ATTACHMENT E

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Abstract

Wet prairies dominated by the perennial bunchgrass *Deschampsia cespitosa* occurred extensively in the Willamette Valley at the time of Euro-American settlement. Historical evidence and recent habitat changes suggest that late summer fires set by Native Americans suppressed woody vegetation and promoted vegetative growth, seed production and seedling recruitment of herbaceous species. Using prescribed fire for prairie management is challenging; dry season mowing is often the preferred alternative in wet prairies. We initiated a seven year experiment to compare the effects of late summer/fall mowing and burning on native and non-native vascular plants in a remnant Willamette Valley wet prairie. We analyzed change in percent frequency from pre-treatment to the first two post-treatment years (and over all years) with ANOVA for a randomized complete block design. Twenty-five of 61 species or life stages showed treatment effects from burning or mowing. Ordination and MRBP tests indicated small treatment effects on overall species composition. With burning, the response of 15 species was desirable relative to management objectives (the increase of a native herbaceous or decrease of non-native or woody species) and eight showed undesirable effects. With mowing, eight and seven species exhibited desirable and undesirable treatment outcomes, respectively. While both fire and mowing appear to provide short term benefits to native wet prairie plants, more species benefitted from burning than mowing. While prescribed fire may be a preferred management tool where and when it can be implemented, the optimal management treatment will depend upon the suite of introduced species at a given site.

Introduction

Wet prairies were extensive in the Willamette Valley at the time of Euro-American settlement, occupying approximately 138,000 ha, or about 10% of the Willamette Valley ecoregion. Wet prairies occupied areas of seasonally wet or saturated soils, typically on valley terraces, within a larger landscape mosaic of over 670,000 ha dominated by wet prairie, upland prairie, and savanna (Christy and Alverson 2011). Since settlement, most of these plant communities have been lost to agriculture, urban development, invasive plant species, and ecological succession (Johannessen et al. 1971, Christy and Alverson 1994), and only small fragments, amounting to less than 2% of the original extent, still remain as remnant native-dominated prairie and savanna (E. Alverson, unpublished data).

Many ecologists conclude that fires, largely set by Native Americans, were an important ecological influence for maintaining the prairie-savanna mosaic on the Willamette Valley landscape (Johannessen et al. 1971, Boyd 1999). This conclusion is supported by anecdotal historical evidence as well as modern observations of secondary succession occurring in extant prairies and savannas. Frequent fires effectively retard establishment of woody vegetation in prairies and savannas. This is accomplished by killing woody seedlings and some saplings (particularly conifers), and by top-killing broadleaf shrubs and tree saplings, though broadleaf woody plants often resprout from a protected root system. Fire also has other potential and differential effects on recruitment, vegetative growth, survival, distribution, and reproductive output of herbaceous plants in prairie and savanna habitats. Fire effects on abundance of both native and non-native herbaceous plants have been documented in Willamette Valley wet prairies (Pendergrass 1995, Streatfield and Frenkel 1997, Taylor 1999, Jancaitis 2001, Clark and Wilson 2001, Wilson 2002).

Prescribed fire has been used to manage Willamette Valley wet prairies since the 1970s. However, implementing controlled burns in small remnants within a larger context of agricultural and urban lands is logistically challenging (Hamman et al. 2011), prompting consideration of alternative methods of maintaining native prairies. Mowing vegetation during the dry

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season (late summer or early fall), at the same time that fires typically occur, is an alternative commonly employed by prairie managers in the region (Campbell 2004). Mowing is clearly effective at suppressing woody vegetation, at least for the short term, with little or no apparent damage to native herbaceous species that are largely dormant at this time of year. However, it is less clear whether mowing produces a beneficial response of native herbaceous plant species relative to introduced species. To investigate this question, we initiated a seven year experiment to compare the effects of late summer/fall mowing and burning on native and non-native vascular plants within a remnant Willamette Valley wet prairie. Our study is the first to compare species responses to fire and mowing in a high quality Willamette Valley wet prairie.

Methods

We designed a replicated field study in a wet prairie remnant at the Willow Creek Natural Area, a 210 ha preserve managed by The Nature Conservancy and located on the west side of Eugene, Lane County, Oregon (Figure 1). Though one of the best remaining examples of wet prairie in the Willamette Valley, Willow Creek is typical in that remnant habitat is surrounded by a land use mix that includes protected lands, urban development, agricultural lands, and rural residential lands. Prescribed fire has been used as a management treatment over about 20 ha of wet prairie at Willow Creek since 1986, with return intervals generally between 2 and 5 years. The study was implemented as a randomized complete block design in four macroplots (each 50 x 100 m) originally established for monitoring the wet prairie community. Each macroplot served as an experimental block, with a third randomly assigned to a burn, mow, or control (no management) treatment. In the late summer of 2001, treatments were applied to three macroplots, and in 2005, treatments were applied to all four macroplots. No other treatments were applied in intervening years. The burns were completed October 2, 2001, and September 27, 2005. Both took place under similar conditions between 1100 and 1500 hrs PDT at temperatures ranging 24 to 30 °C, with relative humidity ranging from 30 - 40% and winds from 5-10 kph. Standard fire behavior calculations provide an output reference fine fuel moisture of approximately 6% for these conditions and a resulting flame length of 1-1.5 m. Mow treatments were applied the week before burn treatments using rotary style mowers set at heights of approximately 15 cm.

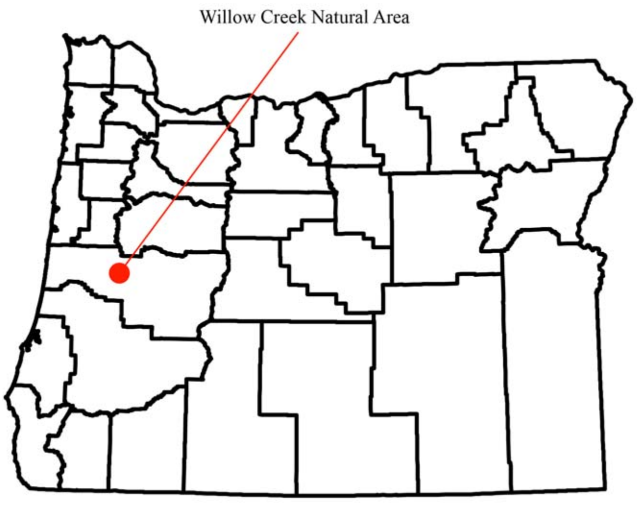

Figure 1. Location of the Willow Creek Natural Area, Lane County, Oregon.

We measured vegetation response to treatments with nested frequency plots, the same method historically used for monitoring the plant community. We estimated percent frequency of plant species by noting presence in permanently located, nested quadrats of 1.0, 0.10, and 0.01 m^2 (48 per treatment unit) in mid- to late summer every year between 2001 and 2007. Nested quadrats provide a way of simultaneously estimating frequency at varying spatial scales for rare and common species (Elzinga et al. 1998). Plots were systematically located after a random start along nine transects in each macroplot. Quadrats were spaced at 2 m intervals along each transect for all macroplots, except 3 m intervals for macroplot 1. Presence in the smallest sized quadrat was noted for each species. Sampling of vascular plants involved a subset of all species that occurred with at least 10% frequency across all macroplots when comprehensive vegetation monitoring was initiated in 1993, though a few additional taxa were added in subsequent years prior to 2001 (Table 1). Taxonomy generally follows Cook and Sundberg (2011), with the exception of *Danthonia*, which follows Hitchcock (1950).

For each treatment period, we compared effects of burning and mowing on the change in percent frequency from pre-treatment to the first two post-treatment years (calculated as post-pretreatment) with ANOVA for a randomized complete block design (α = 0.1). Treatment effects on change from 2001 to 2007 were also analyzed, resulting in five ANOVA models for each species. Macroplot 1 was excluded from analysis for 2001 and overall treatment effects because it did not receive the first round of treatments. Fisher's LSD was used for comparing treatment means. We analyzed data for 61 species or life stages (32 native herbaceous, 27

TABLE 1. List of species sampled for the Willow Creek wet prairie burn/mow experiment. Congeneric species pairs indicate taxa that were not distinguished in field data collection. An asterisk * denotes species for which data were analyzed. All guilds with more than one species were also analyzed for treatment effects.

Native Annual Forbs	**Introduced Annual Forbs**
Centaurium muhlenbergii	*Centaurium erythraea* [reprod.]*
*Centunculus minimus**	*Centaurium erythraea* [veg.]*
Cicendia quadrangularis	*Galium divaricatum* or *G. parisiense**
Lotus unifoliolatus	*Geranium dissectum*
Madia spp.*	*Linum bienne**
	*Parentucellia viscosa**
Native Perennial Forbs	*Trifolium dubium**
*Allium amplectens**	*Vicia hirsuta* or *V. tetrasperma**
Apocynum cannibinum	*Vicia sativa* var. *angustifolia*
Brodiaea coronaria or *B. elegans* ssp. *hooveri**	
Camassia leichtlinii ssp. *suksdorfi*i	**Introduced Biennial Forbs**
Camassia quamash ssp. *maxima* [reprod]*	*Daucus carota* [reprod.]*
Camassia quamash ssp. *maxima* [veg.]*	*Daucus carota* [veg.]*
Epilobium ciliatum s.l.	*Leucanthemum vulgare* [reprod.]*
Erigeron decumbens var. *decumbens**	*Leucanthemum vulgare* [veg.]*
Eriophyllum lanatum var. *leucophyllum**	
Fragaria virginiana var. *platyphylla**	**Introduced Perennial Forbs**
*Grindelia integrifolia**	*Hypericum perforatum**
Horkelia congesta ssp. *congesta**	*Hypochaeris radicata**
*Lomatium bradshawii**	*Leontodon saxatilis* ssp. *saxatilis* *
*Lotus formosissimus**	*Mentha pulegium**
Microseris laciniata ssp. *laciniata**	*Plantago lanceolata**
Perideridia montana or *P. oregana**	*Senecio jacobea*
Potentilla gracilis var. *gracilis**	
Prunella vulgaris var. *lanceolata**	**Introduced Annual Graminoids**
*Pyrrocoma racemosa**	*Aira caryophyllea* or *A. elegans**
Ranunculus occidentalis var. *occidentalis*	*Briza minor**
Ranunculus orthorhynchus var. *orthorhynchus*	*Bromus hordeaceus* ssp. *hordeaceus*
*Sericocarpus rigidus**	*Cynosurus echinatus*
Sisyrinchium idahoense, S. bellum, or *S. hitchcockii**	
*Symphyotrichum hallii**	**Introduced Perennial Graminoids**
*Toxicoscordion venenosum**	*Agrostis capillaris**
*Triteleia hyacinthina**	*Anthoxanthum odoratum**
*Wyethia angustifolia**	*Festuca rubra* var. *commutata**
	*Holcus lanatus**
Native Annual Graminoids	*Juncus marginatus**
Juncus bufonius s.l.*	*Phleum pretense*
	Poa compressa
Native Perennial Graminoids	*Schedonorus arundinaceus**
*Carex aurea**	
Danthonia californica var. *americana**	**Introduced Shrubs & Trees**
Deschampsia cespitosa var. *cespitosa**	*Pyrus communis**
Dichanthelium acuminatum var. *fasciculatum**	*Rosa eglanteria* or *R. nutkana* (invasive native shrub)*
Eleocharis acicularis var. *acicularis*	*Rubus armeniacus**
Juncus nevadensis var. *nevadensis**	
Juncus occidentalis or *J. tenuis**	
Luzula comosa s.l.*	
Native Shrubs & Trees	
Crataegus suksdorfii	
*Fraxinus latifolia**	
Spiraea douglasii var. *douglasii**	
Toxicodendron diversilobum	

introduced herbaceous, and 2 native woody invasive species). We limited data analysis to species with an average change of at least 10% absolute frequency in at least two treatment blocks, as well as some rare species not meeting these criteria, and most woody species occurring in the wet prairie. Species omitted from analysis were generally at low frequency or not widely distributed within the wet prairie habitat. In addition, we analyzed data for plant guilds (scored as present at the smallest scale containing a guild member for each quadrat) to compare treatment responses of the functional group and its component species.

We chose to analyze absolute change in frequency because this provides the simplest interpretation of treatment effects for management applications. An alternative approach would have been to analyze post-treatment frequency with the pre-treatment abundance as a covariate in ANCOVA. While ANCOVA has greater power at larger sample sizes, it may have less power for small studies such as ours because it uses an extra degree of freedom for estimating the effect of the covariate. The problem of low power extends to testing the assumption of equal slopes among treatments. A simple interpretation of treatment effects is not possible when slopes are unequal, and this condition may also lead to a low power test for the main effect (Engqvist 2005). Finally, it is inappropriate to use ANCOVA to adjust for initial differences of the covariate (i.e., pre-treatment abundance) between treatments (Quinn and Keough 2002). Although baseline abundance was similar across treatments for most species, this was not true for some of the non-native species and guilds.

Data for the quadrat size exhibiting the largest average temporal change were typically used for each species or guild (usually 1 m^2). We examined residual plots and max/min variance (of change) ratios to identify severe violations from the assumption of homogeneous variances (> 5). ANOVA on balanced designs is very robust to departures from normality, but not to heterogenous variances (Quinn and Keough 2002). Percentage data outside the midrange of 30-70% are known to be more problematic for ANOVA, because the variance of binomial data is a quadratic function of the mean (Zar 1996, Warton and Hui 2011). The arcsine square-root transformation is a commonly recommended remedy, although Zar (1996) states that a transformation is not warranted for balanced designs. Our analysis revealed a few cases where the arcsine transformation reduced treatment variance ratios and detected small treatment effects (usually < 10% absolute change in frequency) that were not significant for raw data. However, these cases were typically introduced upland species uncharacteristic of native wet prairie, and the transformation produced larger variance ratios and non-significant results for other species with larger treatment differences. Because of these discrepancies and the difficulty interpreting results (i.e., change in the arcsine scale), we report results only for untransformed data. Although logistic regression may be the most suitable analysis for binomial data, it can result in inflated Type I error rates and lower power for very small sample sizes (Warton and Hui 2011). SAS 9.2 and Systat 13 were used for univariate analysis and graphing time trends for species and guilds.

We characterized treatment effects as desirable or undesirable according to species origin. We considered a desirable treatment effect to be one that indicates success in attaining our management objectives (Wilson and Clark 2001). For example, a desirable treatment effect is an increase in frequency of a native herbaceous species, or a decrease in an introduced (or any woody) species. An undesirable treatment effect is a decrease in frequency of a native species or an increase in an introduced species. Only treatments significantly different from the control were counted. For example, if frequency of a native species increased significantly more in burn than mow but neither treatment was different from control, it was not scored as a desirable effect for burn or undesirable effect for mow. Plot data were collected separately for vegetative and reproductive life stages for four taxa, (one native and three introduced) because we anticipated different responses in their vegetative and reproductive life stages (Table 1). The different life stages are therefore treated as separate "species" for this analysis.

To illustrate annual changes in species composition for each macroplot and treatment, we used non-metric multi-dimensional scaling (NMS) in PC-ORD (v. 5.32). Data were relativized by species maxima to equalize the importance of common and rare species (McCune and Grace 2002). The autopilot mode of NMS was used with the Sorensen (Bray-Curtis) distance measure, the maximum thoroughness setting and randomization tests; the best configuration was re-run to apply the varimax rotation to increase orthogonality among axes. Separate ordinations were done for the years of 2001-2003 (excluding macroplot 1) and 2005-2007 (using all four macroplots). Successional vectors were used to illustrate the rate and direction of changes in species composition for each macroplot; vectors were also translated to the origin to highlight treatment differences (McCune and Grace 2002). We report Kendall's tau (a rank correlation coefficient) instead of Pearson's r to examine correlations of species abundance with ordination axes, because the former does not assume linearity.

We used the Blocked Multi-Response Permutation Procedure (MRBP) in PC-ORD to test for differences in species composition among treatments in each year (McCune and Grace 2002). This procedure compares the observed average distances within treatments with those expected by chance. A measure of effect size, the chance-corrected within-group agreement (*A*) is reported along with *P*-values. $A = 0$ if within-group differences are equal to the random expectation, is < 0 when group members more dissimilar than expected, and $= 1$ if all plots within groups are identical. Values for ecological data are commonly < 0.1 even when groups are significantly different (McCune and Grace 2002). Data were relativized by species maxima to reflect ordination results. We used the default Euclidean distance measure and median alignment of blocks to emphasize differences among treatments within blocks for MRBP tests, setting $\alpha = 0.1$ for all comparisons. To determine whether treatment effects on composition were being driven by only larger changes of more abundant species, we also ran MRBP on data relativized by species totals, giving equal weight to common and rare species (McCune and Grace 2002). Only species analyzed for treatment effects with ANOVA were included in the multivariate analyses.

Results

Of the 61 species or life stages (all hereafter called species) included in the analysis, 25 responded at least once to mowing, prescribed fire, or both treatments. Fourteen of these were native herbaceous species, 10 were introduced herbaceous species, and one an invasive native woody species. In addition, one native guild and four introduced guilds were impacted by treatments (Tables 2 and 3).

The magnitude and persistence of treatment effects varied considerably across species and over time. Statistically significant effects were often of short duration and not consistent for both treatment periods. Fourteen species had a significant response to a given treatment in only one comparison, while 11 responded to a given treatment in more than one comparison. There was no indication of cumulative treatment effects even for the latter group.

The importance of prescribed fire as a management treatment was highlighted by a simple tally of species with a significant response in any one of the five pre-post treatment comparisons. These comparisons included both the first and second years following the 2001 and 2005 treatments, as well as a comparison of the final year of the study (2007) and the pre-treatment conditions (Table 4). Fifteen species showed a significant desirable response to fire, while eight responded in a desirable direction to mowing. Fewer species responded in an undesirable direction, and the burn and mow treatments were more equal in this regard (eight for fire and seven for mowing). Thus, nearly twice as many species exhibited a desirable response to fire compared to mowing, and exhibited a more favorable ratio of desirable to undesirable outcomes.

With native guilds, the only treatment effect that was undesirable was for perennial forbs from 2005 to 2006 for both burn and mow treatments (Table 2). This effect was the result of a greater increase from 2005 to 2006 in the control than in either treatment.

For introduced guilds, we documented treatment effects for biennial forbs, perennial forbs, and annual graminoids. Burning temporarily suppressed introduced biennial forbs in 2006, but delivered persistent, unfavorable management responses in introduced annual graminoids in each two year post-treatment period. Introduced perennial forbs were the only guild that showed contradictory results, with a desirable treatment effect in the first year after the 2005 burn, but an undesirable treatment effect in the second year after the 2001 burn. An undesirable treatment effect for this guild was also recorded in the mow treatment in the second year after the 2001 burn (Table 3).

Recording frequency of different life stages allowed us to distinguish different responses to the two management treatments (Tables 2 and 3). For *Leucanthemum vulgare*, fire was beneficial in reducing vegetative plants relative to the control, but no burn treatment effect was observed for the flowering life stage. In contrast, an undesirable response to mowing was detected as the flowering life stage increased in the first year after both the 2001 and 2005 treatments. Flowering *Camassia quamash* increased significantly relative to the control in the first year following the 2001 burn, but not significantly in the second year, while vegetative *C. quamash* increased significantly in the second year but not significantly in the first (Figure 2 and Table 2). The significant second year increase in the vegetative plants may have resulted from seed produced in the first year after the burn, but we did not distinguish first year seedlings from older vegetative plants.

The direction of treatment effect was consistent for the ten species with significant responses to the same treatment in more than one pre-post comparison. Only one species exhibited inconsistent treatment effects. *Linum bienne*, an introduced annual forb, decreased in abundance relative to control after the 2001 prescribed burn but showed a relative increase from 2001 to 2007 (Table 3). One possible explanation for this result is the timing of the burns relative to seedling germination triggered by fall precipitation. Local weather data from the Eugene airport are consistent with the hypothesis that more seed was left to germinate after the 2005 burn. Measuring from August 1 of each year, more rain and more days with measurable precipitation occurred prior to the 2001 burn (2.7 cm over 13 days before October 2) compared to the 2005 burn (1.6 cm over 6 days before September 27). Furthermore, the magnitude of the desirable treatment effect (3.5) was much smaller than that of the undesirable one (22.9). We interpret these results as representing variation in response reflecting the subtle interplay between the phenology of each plant species and the specific unique conditions of the vegetation at the time of treatment application.

Time vectors from NMS ordinations showed that most of the variation in composition was due to spatial (macroplot) differences and temporal changes common across treatments (Figures 3 and 4). Many of the species more highly correlated with ordination axes were unaffected by treatments (Table 5).

However, we did document treatment effects on composition (Table 6). Treated plots within the same macroplot varied in the rate (vector length) or direction of compositional change, especially in the first post-treatment year (Figures 3b and 4b, Table 6a). Treatment effects were smaller and inconsistent in 2002-03, with $A < 0.1$ even for significant P-values. The burn-mow difference in 2002 was driven largely by trends in Macroplot 3, which also contributed largely to the burn effect in 2003 (Figure 3b). Effects were larger after the second set of treatments in 2006, when composition varied among all three treatment levels (Figure 4b). This is likely due to the greater power from an additional macroplot. The 2007 difference between control and burn was largely due to Macroplots 1 and 7 (Figure 4b). MRBP results for data relativized by species totals are similar to those from the relativization by maxima, suggesting that real changes in composition (and not just abundance) contributed to these differences (Table 6b).

Discussion

The results of our study can be viewed both as a broad measure of the value of implementing management treatments in wet prairie and as a focused appraisal of individual species responses to a limited number of treatment events. However, interpretation of our results is somewhat complicated by variation in abiotic and biotic environmental parameters during the course of the study. In particular, the years 2001 and 2005 were marked by both extremely low precipitation and by high population numbers of voles (*Microtis* sp.). Vole herbivory appeared to be selective, with a disproportionate impact on certain species of herbaceous plants, both native and introduced. The effect of low precipitation and high vole abundance in 2005 is particularly illustrated by the graph of time trends for *Camassia quamash* (Figure 2). Because the 2001 and 2005 vegetation data represent both the pre-treatment vegetation condition and the high impact of vole herbivory, treatment effects on individual species (and on species composition) are inevitably confounded with influences of these other factors. Large changes in frequency of some species were observed in control plots, sometimes larger than the changes observed in the treatment plots. As a result, ordination analysis revealed that treatment effects on composition were small relative to the natural temporal variation observed across all plots (Figures 3–4).

The greater ratio of desirable to undesirable treatment responses (particularly the 1.9:1 ratio for the burn treatment), highlights the importance and value of management in Willamette Valley wet prairies. Furthermore, only 13 of the 61 species analyzed (seven native and six introduced) exhibited an undesirable response to either management treatment for any year to year comparison. In the absence of natural and historic anthropomorphic disturbance regimes (primarily fire), active management is needed to prevent conversion of prairie to forest and halt the increase of introduced herbaceous species at the expense of declining native species. The challenge is identifying the set of management approaches that most favor native over non-native (or native invasive) species appropriate for a given site.

In our study more species/life stages responded favorably to fire than mowing (15 vs. 8). Of particular management importance is the desirable response to fire by seven of ten native perennial forbs showing significant treatment effects, five "species" of which (*Brodiaea coronaria/ elegans, Camassia quamash*/ reproductive, *Camassia quamash*/vegetative, *Toxicoscordion venenosum*, and *Triteleia hyacinthina*) were geophytes growing from underground bulbs or corms.

However, both treatments promoted favorable responses for several native species. The perennial forb *Potentilla gracilis* and the perennial graminoids *Deschampsia cespitosa* and *Juncus occidentalis* all responded in a desirable direction to both treatments. Two introduced annual forbs, *Centaurium erythrea* (the reproductive life stage) and *Galium divaricatum* or *G. parisiense*, showed beneficial responses to either treatment as well. Suppressing establishment of woody vegetation in wet prairie is another goal of our management, and we found both burning and mowing effective at reducing the invasive native woody plant *Fraxinus latifolia* in the second year after the 2005 treatments.

TABLE 2. Significant treatment effects of the Mow/Burn experiment for native guilds and herbaceous species at the Willow Creek Preserve, 2001-2007. Change in % frequency from pre- to two post treatment years (and from 2001 to 2007) is reported for Control. Treatment effects are calculated as the difference between the change in % frequency between each treatment and Control, e.g., Δ Burn - Δ Control. Results are for 1 m² unless noted otherwise. Significant treatment effects at the 0.1 level (Fisher's LSD) are in bold text; a positive number in bold represents a desirable treatment effect, and negative number in bold represents an undesirable treatment effect.

	2001 Treatments: Change from 2001 to (n = 3)									2005 Treatments: Change from 2005 to (n = 4)					
	2002			2003			2007			2006			2007		
		Treatment effect			Treatment effect			Treatment effect			Treatment effect			Treatment effect	
Guild/Species	Δ Control	Δ Burn - Δ Control	Δ Mow - Δ Control	Δ Control	Δ Burn - Δ Control	Δ Mow - Δ Control	Δ Control	Δ Burn - Δ Control	Δ Mow - Δ Control	Δ Control	Δ Burn - Δ Control	Δ Mow - Δ Control	Δ Control	Δ Burn - Δ Control	Δ Mow - Δ Control
Perennial Native Forbs (0.01 m²)	7.6	7.6	2.8	9.7	-0.7	-1.4	15.3	-4.2	0.7	10.4	**-8.8**	**-8.3**	7.8	4.2	1.0
Brodiaea coronaria or *B. elegans*	1.4	-4.2	-3.5	2.1	**14.6**	0.0	9.0	**8.4**	-6.2	2.6	3.1	0.0	10.9	**11.5**	-4.1
Camassia quamash ssp. *maxima* [reprod]	11.8	**25.7**	4.9	35.4	11.8	**-28.5**	34.7	27.1	0.0	25.0	11.5	4.2	53.1	20.3	1.6
Camassia quamash ssp. *maxima* [veg.] (0.1 m2)	13.9	9.0	0.0	13.9	**13.2**	**-11.8**	20.1	**12.5**	-6.2	28.6	-3.1	-2.6	31.8	2.6	-6.3
Grindelia integrifolia	0.0	-2.1	4.2	6.9	**-6.2**	**6.3**	16.0	**-12.5**	**8.3**	1.0	-2.6	**4.7**	1.6	1.5	**8.8**
Horkelia congesta ssp. *congesta*	0.0	-2.1	2.1	0.0	**-2.1**	0.7	0.0	-1.4	0.7	0.0	0.5	-0.5	0.0	0.5	-0.5
Lotus formosissimus	-7.6	0.0	1.4	-8.3	1.4	2.1	-13.2	**-7.6**	6.3	5.2	-5.2	-6.3	2.1	**-12.5**	-2.6
Microseris laciniata ssp. *laciniata* (0.1 m²)	2.8	11.8	2.8	-0.7	**9.7**	4.2	-2.8	1.4	3.5	6.8	0.5	-2.6	1.6	-0.5	0.0
Potentilla gracilis var. *gracilis*	-2.8	-2.1	3.5	-3.5	0.0	**8.4**	-3.5	**5.6**	**14.6**	1.0	1.6	2.1	-4.7	7.3	6.8
Toxicoscordion venenosum	2.1	2.8	0.0	2.1	0.7	0.0	5.6	2.7	9.0	1.6	**17.2**	0.5	5.7	0.6	9.9
Triteleia hyacinthina	2.1	1.4	0.0	1.4	**17.4**	-0.7	1.4	2.1	0.0	-0.5	2.6	0.5	0.5	2.6	0.5
Native Annual Graminoids															
Juncus bufonius s.l.	0.7	11.1	1.4	6.3	-2.8	-1.4	0.7	3.5	0.7	15.6	2.1	**-13.5**	1.6	1.0	-1.0
Native Perennial Graminoids (0.01 m²)	-3.5	0.0	2.1	-3.5	1.4	4.9	-14.6	6.2	6.9	-2.1	3.6	4.7	3.1	4.7	2.6
Danthonia californica var. *americana* (0.1 m2)	4.2	-20.1	-4.2	4.2	**-15.3**	-1.4	2.1	-3.5	0.7	-6.3	0.0	5.2	-3.1	1.0	1.0
Deschampsia cespitosa var. *cespitosa* (0.01 m2)	-4.9	11.1	9.0	-9.0	**9.0**	**11.1**	-14.6	1.4	2.8	-5.2	0.5	7.3	4.2	-2.6	3.6
Juncus occidentalis or *J. tenuis*	-16.7	**11.1**	**7.0**	-16.7	9.7	0.0	6.9	-9.7	-1.4	31.8	-2.6	2.6	30.7	-5.2	6.3

TABLE 3. Significant treatment effects of the Mow/Burn experiment for introduced guilds herbaceous species, and native woody species at the Willow Creek Preserve, 2001-2007. Change in % frequency from pre- to two post treatment years (and from 2001 to 2007) is reported for Control. Treatment effects are calculated as the difference between the change in % frequency between each treatment and Control, e.g., Δ Burn - Δ Control. Results are for 1 m² unless noted otherwise. Significant treatment effects at the 0.1 level (Fisher's LSD) are in bold text; a negative number in bold represents a desirable treatment effect, and a positive number in bold represents an undesirable treatment effect.

	2001 Treatments: Change from 2001 to (n = 3)									2005 Treatments: Change from 2005 to (n = 4)					
	2002			2003			2007			2006			2007		
		Treatment effect			Treatment effect			Treatment effect			Treatment effect			Treatment effect	
Guild/Species	Δ Control	Δ Burn - Δ Control	Δ Mow - Δ Control	Δ Control	Δ Burn - Δ Control	Δ Mow - Δ Control	Δ Control	Δ Burn - Δ Control	Δ Mow - Δ Control	Δ Control	Δ Burn - Δ Control	Δ Mow - Δ Control	Δ Control	Δ Burn - Δ Control	Δ Mow - Δ Control
Introduced Annual Forbs (0.1 m²)	-2.1	-6.2	4.2	-11.1	**-9.7**	**9.7**	-31.9	0.0	-2.1	-8.9	-9.3	8.9	-39.6	-4.7	-5.7
Centaurium erythraea [reprod.]	-1.4	**-43.0**	6.3	0.0	**-36.8**	7.6	-19.4	-28.5	-13.2	-14.6	**-68.2**	0.5	-44.8	**-27.1**	**-16.7**
Centaurium erythraea [veg.]	-23.6	**-34.7**	14.6	-65.3	2.8	5.6	-55.6	-1.4	-11.1	-54.2	-9.9	8.3	-65.1	-2.1	-10.9
Galium divaricatum or *G. parisiense*	-2.1	0.7	-11.1	-6.9	-4.2	**-21.6**	-17.4	-2.7	**-24.3**	21.9	**-27.1**	-11.0	-28.1	-6.8	-19.8
Linum bienne	1.4	**-3.5**	2.1	4.9	2.1	2.1	1.4	**22.9**	0.7	12.0	1.0	**5.2**	2.6	9.4	-4.2
Trifolium dubium	5.6	-1.4	-1.4	4.9	-4.9	-3.5	-1.4	-0.7	-6.9	0.0	**5.2**	**5.7**	0.0	0.0	0.5
Introduced Biennial Forbs	-16.7	-2.1	8.3	-11.1	-6.9	-1.4	-0.7	-5.6	-4.2	3.1	**-14.0**	1.1	1.6	-6.8	-2.6
Leucanthemum vulgare [reprod.]	-7.6	3.4	**36.8**	15.3	-15.3	6.9	21.5	-6.9	3.5	-22.9	12.5	**24.5**	6.3	-2.6	-7.3
Leucanthemum vulgare [veg.]	-17.4	-4.2	6.9	-27.1	1.4	13.2	-1.4	-8.3	-8.3	-1.0	**-11.0**	4.6	-1.0	-6.3	-3.6
Introduced Perennial Forbs) (0.1 m²	-10.4	3.5	6.9	-29.9	**21.6**	**24.3**	9.0	5.6	0.0	7.8	**-11.4**	4.2	0.0	-4.7	2.1
Mentha pulegium	-5.6	2.1	**8.4**	-2.8	3.5	**10.4**	22.9	-7.6	5.6	2.6	-8.9	-3.1	3.6	-2.6	-3.1
Introduced Annual Graminoids (0.1 m²)	0.7	**33.3**	-9.0	3.5	**29.1**	-6.3	-0.7	19.4	-15.3	16.1	**16.7**	2.7	4.2	**16.1**	-9.9
Aira caryophyllea or *A. elegans*	-20.8	9.0	3.5	-11.1	9.0	9.7	-3.5	16.0	2.8	3.6	-2.1	-0.5	-0.5	**10.4**	-1.1
Briza minor	1.4	**39.6**	6.2	6.9	**29.9**	1.4	2.1	19.4	-11.8	36.5	**13.0**	**-13.1**	15.6	**16.2**	**-19.8**
Introduced Perennial Graminoids	0.0	0.0	0.7	0.0	0.7	1.4	0.7	0.7	0.0	0.5	0.5	0.0	0.5	0.5	0.0
Native Trees - *Fraxinus latifolia*	0.0	-3.5	-0.7	0.0	0.0	1.4	0.7	-1.4	0.0	4.2	-3.6	-2.6	5.2	**-6.8**	**-4.2**

TABLE 4. Vascular plant species showing significant treatment effects of the Mow/Burn experiment at the Willow Creek Preserve, for at least one year-to-year comparison for the period 2001-2007. Treatments showing significant effects are indicated with an asterisk (*). Results are for the 1 m² quadrat size unless noted otherwise.

Species responses in any year to year comparison	Positive Response		Negative Response	
Species	Burn +	Mow +	Burn -	Mow -
Native Perennial Forbs				
Brodiaea coronaria or B. elegans	*			
Camassia quamash ssp. maxima [veg.] (0.1 m2)	*			*
Camassia quamash ssp. maxima [reprod]	*			*
Grindelia integrifolia		*	*	
Horkelia congesta ssp. congesta			*	
Lotus formosissimus			*	
Microseris laciniata ssp. laciniata (0.1 m²)	*			
Potentilla gracilis var. gracilis	*	*		
Toxicoscordion venenosum	*			
Triteleia hyacinthina	*			
Native Annual Graminoids				
Juncus bufonius s.l.				*
Native Perennial Graminoids				
Danthonia californica var. americana (0.1 m2)			*	
Deschampsia cespitosa var. cespitosa (0.01 m2)	*	*		
Juncus occidentalis or J. tenuis	*	*		
Introduced Annual and Biennial Forbs				
Centaurium erythraea [veg.]	*			
Centaurium erythraea [reprod.]	*	*		
Galium divaricatum or G. parisiense	*	*		
Linum bienne	*		*	*
Trifolium dubium			*	*
Leucanthemum vulgare [veg.]	*			
Leucanthemum vulgare [reprod.]				*
Introduced Perennial Forbs				
Mentha pulegium			*	
Introduced Annual Graminoids				
Aira caryophyllea or A. elegans			*	
Briza minor		*		*
Native Woody Species				
Fraxinus latifolia	*	*		
Overall number of significant responses per treatment category:	**15**	**8**	**8**	**7**

Results that contradict our management goals are of equal interest. Both treatments were generally ineffective at suppressing introduced grasses (Table 3). Fire produced relatively large and consistent increases in *Briza minor* after both treatment periods, while mowing appeared to suppress it in 2006-2007 (Table 3). Fire also increased *A. caryophyllea/elegans* after the 2005 treatment. However, both species are small statured annuals, which are likely to benefit from a short term removal of thatch and litter after a burn, and do not appear to suppress associated native species. Both species tend to decline to pre-burn abundance a few years after

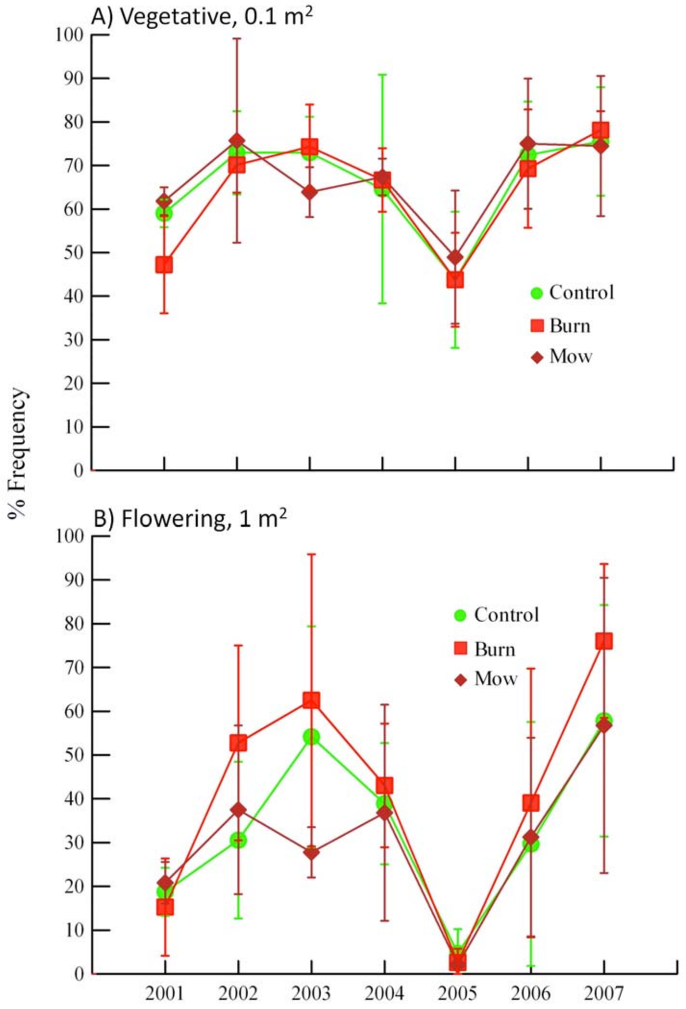

Figure 2. Mean (± SD) percent frequency by treatment and year for vegetative and flowering *Camassia quamash*. n = 3 for 2001-2004; n = 4 for 2005-2007.

the burn (there was no significant treatment effect for either species in the 2001 to 2007 comparison), so provided burns are not conducted on short rotation they are unlikely to be highly problematic in Willamette Valley most wet prairies.

Several native species also exhibited undesirable responses to burning. *Danthonia californica* var. *americana* was suppressed by the 2001 fire. This may be of little consequence from a community perspective, since *D. californica* var. *americana* is among the most abundant native herbaceous species in the wet prairie at Willow Creek. The fire effect did not persist to the 2001-2007 comparison and was not generated by the second round of treatments. *Lotus formosissimus* is a relatively uncommon native perennial forb in the Willamette Valley, and concern for this species is more about its substantial decline from 2001 to 2007 across all treatments than about the negative impact of the 2005 burn.

Horkelia congesta ssp. *congesta* declined in the second year after the 2001 burn relative to the control, though the treatment effect in this study was perhaps too small to be considered biologically important. This is a globally at-risk taxon restricted to a small number of prairie remnants throughout its global range of the Willamette and Umpqua Valleys as a consequence of habitat loss, invasive species, and grazing (U.S Fish and Wildlife Service 2010). However, this species is also monitored at Willow Creek with more intensive census plots. Unburned subpopulations of *H. congesta* located outside of the treated macroplots declined after 2001 even more strongly

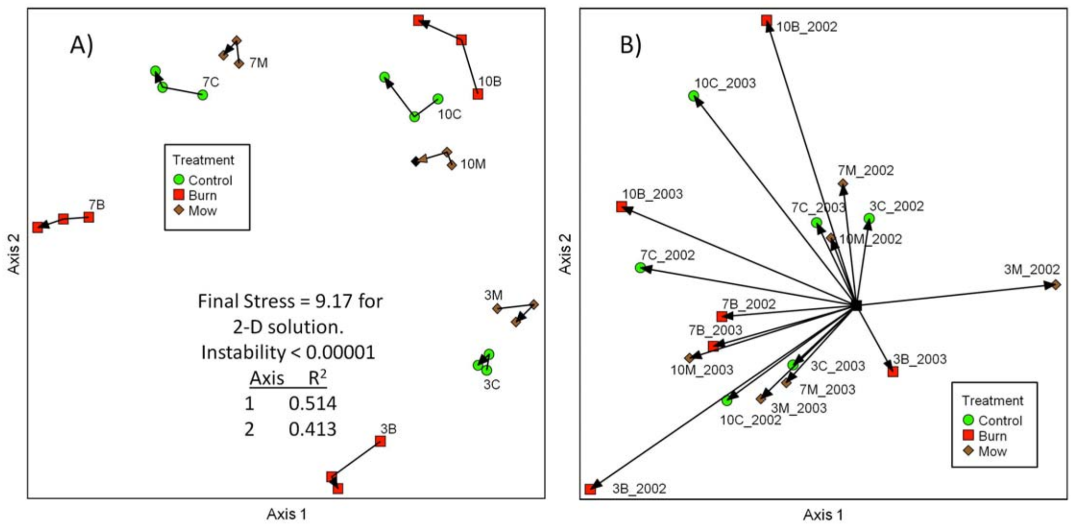

Figure 3. A) Time vectors (2001-2003) for treatment plots from NMS ordination with arrow indicating the direction of time vector (last point is 2003). B) Vectors translated to the origin. Data relativized by species maxima.

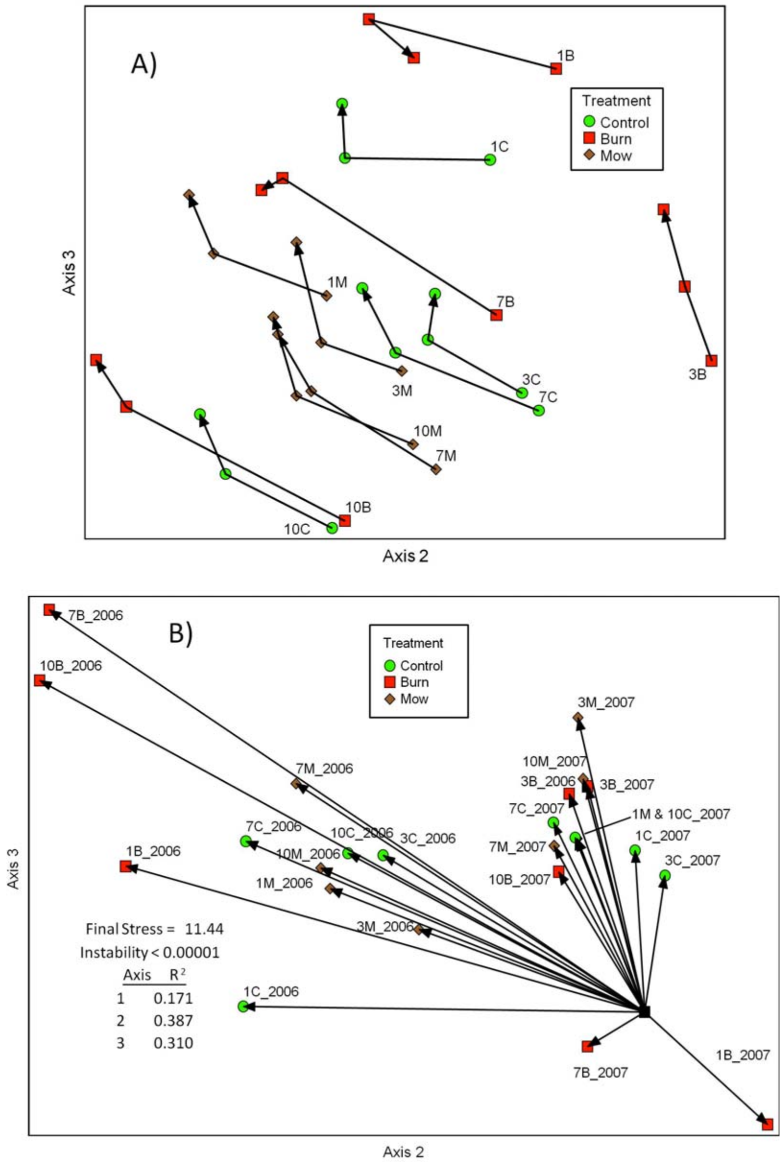

Figure 4. A) Time vectors (2005-2007) for treatment plots from NMS with arrow indicating the direction of time vector (last point is 2007). B) Vectors translated to the origin. Data relativized by species maxima.

than in the burn treatments. This focused monitoring allows managers to track population trends more precisely and make specific modifications to management treatments (such as exclude areas of occupied habitat from future burn units) if warranted.

Grindelia integrifolia was the only native species that increased with mowing while decreasing after burning. Its response to mowing was consistent for both the 2001 and 2005 mow treatments, but the negative response to fire was only observed in the first post-treatment period. This is a relatively weedy native species and fluctuations in its abundance are not especially problematic from a management perspective.

Because some non-native plant species in Willamette Valley wet prairies may be adapted to fire or mowing, decisions about management treatments may differ depending upon the suite of introduced species that occur at a given site. In the case of Willow Creek, we feel that the fire-adapted species (particularly non-native annual grasses) are not especially problematic given our likely burn regime. In fact, fire is the preferred treatment for non-native species of greater management concern than introduced grasses, such as the forbs *Leucanthemum vulgare* and *Mentha pulegium*. Both species increased in response to mowing, and the former decreased after burning (in its vegetative life stage). At other sites, fire-adapted non-natives not present at Willow Creek may call for an emphasis on mowing over fire.

Our results are similar in many ways to results of previous studies of management treatments, particularly fire, in Willamette Valley wet prairies (Streatfield 1995, Pendergrass 1995, Taylor 1999, Jancaitis 2001, Clark and Wilson 2001, Wilson 2002). These studies documented desirable responses to a burn treatment relative to the control for native species such as *Camassia quamash, Microseris laciniata, Potentilla gracilis*, and *Toxicoscordium venenosum*, as well as negative responses of the abundant native grass *Danthonia californica*.

Results presented here also share some similarities to studies of fire in a broader range of habitats across the larger Willamette Valley-Puget Trough-Georgia Basin ecoregion as well. For example, Dunwiddie (2002) observed an increase in cover of annual species in upland prairie on Yellow Island, San Juan County, Washington, for the first three years following a 1987 burn, after which cover of annuals returned to pre-burn levels. In our study, a similar fire effect was observed particularly with non-native annual grasses. While the burn treatment exhibited a greater frequency change (increase) over the course of our study (2001-2007) as compared to the change in the control, the difference between the two comparisons was not statistically significant.

Our results also suggest that controlled burns produce beneficial treatment effects that are not duplicated by mowing alone. However, given the logistical constraints

TABLE 5. Kendall's tau rank correlation coefficients with NMS ordination axes for each treatment period. Species listed have a coefficient of at least ± 0.40 for one axis. Statistics for 2005-2007 are provided only for axes 2 and 3, which explained 70% of the variance in that data matrix. * indicates species responding to one or both treatments (Tables 2-3).

	Axis			
	2001-2003		2005-2007	
Species	1	2	2	3
*Aira caryophyllea/elegans**	0.04	0.60	-0.55	-0.50
Allium amplectens	-0.49	0.24	-0.21	0.58
Anthoxanthum odoratum	0.08	-0.51	0.21	0.21
Brodiaea coronaria or *B. elegans**	-0.50	0.07	-0.23	0.34
*Briza minor**	0.01	0.27	-0.51	-0.12
Carex aurea	0.11	-0.44	-0.04	0.45
Centaurium erythraea [reprod.]*	0.44	-0.09	0.26	-0.32
Centunculus minimus	-0.10	-0.41	0.20	0.07
Danthonia californica var. *americana**	-0.02	0.38	-0.41	-0.31
Daucus carota [reprod.]	0.55	-0.18	-0.23	-0.08
Daucus carota [veg.]	0.71	-0.24	-0.07	-0.15
Deschampsia cespitosa var. *cespitosa**	-0.40	0.53	-0.47	-0.09
Erigeron decumbens var. *decumbens*	-0.42	0.43	-0.38	-0.08
Eriophyllum lanatum var. *leucophyllum*	0.07	0.61	-0.48	-0.38
Festuca rubra var. *commutata*	0.40	0.15	-0.40	-0.26
*Fraxinus latifolia**	0.76	-0.20	-0.07	0.12
Fragaria virginiana var. *platyphylla*	0.55	-0.29	-0.10	-0.08
Galium divaricatum or *G. parisiense**	0.14	0.42	-0.04	-0.60
*Grindelia integrifolia**	-0.36	0.56	-0.28	-0.35
Holcus lanatus	-0.09	0.56	-0.41	-0.30
Hypericum perforatum	0.34	-0.21	0.45	-0.19
Hypochaeris radicata	0.58	-0.29	-0.56	0.15
Juncus marginatus	0.30	-0.58	0.16	0.48
Juncus nevadensis var. *nevadensis*	-0.55	-0.10	0.05	0.36
Juncus occidentalis or *J. tenuis**	-0.18	0.49	-0.45	-0.15
Leontodon saxatilis ssp. *saxatilis*	0.27	-0.19	-0.50	-0.11
Leucanthemum vulgare [veg.]*	0.66	-0.23	-0.26	-0.35
Leucanthemum vulgare [reprod.]*	0.65	-0.14	-0.31	-0.25
*Linum bienne**	0.50	-0.02	-0.38	-0.33
Lomatium bradshawii	0.03	-0.44	-0.15	0.47
*Lotus formosissimus**	-0.52	-0.05	0.37	0.34
Luzula comosa s.l.	0.19	0.24	-0.51	0.15
Madia spp.	0.19	0.17	-0.42	-0.38
Microseris laciniata ssp. *laciniata**	-0.52	0.33	-0.46	-0.05
Parentucellia viscosa	0.54	-0.26	0.16	-0.41
Perideridia montana or *P. oregana*	-0.11	0.41	-0.39	-0.29
Plantago lanceolata	0.42	0.29	-0.50	-0.25
Prunella vulgaris var. *lanceolata*	0.28	0.22	-0.48	-0.31
Pyrrocoma racemosa	0.52	-0.49	-0.05	0.41
Rubus armeniacus	0.25	-0.66	0.04	0.50
Schedonorus arundinaceus	0.22	-0.56	0.38	0.18
Sericocarpus rigidus	-0.03	-0.49	0.12	0.68
Sisyrinchium bellum, S. hitchcockii or *S. idahoense*	-0.53	0.27	-0.37	-0.06
Spiraea douglasii var. *douglasii*	0.37	-0.66	0.33	0.07
Symphyotrichum hallii	0.40	0.28	-0.53	-0.06
*Trifolium dubium**	0.66	-0.40	0.05	-0.04
*Vicia hirsuta/*or *V. tetrasperma*	0.40	-0.23	0.08	-0.24
Wyethia angustifolia	0.48	-0.23	-0.13	0.21

TABLE 6. Summary of MRBP tests for differences in species composition among treatments for data relativized by A) species maxima and B) species totals. Stastistics for pairwise comparison are provided where the treatment effect is significant at the 0.1 level. The chance-corrected within-group agreement (*A*) is a measure of within-treatment heterogeneity compared to that expected by chance.

A)	Treatment		Control vs. Burn		Control vs. Mow		Burn vs. Mow	
Year	*A*	*P*	*A*	*P*	*A*	*P*	*A*	*P*
2001	-0.00976	0.6391	----	----	----	----	----	----
2002	0.03553	**0.0937**	0.00282	0.5258	0.04903	0.1555	0.01781	**0.0698**
2003	0.04533	**0.0902**	0.07217	0.0760	-0.02056	0.5539	0.05107	0.1565
2005	0.04775	**0.0844**	0.03980	0.1457	0.02702	0.2667	0.08068	0.1337
2006	0.12432	**0.0019**	0.12857	**0.0299**	0.12174	**0.0355**	0.14549	**0.0402**
2007	0.05059	**0.0816**	0.06107	**0.0453**	0.01044	0.3354	0.05779	0.2019

B)	Treatment		Control vs. Burn		Control vs. Mow		Burn vs. Mow	
Year	*A*	*P*	*A*	*P*	*A*	*P*	*A*	*P*
2001	0.01647	0.2731	----	----	----	----	----	----
2002	0.03553	**0.0937**	0.00282	0.5258	0.04903	0.1555	0.01781	0.0698
2003	0.07715	**0.0707**	0.10458	**0.0907**	0.01667	0.4180	0.04849	0.2667
2005	0.02984	**0.0437**	0.02236	0.1548	0.02430	0.2130	0.03589	0.1673
2006	0.08069	**0.0024**	0.04449	**0.0483**	0.10646	**0.0327**	0.07494	**0.0426**
2007	0.04602	**0.0932**	0.04654	**0.0596**	0.04646	**0.0492**	0.05033	0.2154

to implementing controlled burns and their undesirable effects on some species, an integrated program of fire and mowing may provide the optimal mix for promoting native biodiversity while reducing the risk or magnitude of undesirable ecological responses. Remnant Willamette Valley wet prairies, like upland prairies, savannas, and oak woodlands, therefore require an integrated management approach to achieve biodiversity conservation objectives. Fire and mowing are best viewed as parts of an integrated management regime that includes other activities such as herbicide applications to manage noxious weeds, manual or mechanical removal of woody vegetation, and seeding and planting of native grasses and forbs. Other studies of combined treatments have shown more desirable results can be achieved, especially when enhancing lower quality prairie remnants, if treatments are scheduled with a specific sequence and timing. In this context, the value of burning over mowing as a management tool comes not just from the greater number of desirable effects observed in this study, but also from its potential to create a window for additional restoration treatments such as seeding or herbicide application (Stanley et al. 2011).

Decisions about where, when, and how often to implement fire or mowing treatments are largely made based on context; some factors to consider will inevitably be site specific, but other factors may be common for a class or classes of sites. Based upon the findings of our study and others, there are two situations where the use of fire is especially appropriate. The first is in high quality prairies, where the abundance of native herbaceous plants compared to non-native species makes an overall positive response most likely. In such sites, even where certain native species experience a decline, there is a higher probability that the openings thus created will be colonized by another native species, compared to the response in a low quality prairies. Second, fire is a preferred management tool over mowing in lower quality prairies where individual non-native species that exhibit a desirable response to fire are specific management targets. *Leucanthemum vulgare*, which is abundant in many prairie remnants, is an example of a non-native species that exhibited a desirable response to fire in our study in the vegetative stage, while the effect of mowing on the reproductive stage produced an undesirable effect. Thus our study provides additional insights to support managers' decision-making processes when considering and prioritizing potential prairie management treatments.

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