lichen cover, there was a drop associated with the initial carbon addition. Litter cover tended to increase at West Shore overall, however Big Spires experienced a drop in litter cover associated with the first and third carbon treatment. These results suggest that carbon addition is effective at creating bare ground which could be useful during restoration efforts. While increasing bare ground is often a restoration objective, particularly in areas with high grass cover, it can also promote increased invasion by nonnative species already present. Seeding of native species in combination with carbon treatments could help ensure that bare ground would be colonized by desired species.

Management Implications

We found that across all sites carbon addition tended to decrease plant cover. At West Shore, which initially had higher native forb cover than Big Spires, carbon addition tended to have a slightly greater effect on native plants than exotic plants. At Big Spires, however, carbon addition tended to increase cover of native species while simultaneously decreasing exotic plant cover. These data suggest that plant community composition prior to treatment can greatly affect outcomes of the treatment. If the objective is to increase native species in a site with native species already present, fewer carbon addition treatments may be effective. If the site is primarily exotic dominated, multiple carbon additions could be ideal as they were found to promote native species, at least at Big Spires. These results are very site specific, and future studies at more sites would enable us to tease apart these interesting trends and their implications for habitat management. Carbon addition tended to increase bare ground at both sites, suggesting that targeting carbon treatments with seed addition might help promote native species abundance.

This study has promising results with regard to prairie restoration in the Willamette Valley and beyond. Carbon addition, particularly at a small scale, could be an option in systems where herbicide use is prohibited. For example, there is a large area at West Shore that houses the federally threatened Kincaid's lupine (*Lupinus oreganus*); it would be interesting to test these methods in the occupied area to see if this is a tool that could be useful in reducing non-native competition. Research into carbon addition on a larger scale and at sites with more variable plant community composition may enable us to determine factors to consider for use of this treatment. The positive effects of carbon addition on native species were site-specific in our study, and were likely related to the plant community present prior to treatment. Future studies investigating various levels of native plant diversity and functional group abundance, paired with different carbon treatment levels, could yield interesting results regarding a potential tool for land managers. Testing seed addition in combination with carbon addition would likely be an effective restoration method, to utilize the increased bare ground associated with these treatments. There are other forms of carbon that have been used for carbon addition including sawdust; exploring these in combination with sucrose and the ability to scale-up such methods could yield promising new tools for land managers fighting exotic species in a restoration setting. Though our study was conducted for two years, the long-term effects of sucrose as a carbon source could be another potential direction for future studies; in the Puget Lowlands, Kirkpatrick and Lubetikin (2011) found that the effects of sucrose addition did not last past two years.

We suggest initiating a new study at multiple sites to build on results presented this study. Treatment combinations could include various levels of sucrose addition with seed addition, and potentially testing other methods carbon addition (including sawdust or activated carbon). Additionally, comparing the financial feasibility of use of these tools could be very useful in determining the scale at which they might be applicable for restoration efforts. Future studies would enable us to tease apart how affects might differ depending on the initial plant community and present recommendations for land managers in the Willamette Valley.

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APPENDICES

Appendix A. Species found at West Shore in 2013, sorted by nativity and functional group.

Species	Nativity	Functional Group	Species	Navity	Functional Group
Crepis setosa	Exotic	Forb	*Apocynum androsaemifolium*	Native	Forb
Daucus carota	Exotic	Forb	*Fragaria virginiana*	Native	Forb
Hypericum perforatum	Exotic	Forb	*Lotus unifoliolatus*	Native	Forb
Hypochaeris radicata	Exotic	Forb	*Microseris laciniata*	Native	Forb
Leucanthemum vulgare	Exotic	Forb	*Pteridium aquilinum*	Native	Forb
Myosotis discolor	Exotic	Forb	*Sidalcea campestris*	Native	Forb
Parentucellia viscosa	Exotic	Forb	*Bromus carinatus*	Native	Graminoid
Plantago lanceolata	Exotic	Forb	*Danthonia californica*	Native	Graminoid
Sherardia arvensis	Exotic	Forb	*Luzula sp.*	Native	Graminoid
Taraxacum officinale	Exotic	Forb	*Crataegus douglasii*	Native	Shrub
Vicia hirsuta	Exotic	Forb	*Pseudotsuga menziesii*	Native	Shrub
Vicia sativa	Exotic	Forb			
Anthoxanthum odoratum	Exotic	Graminoid			
Arrhenatherum elatius	Exotic	Graminoid			
Dactylis glomerata	Exotic	Graminoid			
Festuca arundinacea	Exotic	Graminoid			
Holcus lanatus	Exotic	Graminoid			
Rubus armeniacus	Exotic	Graminoid			

Appendix B. Species found at Big Spires in 2013, sorted by nativity and functional group.

Species	Nativity	Functional Group	Species	Nativity	Functional Group
Centaurium erythraea	Exotic	Forb	*Achillea millefolium*	Native	Forb
Cerastium glomeratum	Exotic	Forb	*Aster hallii*	Native	Forb
Cirsium vulgare	Exotic	Forb	*Epilobium*	Native	Forb
Crepis capillaris	Exotic	Forb	*Eriophyllum lanatum*	Native	Forb
Crepis setosa	Exotic	Forb	*Lotus unifoliolatus*	Native	Forb
Daucus carota	Exotic	Forb	*Prunella vulgaris*	Native	Forb
Geranium dissectum	Exotic	Forb	*Ranunculus occidentalis*	Native	Forb
Gnaphalium sp.	Exotic	Forb	*Danthonia californica*	Native	Graminoid
Hypericum perforatum	Exotic	Forb	*Elymus glaucus*	Native	Graminoid
Hypochaeris radicata	Exotic	Forb	*Festuca roemeri*	Native	Graminoid
Leucanthemum vulgare	Exotic	Forb	*Luzula comosa*	Native	Graminoid
Myosotis discolor	Exotic	Forb			
Parentucellia viscosa	Exotic	Forb			
Plantago lanceolata	Exotic	Forb			
Rumex acetosella	Exotic	Forb			
Rumex acetosella	Exotic	Forb			
Sherardia arvensis	Exotic	Forb			
Taraxacum officinale	Exotic	Forb			
Vicia hirsuta	Exotic	Forb			
Vicia sativa	Exotic	Forb			
Agrostis stolonifera	Exotic	Graminoid			
Anthoxanthum odoratum	Exotic	Graminoid			
Arrhenatherum elatius	Exotic	Graminoid			
Festuca arundinacea	Exotic	Graminoid			
Holcus lanatus	Exotic	Graminoid			
Vulpia bromoides	Exotic	Graminoid			

Appendix C. Analysis of Variance (ANOVA) table for the response of total mean vegetative cover at West Shore. *P* values < 0.10 are in bold.

	Df	SS	MS	F value	*P* value
Treatment	1	69.59	69.59	6.35	**0.02**
Residuals	18	197.35	10.96		

Appendix D. Analysis of Variance (ANOVA) table for the response of total mean exotic cover at West Shore. *P* values < 0.10 are in bold.

	Df	SS	MS	F value	*P* value
Treatment	1	237.27	237.27	34.46	**<0.001**
Residuals	18	123.92	6.89		

Appendix E. Analysis of Variance (ANOVA) table for the response of total mean native cover at West Shore. *P* values < 0.10 are in bold.

	Df	SS	MS	F value	*P* value
Treatment	1	49.87	49.87	5.28	**0.03**
Residuals	18	170.04	9.45		

Appendix F. Analysis of Variance (ANOVA) table for the response of total mean exotic cover at Big Spires. *P* values < 0.10 are in bold.

	Df	SS	MS	F value	*P* value
Treatment	1	89.95	89.95	5.46	**0.03**
Residuals	18	296.28	16.46		