FINAL REPORT

for the project

Controlling Tall Oatgrass in Fender's Blue Butterfly Habitats

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SUMMARY

1. We report final results from a five-year field experiment evaluating the effects of different mowing regimes on groups of native and non-native grasses and forbs. The study site was a degraded prairie at Baskett Slough National Wildlife Refuge dominated by the pest plant *Arrhenatherum elatius* (tall oatgrass). Mowing treatments differed in time of year they were applied, mowing height, and removal of cut material. Treatments started in 1994 and continued through 1998.

2. Although some treatment effects on plant cover became evident in the second year after initial treatments, differences among treatment resolved only by the third and fourth years. This delay in response reinforces the need for long-term studies. In 1998, after four years of treatment, all treatments had lower average cover of *Arrhenatherum* than in controls, with statistically significant reduction in three of the treatments (mowing in late spring, mowing in early summer, and double mowing). Treatments increased the cover of the native perennial grass *Danthonia californica*, with late spring mowing having the strongest effect. The increase in *Danthonia* was due largely to the reduction in *Arrhenatherum* cover. Late spring mowing also caused a significant increase in the cover of the native bunchgrass *Festuca idahoensis* var. *roemeri*. This is one of the few documented cases of pest plant control leading to increased abundance of native plants.

3. Many treatments significantly reduced the number of inflorescences of *Arrhenatherum* compared to controls. In contrast, most treatments also supported higher numbers of *Danthonia* inflorescences than in controls, with Treatments 1 (mowing in late spring) and 2 (mowing in early summer) producing about ten times the number of inflorescences than in controls. Treatment effects on flowering in *Arrhenatherum* and *Danthonia* stemmed primarily from changes in their vegetative cover. *Festuca* produced few inflorescences, and treatment effects were not evident.

4. Changes in flowering of *Arrhenatherum* and *Danthonia* did not translate into measurable changes in seedling numbers with treatment. Nearly all seedlings observed were non-native annual grasses and forbs.

5. Overall performance at meeting management objectives was determined by the use of an Effectiveness Index. This index accounted for a treatment's ability to reduce the target pest plant *Arrhenatherum*, reduce other non-native plants, and increase native plants. Treatment 1 (mowing in late spring), was particularly effective (EI = 1.14). Treatment 5 (mowing in early summer, with removal of cut material) and the control (no manipulation) were least effective (EI = -0.44).

6. Several mowing treatments were effective at fulfilling the management objectives of reducing non-native cover and encouraging native cover. **We recommend Treatment 1**

(mowing at 10 cm - 15 cm in late spring) as the best overall treatment. In areas with Kincaid's lupine and Fender's blue butterfly, however, **mowing should be delayed until July, after the flowering and flight seasons**. Delayed mowing, as in Treatment 2 (mowing at 10 cm - 15 cm in early summer) and Treatment 3 (mowing at 10 cm - 15 cm in early fall), had the next best overall performance. We recommend that **removing cut material (Treatment 5) and double mowing (Treatment 7) be avoided** in degraded prairies, because of their potential for promoting annual non-native plants.

INTRODUCTION

The rare Fender's blue butterfly (*Icaricia icarioides fenderi*) is found only in the Willamette Valley of Oregon (Hammond and Wilson, 1993). The low abundance of this butterfly makes it a high priority for conservation and management. Native upland grasslands support the largest populations of this butterfly and its preferred host plant, Kincaid's lupine (*Lupinus sulphureus* ssp. *kincaidii*). These remnant grasslands supply the butterfly with food plants, egg-laying sites, and proper flight conditions. The grasslands supply the lupine with essential light and nutrient resources and proper growing conditions. To a large extent, the recovery of the Fender's blue butterfly relies on the protection and restoration of these native grasslands (Wilson et al., 1992; Wilson et al., 1997).

The native grasslands that support the Fender's blue butterfly are threatened by habitat destruction, succession, and pest plant dominance. Most habitat destruction in the past has been from urbanization and agricultural activities; these threats are also prominent today (Hammond and Wilson, 1993). Succession is a threat because the woody species that replace many of the early successional herbaceous plants do not provide the resources and conditions necessary for the Fender's blue butterfly and Kincaid's lupine. Fire suppression has allowed succession to woody plants to proceed at most sites. Pest plant dominance is a threat because these non-native plants suppress the native vegetation, including Kincaid's lupine and plants that supply nectar for Fender's blue butterfly adults. The tall foliage of some pest plants shades many native species, and their extensive root systems can out-compete native species for nutrients and water. The tall foliage of both pest herbaceous plants and woody plants also shades the flight paths of the Fender's blue butterfly, slowing its activities, which probably lowers its feeding and reproductive rates. For example, Fender's blue females will lay fewer eggs on Kincaid's lupine plants in the shade (P. C. Hammond, pers. comm.). Hammond and Wilson (1993) report that aggressive weeds are a threat to 7 of 13 sites. Tall oatgrass (*Arrhenatherum elatius*) is one of the most important of these pest plants.

Protecting and improving suitable habitat is a high priority for butterfly conservation (New et al., 1995; Pullin, 1996), and has been emphasized by individuals concerned with protecting the Fender’s blue butterfly (Hammond and Wilson, 1993; Schultz, 1997; USFWS, 1998). Mowing is a widely used tool for vegetation improvement in Willamette Valley prairies. Few studies, however, document the success or failure of mowing in controlling pest plants. Often mowing is done without consideration of timing or height of mowing. Differences in both heights and life-history timing between many pest plants and native herbaceous species provide opportunities for improving the effectiveness of mowing as a control technique while reducing its impact on favored plants and animals.

The objective of this study was to evaluate different mowing regimes in reducing the abundance of tall oatgrass, reducing other non-native plants, and possibly promoting native species. These studies were initiated in 1994; this report presents results from four years of experimental manipulations.

Study area

We conducted these studies within the Baskett Slough National Wildlife Refuge (Polk County, Oregon), which is administered by the U.S. Fish and Wildlife Service. The refuge contains several types of vegetation, including native grasslands dominated by the fescue *Festuca idahoensis* var. *roemeri*[1], disturbed grasslands dominated by non-native weeds, and oak woodlands. Relatively large populations of the endangered Willamette daisy, *Erigeron decumbens* var. *decumbens*, and Kincaid's lupine, *Lupinus sulphureus* ssp. *kincaidii*, are also present. The Refuge harbors the largest remaining population of the Fender's blue butterfly.

The study area for the experiment was at the saddle section south of Baskett Butte (44º58'N, 123º15'W). We chose this area for several reasons. First, the area had an abundance of *Arrhenatherum elatius*. Second, the native grasses *Festuca idahoensis* var. *roemeri* and *Danthonia californica* were present, allowing us to see the effects of control measures on key native plants. Third, Kincaid's lupine and Fender's blue butterfly occurred just outside the study area, showing the area's potential as suitable habitat for these species of concern. Fourth, the vegetation was relatively homogeneous.

Arrhenatherum elatius is native to Eurasia but widely introduced throughout western North America, New Zealand and Australia (Pfitzenmeyer 1962). It is a tall (up to 180 cm), usually erect, tussock-forming perennial grass with very short rhizomes (Pfitzenmeyer 1962). Caryopses are produced annually from the first year of germination, with each mature plant producing 25-30 panicles each with 50-100 spikelets and one caryopsis per spikelet, which readily shed at maturity (Pfitzenmeyer 1962). The seeds have no innate dormancy (Pfitzenmeyer 1962, Tanphiphat and Appleby 1990, Maret 1996), apparently not forming a persistent seedbank (Maret and Wilson, unpublished data). Germination occurs entirely after the fall rains (Maret 1996); sprouts also appear on mature plants at this time (Tanphiphat and Appleby 1990). Little growth of seedlings or sprouts occurs during the winter, but rapid growth occurs in the spring, with senescence occurring during the summer drought (Tanphiphat and Appleby 1990).

METHODS

Experimental design

We used a replicated before-after-control-intervention approach with a randomized complete block design. Each of the four blocks was 8 m × 12 m, and contained 8 mowing treatments. We initiated treatments in 1994 and continued them through 1998. Treatments were selected to reflect the range of options available for management and to explore scientific

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[1]Recent taxonomic work suggests that within the study area *Festuca idahoensis* var. *roemeri* populations might include individuals of *Festuca rubra* (B. L. Wilson, pers. comm.)

questions about the effectiveness of mowing at different growth stages (Table 1). Growth stages were quantified by recording the predominant maximum height of vegetative and flowering structures of *Arrhenatherum*, *Danthonia*, and *Festuca* in the control plots at the times of treatment. Mowing treatments were applied with a hand-held rotary cutter. We regulated the height of cutting by placing several short stakes within each quadrat, with their tops at the proper cutting height. Appendix 1 lists specific treatment dates.

Measurements

We collected pre-manipulation vegetation measurements May 23-27, 1994. We collected post-manipulation vegetation data May 17-30, 1995, May 22-29, 1996, May 23-30, 1997, and May 22-30, 1998, when the community was at approximately the same phenological stage as during 1994 measurements. Measurements were recorded within two 1-m × 0.5-m quadrats inside the treatment area. Each measurement area had a 1-m buffer around it.

We measured within each quadrat the total cover of vascular plants and the cover of the non-native *Arrhenatherum*, other non-native grasses as a group, the native grasses *Danthonia*, and *Festuca*, non-native forbs as a group, native forbs as a group, and mosses as a group. Appendix 2 lists the species comprising these categories. In all estimates of cover, two investigators reached a consensus value, using calibrated templates as standards.

On June 9, 1997 and May 22-28, 1998 we recorded the number of inflorescences of *Arrhenatherum*, *Danthonia*, and *Festuca* in treatment areas. On May 26, 1995, May 23, 1997 and May 28, 1998 we recorded the number of seedlings within 300 cm^2 subplots. Seedlings were assigned to one of six categories: *Arrhenatherum*, other non-native grasses (1995), *Danthonia*, and *Festuca*, non-native forbs (1995 and 1998), and native forbs. We also recorded litter depth at four positions within each subplot.

Analysis

We used analysis of covariance to analyze the experimental results. The main statistical model was

$$C_a = \beta_0 + (\beta_1 \cdot C_b) + (\beta_2 \cdot B) + (\beta_3 \cdot T) + (\beta_4 \cdot B \cdot T) + \varepsilon \quad ,$$

where C_a is the cover of a species or group after treatment, C_b is cover before treatment (the covariate), B is the blocking effect, T is the treatment effect, $B \cdot T$ is the block×treatment interaction, and ε is error. Analysis followed the recommendations of Underwood (1997) for blocked designs with subsampling. Transformation of response variables and covariates were sometimes necessary to meet the assumptions of statistical analysis.

The significance level (α) for testing main effects was set to 0.05. If main effects were significant, pairwise treatment comparisons were examined using Tukey's HSD (Steel and Torrie, 1980; Day and Quinn, 1989) at the 0.05 level.

We also developed an Effectiveness Index (EI) to show the overall effectiveness of treatments in meeting management objectives. The index is the sum of the proportional *decline* in *Arrhenatherum* (Ar), the proportional *decline* in the group of other non-native species (NN), and the proportional *increase* in the group of native species (Nat). That is, for the first year of response,

$$EI = \frac{Ar_{94} - Ar_{95}}{Ar_{94}} + \frac{NN_{94} - NN_{95}}{NN_{94}} + \frac{Nat_{95} - Nat_{94}}{Nat_{94}}.$$

The effectiveness index and numbers of inflorescences were analyzed as above, except no covariate was used with EI. Number of seedlings were analyzed with Friedman's non-parametric analysis of variance (Conover, 1980).

RESULTS

Pre-manipulation community composition

Sampling confirmed the impression that *Arrhenatherum* dominated the site in 1994 (Table 2). *Arrhenatherum* had 14%-33% cover, about one-third of the overall cover of vascular plants. The two native grasses present had less cover, with *Festuca* at 5%-20% and *Danthonia* at 8%-20%. The group of other non-native grasses was also abundant (11%-26%). Most of these other non-native grasses were annuals, including *Bromus rigidus* and *Elymus caput-medusae*. Forbs were relatively rare in 1994.

Effects of experimental manipulations on vegetation cover

Developments over time

Treatment effects varied during the course of the study. For example, no strong patterns emerged after only one year of manipulations (Table 2, Figure 1) (Wilson and Clark, 1995; Wilson and Clark, 1996), but by the second year after manipulation, the cover of *Arrhenatherum* had declined significantly in some treatments (Wilson and Clark, 1996). Some treatments, especially Treatment 5 (early summer mowing with removal of cut material) also *increased* the cover of other non-native grasses. Overall, meaningful patterns tended to emerge after two or three years of treatments (Wilson and Clark, 1997); by 1998 (after four years of treatment) treatment effects were more-or-less stable.

These patterns over time suggest that conclusions based on short-term results can be misleading. For example, increases in the cover of native grasses were not evident until after three or four years of treatment (Figure 1). For this reason, we do not analyze these early results statistically. The relative stability of patterns by 1998, however, suggest that they should better reflect longer-term trends. Therefore, our statistical analysis is focused on the 1998 results.

1998 analysis

After four years of manipulations, treatments significantly affected the cover of *Arrhenatherum*, *Danthonia*, and *Festuca* (Table 3). All treatments resulted in less *Arrhenatherum* cover than in controls, with Treatments 1 (late spring mowing), 2 (early summer mowing) and 7 (double mowing in late spring and the following early spring) causing the largest reduction. After accounting for block-to-block variability and differences in initial abundance of *Arrhenatherum*, these treatments caused a statistically significant 70%-80% decline *Arrhenatherum* cover, compared to unmanipulated controls (Table 3).

In contrast, treatments increased the cover of the native grasses *Danthonia* and *Festuca*. *Danthonia* was more than twice as abundant in treated areas than in controls (Table 3), with the strongest improvement with Treatment 1 (late spring mowing). Treatment 1 also produced the biggest increase in *Festuca* cover. Treatment 6 (mowing at 50 cm in early summer) produced the next biggest increase. The 1998 cover of *Festuca* was highest in Treatment 6 (Figure 1d), but because those plots also had the most *Festuca* before treatment, the increase was not as prominent as with Treatment 1.

Treatments also tended to increase the cover of other non-native grasses (Table 3), although this pattern was not strong ($P = 0.14$). Treatment 5 (early summer mowing with removal of cut material), which had stimulated the growth of other non-native grasses in past years (Table 2, Figure 1c; Wilson and Clark, 1997), did not in 1998 (Table 3). Nearly all of the other non-native grasses in this study were annuals, and their increase in cover must originate with seedling establishment. Establishment rates and subsequent growth of annuals in Willamette Valley prairies can be stimulated by reduced litter (Maret, 1996). Over all treatments, however, there was little relationship between litter depth and 1998 cover of other non-native grasses (Spearman's rank correlation, $r_s = -0.09$, $P > 0.59$).

All treatments caused a two- to four-fold increase in the cover of native plants as a group, compared to control plots (Table 3). Patterns for non-native plants as a group were weak ($P = 0.43$), because treatments that reduced *Arrhenatherum* cover tended to have promote higher cover of other, mostly annual non-native plants.

Effects of experimental manipulations on reproduction

The long-term effects of management on populations includes the impact on reproduction. We recorded two aspects of reproduction: flowering (measured as the production of inflorescences) and seedling establishment.

Flowering

The number of *Arrhenatherum* inflorescences varied considerably among treatments in 1998 (Table 4). Unmanipulated controls had nearly the highest densities of *Arrhenatherum* inflorescences. Treatments 2 (early summer mowing) and 7 (double mowing) were particularly effective at reducing the number of *Arrhenatherum* inflorescences.

There was abundant flowering of *Danthonia* in many treatment areas in 1998, with about ten times the number of inflorescences in plots of Treatment 1 (late spring mowing) and Treatment 2 (early summer mowing) compared to unmanipulated controls (Table 4). All treatments but Treatments 4 (mowing in early spring) and 6 (mowing at 50 cm in early summer) caused a significant increase in number of inflorescences compared to unmanipulated controls.

Few *Festuca* flowered in 1998 or in other years of the study.

Seedlings

Nearly all seedlings recorded were of non-native grasses and forbs (Table 5), most of which were annuals or biennials (Appendix 2). (Note that in 1997 and 1998 we recorded seedlings of annual non-native grasses only as cover, not by number.) No relation between non-native forb seedling density and treatment was evident, except for *Arrhenatherum* in 1997, when unmanipulated controls had significantly more *Arrhenatherum* seedlings.

DISCUSSION

Mechanisms

The consistent reduction in *Arrhenatherum* cover by most mowing treatments is probably caused by the direct depletion of resources through removal of tissues (Hewett 1985). Shoot and corm development in the closely related *Arrhenatherum elatius* var. *bulbosum* peaks in late May in the Willamette Valley (Tanphiphat and Appleby, 1990). After this period of rapid growth, translocation of resources to roots becomes more important. Our phenological measurements also show that the *Arrhenatherum* in this study followed similar patterns, nearly reaching its maximum height by late spring (Table 1). These patterns suggests that late spring mowing was effective because a higher proportion of *Arrhenatherum* resources were removed by mowing at this time. Berendse et al. (1992) suggest that nitrogen is the key resource lost by *Arrhenatherum* with clipping or mowing.

Two mowings per year (Treatment 7) produced the best reduction in *Arrhenatherum* cover, a pattern effective in the control of other pest plants (O'Keefe, 1995; P.C. Hammond, pers. comm.). On the other hand, a single mowing at the right time was almost as effective, as seen in the similar effects between Treatment 7 (mow in late spring and in early spring the next year) and Treatment 1 (mowing just in late spring).

The reduction in *Arrhenatherum* cover also intensified with repeated annual treatments. This is similar to the findings of Hewett (1985), who reports that five years of mowing was necessary to control *Arrhenatherum elatius* var. *bulbosum* in Great Britain.

Several mowing treatments increased the cover and flowering intensity of *Danthonia* and the cover of *Festuca*. But the direct effects of mowing should either be adverse (because of the removal of tissues) or neutral (because most or all of the tissues of these plants were below mowing height). Thus, any beneficial effects of mowing on these plants are likely to be indirect, though reduced competition pressure of *Arrhenatherum* (Berendse et al., 1992) or through other alterations of growing conditions. Treatment effects on flowering could only be indirect because each treatment allowed a full season of inflorescence development. Inflorescences of the dominant perennial grasses develop in early spring, but reach a height affected by our mowing treatments only after the early spring treatment (Treatment 4)(Table 1). The next treatment (1, mowing in late spring) occurred *after* recording inflorescences. Thus, any treatment effects on inflorescences must be mediated through changes in plant vigor.

We examined possible causes of increases in the native grasses through a series of statistical models. Each model differed in the addition of either treatment type or the actual reduction in *Arrhenatherum*. A significantly improved fit of the expanded model shows that the new factor(s) is important in explaining responses (McNeil et al., 1996). In this analysis, cover of the species in 1994 represents initial conditions and blocking effects represent spatial variability.

Initial conditions and spatial pattern were responsible for a small proportion (R^2_{adj} = 29%) of the variability in *Danthonia* cover in 1998 (Table 6A). The treatment effect added significant explanatory power (additional R^2_{adj} of 38%). The factor of *Arrhenatherum* reduction, without accounting for the treatment effect directly, added a significant but smaller degree of explanation (additional R^2_{adj} = 22%). Thus a partial mechanism by which mowing acts to increase *Danthonia* cover seems to be decreased competitive pressure from *Arrhenatherum*, but mowing has other, unexplained effects as well.

Initial conditions and spatial pattern accounted for nearly all the variability in cover of *Festuca* in 1998 (R^2_{adj} = 79%). Treatments added a small but statistically significant increase explanation (additional R^2_{adj} = 8%). In contrast to the case with *Danthonia*, the mowing effect was unrelated to reduction of *Arrhenatherum* (no increase in R^2_{adj}).

Initial conditions and spatial pattern accounted for much of the variability in number of *Danthonia* inflorescences in 1998 (R^2_{adj} = 42%). As with the case of *Festuca* cover in 1998, mowing effects were unrelated to the reduction of *Arrhenatherum* cover, with only a statistically insignificant 3% increase in R^2_{adj}, compared to the 32% increase in R^2_{adj} in the statistical model with treatments.

Increased flowering with mowing might have occurred indirectly though increased plant size. We examined this possibility through a second set of statistical models. Each model differed in the addition of either treatment type or the cover of the species in 1998. A significantly improved fit of the expanded model shows that the new factor is important in explaining responses (McNeil et al., 1996).

Initial conditions and spatial pattern contributed limited explanation (R^2_{adj} = 28%) of *Arrhenatherum* flowering patterns in 1998 (Table 6B). The treatment effect added a large and statistically significant increase in explanation (additional R^2_{adj} of 44%). A similar increase with just the addition of *Arrhenatherum* cover (additional R^2_{adj} of 40%) suggests that diminished *Arrhenatherum* reproduction induced by treatments is mediated through decreased vegetative cover.

Initial conditions and spatial pattern were important to 1998 flowering by *Danthonia* (R^2_{adj} = 42%) (Table 6B). Increases in *Danthonia* cover added as much explanatory power (additional R^2_{adj} of 34%) and did the treatment effect (additional R^2_{adj} of 32%). So, analogous to *Arrhenatherum*, increased *Danthonia* flowering seems to be almost entirely mediated through increased vegetative cover.

These analyses show that treatment effects on *Danthonia* cover are explained in large part by the reduction of *Arrhenatherum* by those treatments. The mechanism by which mowing treatments increased *Festuca* cover remains unclear. Loss of inflorescences through mowing might have caused a shift in allocation to vegetative growth, although this seems unlikely considering that *Festuca* cover largely escaped mowing during the period of spring growth when developmental pattern could change. A more promising, indirect effect of mowing is through the timing of litter deposition from mowing. Litter effects that could promote *Festuca* include a flush of nutrients, fewer herbivores (Reader, 1991; Hulme, 1994; Maron, 1997), and changes in soil microbial activity (Knapp and Seastedt, 1986). The only treatment to have a large effect on *Festuca* was Treatment 1 (mowing in late spring), so the addition of fresh litter at the time of rapid growth seems to be crucial to promoting *Festuca*.

The situation is clearer for flowering by *Arrhenatherum* and *Danthonia*. In both cases, treatment effects on the number of inflorescences are essentially explained through treatment effects of cover (decreased cover of *Arrhenatherum*, increased cover of *Danthonia*).

Changes in flowering of *Arrhenatherum* and *Danthonia* did not translate into measurable changes in seedling numbers with treatment. Small plot sizes ($6m^2$ treatment areas) possibly allowed seed dispersal across plots, obscuring patterns.

Although treatments had little direct effect on seedling numbers, mowing can indirectly affect seedling establishment by stimulating or inhibiting the germination of seeds and changing the growing conditions for seedlings. Removing plant cover reduces shading and competition for water and nutrients, which should stimulate seedling germination and growth (Peart, 1989; Silvertown and Tremlett, 1989; Aguilera and Laurenroth, 1993; Reader, 1993). Litter depth can also influence seedling densities (Facelli and Pickett, 1991; Maret, 1996). Thinner litter layers might reduce shelter for seedling herbivores, leading to greater seedling survival (Lamont et al., 1993). If so, removing cut material (as in Treatment 5), and hence slowing litter build-up, should particularly stimulate seedling germination by exposing more soil. Finally, moss cover can inhibit seedling establishment by shading germinants or can increase establishment by ameliorated droughty soil conditions.

There were seven cases in which seedlings were abundant enough to compare seedling densities with total cover, litter, and moss cover (Table 5). Only three of the 21 pairwise comparisons were significant (Table 7). Nor were patterns consistent. For example, total cover was inversely related to the number of *Arrhenatherum* seedlings in 1998 but not in 1997. We conclude that seedling establishment is controlled by something other than total cover, litter depth, or moss cover.

Litter depth might not reflect the mode of action of litter on seedling establishment. Treatment 5 (mowing in early summer with removal of cut material) was associated in 1996 and 1997 with sharp increases in the cover of non-native grasses other than *Arrhenatherum* (Table 2, Figure 1c). Although this pattern did not materialize in 1998 (Table 3), it suggests some connection between removal of cut material and promoting non-native annual grasses.

Management recommendations

The management objectives evaluated in this study were the reduction in *Arrhenatherum*, the reduction of other non-native plant species, and the promotion of native plant species. Treatment 7 (double mowing) was the best at reducing the cover (Table 3) and flowering (Table 4) of *Arrhenatherum*, although Treatments 1 (late spring mowing) and 2 (early summer mowing) were almost as effective. Treatment effects on other non-native plants were unclear. Treatment 1 (late spring mowing) was best in promoting the cover of the native grasses *Danthonia* and *Festuca* (Table 3) and the flowering of *Danthonia* (Table 4).

Because these patterns of change caused by treatments are complex, we developed an Effectiveness Index (EI: see Methods) that integrates performance in the management objectives of *Arrhenatherum* decline, decline of other non-native species, and increase of native species. Thus EI reflects changes in general vegetation quality.

Strong treatment effects on EI were unclear until three years of manipulations (Figure 2). An exception is the poor performance of Treatment 5 (early summer mowing with removal of cut material), which was evident after just two years of manipulations. The poor performance of

Treatment 5 was due primarily to the relatively high inhibition of *Festuca* and large increases in mostly annual non-native plant cover, especially in 1996 and 1997 (Table 2). Treatment 5 was much less effective than Treatment 2 (Table 2), even though the *only* difference between these two is that cut material was removed in Treatment 5. Removing cut material would prevent litter build-up, suggesting that litter is important in affecting plant cover.

After four years of manipulations, patterns of EI were relatively stable. From 1994 to 1998, the vegetation in the unmanipulated controls dropped markedly in quality (EI = -0.44; Table 3). In contrast, Treatments 1 (late spring mowing) produced marked increases in vegetation quality (EI = 1.14). Treatments 2 (early summer mowing) and 3 (early fall mowing) were also effective at meeting management objectives.

Taking into consideration overall mowing effects on the cover, flowering, and seedling densities of the community (Table 8), Treatment 1 (late spring mowing) was best at fulfilling management objectives. We recommend this mowing treatment for the control of *Arrhenatherum* in Willamette Valley prairies. The results of this study also suggest that Treatment 1 is best at promoting residual native grasses.

Late spring mowing might be unacceptable in certain circumstances. For example, if heavy equipment was used for mowing, damage to moist soil could be extensive. Late spring mowing would also be unsuitable for prairies supporting the Fender's blue the butterfly. Adults of this butterfly are active in May and early June. Mowing at these times would damage their food plants, like *Lupinus sulphureus* spp. *kincaidii*, and could directly disrupt adults. In these two circumstances, delayed mowing, such as with Treatment 2 (early summer mowing) and Treatment 3 (early fall mowing), would provide substantial control of *Arrhenatherum* without adverse effects on soil or butterflies.

We recommend at this time that removing cut material (Treatment 5) and double mowing (Treatment 7) be avoided in degraded prairies, because of their potential for promoting annual non-native plants.

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Table 1. Treatments evaluated in this study and the typical maximum heights of dominant grasses at the times of treatments. Vege is the height of vegetative tissues; Infl is the height of inflorescences; nd–no data.

Treatment	Action		Heights (± sd) of dominant grasses at time of manipulation (cm)					
			Arrhenatherum elatius		*Danthonia californica*		*Festuca idahoensis* var. *roemeri*	
			Vege	Infl	Vege	Infl	Vege	Infl
1	Mowing at 10 cm - 15 cm in late spring, when *Arrhenatherum elatius* is 50 cm -70 cm tall		60.9 ±11.0	82.1 ±15.4	25.0 ±5.0	40.0 ±5.0	16.5 ±4.0	56.8 ±11.4
2	Mowing at 10 cm - 15 cm in early summer, just before *Arrhenatherum elatius* matures seeds		68.6 ±11.3	98.4 ±21.0	nd	nd	16.9 ±4.8	52.0 ±32.0
3	Mowing at 10 cm - 15 cm in early fall, the typical time for managers to mow		63.1 ±16.1	101.2 ±17.4	11.0 ±1.7	0.0	15.0 ±3.5	66.0 ±21.4
4	Mowing at 10 cm - 15 cm in early spring, when *Arrhenatherum elatius* starts rapid growth		26.3 ±5.3	0.0	11.3 ±1.5	0.0	21.2 ±5.4	0.0
5	Mowing at 10 cm - 15 cm in early summer, with removal of cut material		68.6 ±11.3	98.4 ±21.0	nd	nd	16.9 ±4.8	52.0 ±32.0
6	Mowing at 50 cm in early summer. At this time, *Arrhenatherum elatius* is generally taller than 50 cm, while the native species are shorter		68.6 ±11.3	98.4 ±21.0	nd	nd	16.9 ±4.8	52.0 ±32.0
7	Double mowing at 10 cm - 15 cm in late spring, and the following early spring	Late spring	60.9 ±11.0	82.1 ±15.4	25.0 ±5.0	40.0 ±5.0	16.5 ±4.0	56.8 ±11.4
		Early spring	26.3 ±5.3	0.0	11.3 ±1.5	0.0	21.2 ±5.4	0.0
Control	No manipulation		—	—	—	—	—	—

Table 2. Total vegetative cover (%) and cover of groups of species, before treatment (1994) and after treatment (1995, 1996, 1997, and 1998).

		Treatments							Control
		1	2	3	4	5	6	7	
Total cover	1994	58.5	61.5	57.4	66.8	61.3	59.8	55.4	59.4
	1995	45.1	43.8	37.0	45.0	53.4	43.3	39.4	41.3
	1996	59.9	53.8	51.3	44.0	68.6	56.9	55.0	52.8
	1997	69.5	61.8	50.0	59.6	72.6	58.9	69.1	51.9
	1998	63.8	59.1	54.4	54.4	62.0	53.1	62.0	44.8
Arrhenatherum elatius	1994	20.8	13.9	19.4	32.8	24.8	19.5	26.5	20.4
	1995	7.3	4.3	6.0	13.9	12.6	6.5	10.6	10.8
	1996	6.9	4.4	6.1	5.4	10.9	8.8	4.0	13.0
	1997	6.3	2.6	8.9	6.9	11.6	8.9	5.4	13.3
	1998	4.1	3.6	12.1	8.3	11.8	9.8	4.1	13.9
Other non-native grasses	1994	23.3	24.9	26.0	17.3	11.4	16.6	14.8	24.8
	1995	9.0	9.6	13.5	11.4	7.1	10.3	10.6	13.0
	1996	24.3	23.6	26.9	21.4	26.6	19.0	19.3	20.4
	1997	22.1	28.8	19.6	32.6	36.0	27.1	26.8	24.5
	1998	18.4	22.4	16.4	21.5	18.1	15.0	26.9	14.3
Festuca idahoensis var. *roemeri*	1994	4.8	7.6	4.9	8.1	15.5	20.1	5.6	1.4
	1995	3.9	5.0	3.6	3.3	6.4	12.0	1.9	1.5
	1996	4.5	5.3	2.9	3.4	7.3	16.0	2.0	1.4
	1997	6.8	4.6	4.9	4.9	4.8	12.3	2.6	0.9
	1998	5.7	3.8	3.9	2.9	3.9	11.3	1.8	0.4
Danthonia californica	1994	15.0	19.4	12.6	11.6	11.6	7.8	10.5	18.9
	1995	6.1	13.0	7.5	4.9	9.4	4.8	6.5	8.4
	1996	10.8	12.3	8.9	6.1	11.3	7.4	9.1	7.9
	1997	24.4	23.9	15.0	19.1	15.5	9.4	20.3	11.6
	1998	28.4	28.0	21.4	17.9	21.6	16.0	24.3	8.7
Non-native forbs	1994	3.5	4.8	3.0	4.4	3.5	3.5	5.5	3.1
	1995	25.5	18.0	15.6	18.0	27.9	17.8	18.6	15.8
	1996	22.5	14.5	12.0	8.8	25.9	12.9	26.3	13.6
	1997	18.0	7.3	6.9	4.4	12.9	6.4	20.4	7.9
	1998	20.0	13.1	11.3	13.1	14.8	9.8	15.7	15.9
Native forbs	1994	0.5	0.5	0.0	0.1	2.1	0.1	0.0	0.4
	1995	0.8	1.1	0.0	0.5	0.5	0.4	0.8	0.0
	1996	0.1	1.1	0.0	0.0	0.1	0.3	0.0	0.0
	1997	0.1	1.2	0.1	0.0	0.0	0.1	0.2	0.0
	1998	0.0	0.8	0.1	0.4	0.0	0.0	0.0	0.1
Moss	1994	18.4	36.9	27.3	6.9	17.1	21.1	13.9	7.9
	1995	33.5	40.9	39.3	12.8	20.4	27.9	18.5	14.1
	1996	28.5	42.5	37.6	6.0	18.8	26.8	16.1	10.0
	1997	15.0	29.9	38.3	13.0	11.0	16.9	31.3	11.5
	1998	26.6	43.8	56.3	30.6	20.3	40.5	41.5	43.1

Table 3. Treatment effects on the 1998 vegetative cover (%) of various plant groups and on the Effectiveness Index (see text for explanation). Result for cover are from analyses of covariance, with pre-treatment (1994) cover as the covariate. *P* for treatment effect is the probability that differences among treatments occurred just by chance. Mean cover by treatment are least-square means from the analysis of covariance. When the data were transformed before analysis, means were back-transformed for presentation. Treatment means sharing letters were statistically indistinguishable (Tukey's HSD, α = 0.05). Where treatments had significant effects (*P* < 0.05), the treatment best at reaching management objectives is noted by underlining. (Values without a category do not necessarily add up, because of the adjustment procedure.)

	Treatment		Covariate			Adjusted mean cover (%), by treatment							
	F	*P*	b	F	*P*	1	2	3	4	5	6	7	Control
Total vascular plant cover	1.42	0.25	-0.06	0.19	0.67	63.7	59.2	54.2	54.8	62.8	53.1	61.7	44.7
Arrhenatherum elatius[1]	5.54	<0.01	0.15	2.26	0.14	3.6ab	4.0ab	11.7bc	6.9abc	10.5bc	8.6abc	<u>2.8a</u>	13.6c
Other non-native grasses[1]	1.82	0.14	0.19	0.95	0.34	17.3	20.6	14.7	21.8	19.4	15.1	26.0	13.3
Danthonia californica[1]	2.61	0.04	0.36	3.41	0.07	<u>26.1b</u>	23.8ab	19.4ab	15.8ab	19.3ab	14.8ab	24.1ab	5.7a
Festuca idahoensis var. *roemeri*[1]	3.01	0.02	0.60	90.82	<0.01	<u>4.3b</u>	0.9ab	1.7ab	0.7ab	0.3a	1.8ab	0.6ab	0.9ab
Non-native forbs	0.89	0.53	0.17	0.26	0.61	20.1	13.0	11.4	13.0	14.8	9.8	15.4	16.0
Native forbs[1]	1.24	0.33	-0.02	0.01	0.94	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0
Moss[1]	1.03	0.44	0.39	7.39	0.01	17.8	32.4	44.9	33.3	17.4	34.4	39.6	41.4
Native plants	5.91	<0.01	0.22	2.60	0.12	<u>34.5b</u>	31.4b	26.4b	21.7ab	24.0b	26.1b	27.4b	9.5a
Non-native plants	1.04	0.43	0.41	4.74	0.04	41.8	40.1	38.8	39.4	47.3	37.1	46.4	43.1
Effectiveness index[2]	2.51	0.05	—	—	—	<u>1.14</u>	0.58	0.59	0.31	-0.44	0.26	0.29	-0.44

[1] Square-root transformed; [2] rank transformed

Table 4. Treatment effects on the number of inflorescences in 1998 of the dominant perennial grasses. Result are from analyses of covariance, with pre-treatment (1994) cover as the covariate. *P* for treatment effect is the probability that differences among treatments occurred just by chance. Number of inflorescences and pre-treatment cover were square-root transformed before analysis. Mean number of inflorescences by treatment are least-square means from the analysis of covariance, back-transformed for presentation. Treatment means sharing letters were statistically indistinguishable (Tukey's HSD, α = 0.05). Where treatments had significant effects (*P* < 0.05), the treatment best at reaching management objectives is noted by underlining.

	Treatment		Covariate			Adjusted mean number of inflorescences per 0.5 m^2, by treatment							
	F	*P*	b	F	*P*	1	2	3	4	5	6	7	Control
Arrhenatherum elatius	7.62	<0.01	0.20	0.61	0.44	19.1ab	14.3a	55.2b	51.7b	30.4ab	27.9ab	<u>6.7a</u>	53.4b
Danthonia californica	7.11	<0.01	0.81	4.8	0.04	76.8c	<u>83.1c</u>	56.3bc	33.1abc	51.5bc	25.2ab	60.9bc	8.0a
Festuca idahoensis var. *roemeri*	2.34	0.06	0.73	52.6	<0.01	2.2	0.4	0.8	0.4	0.0	2.5	2.4	0.8

Table 5. Number of seedlings per 300 cm^2 and litter depth in 1995, 1997, and 1998. Values are medians within treatments. *P* are the probabilities that values differed significantly among treatments just by chance (Friedman's non-parametric analysis of variance; Conover, 1980). Treatment medians sharing the same letter were statistically indistinguishable. —: too few seedlings (< 0.5 per plot) to analyze.

	Year	Treatments							Control	*P*
		1	2	3	4	5	6	7		
Arrhenatherum elatius	1995	0.0	0.0	0.0	0.5	1.0	0.0	0.0	0.0	—
	1997	0.0a	0.5a	1.0ab	0.5a	1.0a	0.0a	1.5a	4.5b	<0.05
	1998	0.0	0.5	0.0	0.5	0.0	0.0	0.0	1.0	>0.25
Other non-native grasses	1995	20.5	24.0	24.0	15.0	22.5	18.0	21.0	21.5	>0.25
Festuca idahoensis var. *roemeri*	1995	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	—
	1997	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	—
	1998	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	—
Danthonia californica	1995	not recorded								
	1997	0.5	0.5	0.0	0.0	1	0.0	0.5	0.5	>0.25
	1998	0.5	0.0	0.0	1.0	0.5	0.0	0.5	0.0	>0.25
Non-native forbs	1995	26.0	34.5	22.0	13.5	49.5	19.5	29.0	38.0	>0.10
	1997	not recorded								
	1998	30.5	20.0	30.0	16.0	6.5	14.5	29.5	14.0	>0.25
Native forbs	1995	0.5	0.0	0.0	0.0	0.5	1.0	0.5	0.0	—
	1997	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	—
	1998	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	—
Litter depth (cm)	1995	2.2	2.6	3.5	2.1	1.4	3.8	1.9	2.4	>0.25
	1997	2.8	3.1	3.5	4.3	2.6	3.8	3.0	4.5	>0.05
	1998	2.1	2.8	2.8	2.9	2.9	3.1	1.9	2.5	>0.25

Table 6A. Comparison of direct treatment effects vs. reduction in *Arrhenatherum elatius* cover as possible causes of statistically significant patterns. B: block, C: covariate (cover of the species before treatments), T: treatment, dA: reduction in *Arrhenatherum elatius* cover. *P*: probability that increase in R^2 with the added factors could have occurred simply by chance. Response variables and covariates were square-root transformed before analysis.

Response variable	Reduced model			Model with the addition of either: Treatment effect			or	Reduction in *Arrhenatherum elatius*		
	Factors	R^2_{adj}	*P*	Factors	R^2_{adj}	*P*		Factors	R^2_{adj}	*P*
Cover of *Danthonia californica* in 1998	B, C	29%	<0.01	B, C, T, B×T	67%	<0.01		B, C, dA, B×dA	51%	<0.01
Cover of *Festuca idahoensis* var. *roemeri* in 1998	B, C	79%	<0.01	B, C, T, B×T	87%	0.01		B, C, dA, B×dA	78%	>0.10
Number of *Danthonia californica* inflorescences in 1998	B, C	42%	<0.01	B, C, T, B×T	74%	<0.01		B, C, dA, B×dA	45%	>0.10

Table 6B. Comparison of direct treatment effects vs. increase in cover as causes of statistically significant patterns in flowering. B: block, C: covariate (cover of the species before treatments), T: treatment, V: cover of species in 1998. *P*: probability that the increase in R^2 with the added factors could have occurred simply by chance. Response variables and covariates were square-root transformed before analysis.

Response variable	Reduced model			Model with the addition of either: Treatment effect			or	Cover of species in 1998		
	Factors	R^2_{adj}	*P*	Factors	R^2_{adj}	*P*		Factors	R^2_{adj}	*P*
Number of *Arrhenatherum elatius* inflorescences in 1998	B, C	28%	<0.01	B, C, T, B×T	72%	<0.01		B, C, V, B×V	68%	<0.01
Number of *Danthonia californica* inflorescences in 1998	B, C	42%	<0.01	B, C, T, B×T	74%	<0.01		B, C, V, B×V	76%	<0.01

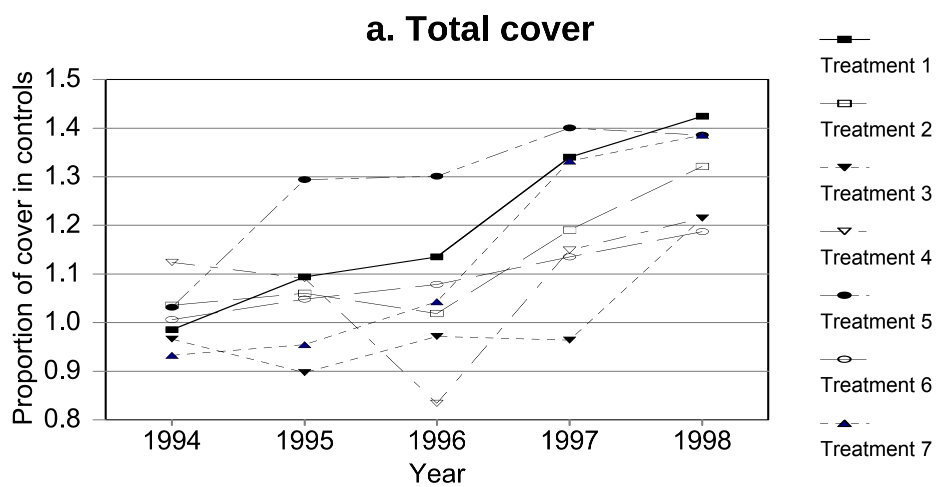
Table 7. Relationships between the number of seedlings recorded in various plant groups and total vascular plant cover, litter depth, and moss cover. Only those cases are shown that had adequate number of seedlings (≥ 0.5 per plot). Values are Spearman's rank correlation coefficients, r_s. *: $P < 0.05$, $r_s > 0.35$ (two-sided test).

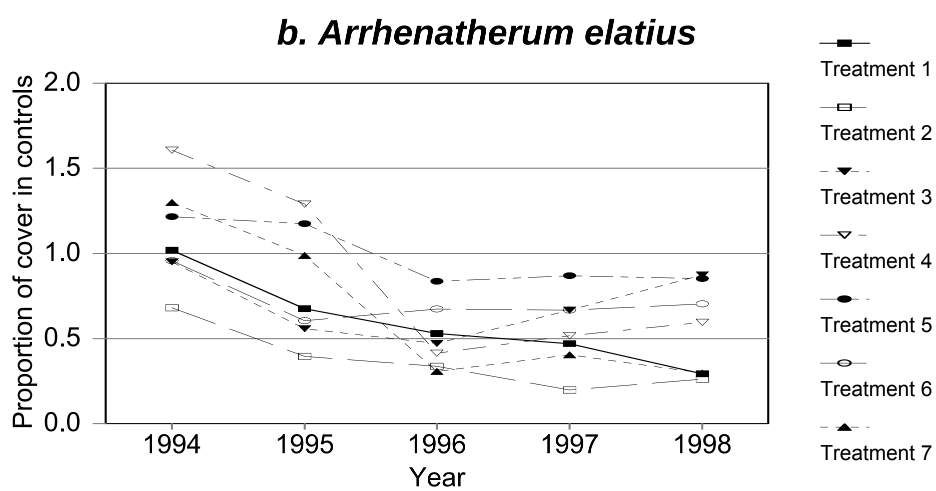
	Total cover	Litter depth	Moss cover
Arrhenatherum elatius			
1997	-0.10	0.06	-0.05
1998	-0.46*	0.02	0.35*
Other non-native grasses (1995)	0.08	0.17	-0.25
Danthonia californica			
1997	0.08	-0.37*	0.02
1998	-0.05	0.12	0.11
Non-native forbs			
1997	-0.02	0.04	-0.13
1998	0.27	-0.33	-0.06

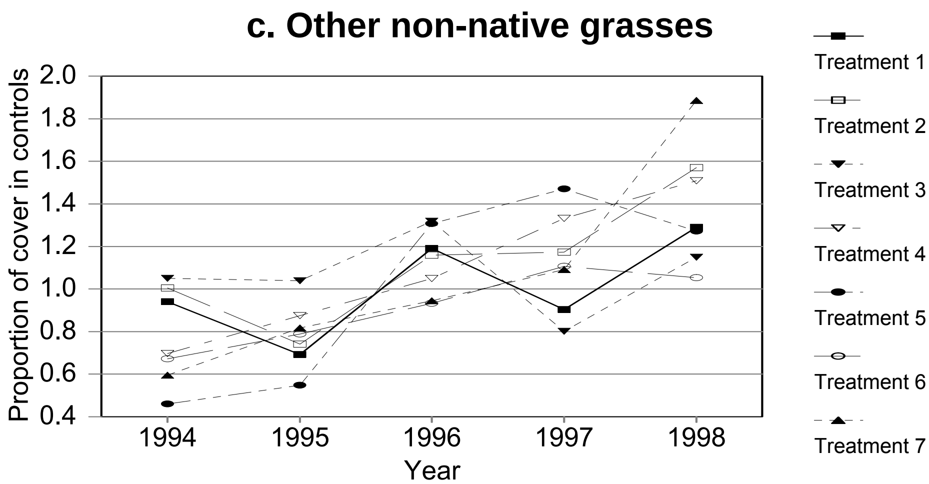
Table 8. Overall performance of mowing treatments on the management objectives of decreasing *Arrhenatherum*, decreasing other non-native plant species, and increasing native plant species. Ratings are based on patterns of vegetative cover, flowering, and seedling density, and consider both the magnitudes and statistical significance of effects.

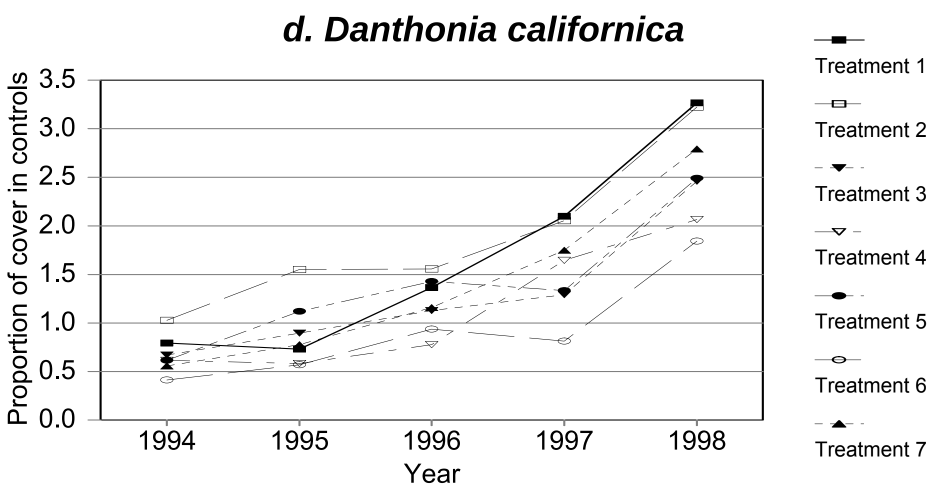
Management objective	Treatment 1	Treatment 2	Treatment 3	Treatment 4	Treatment 5	Treatment 6	Treatment 7	Control
Decreasing *Arrhenatherum*	Very good	Very good					Very good	Bad
Decreasing other non-native plant species			Good?		Bad?	Good?	Bad?	
Increasing native plant species	Very good	Good	Good		Good?	Good	Good	Very bad
Effectiveness (EI)	Very good	Good	Good		Bad			Bad

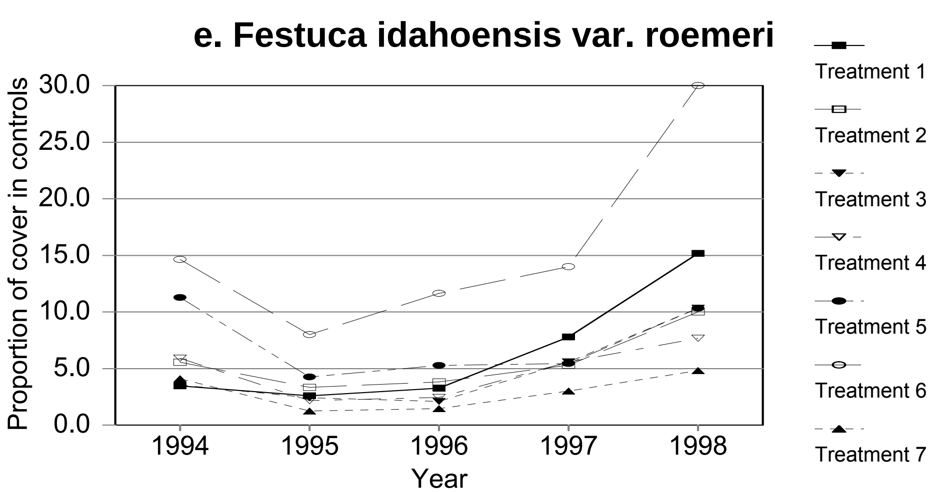
Figure 1. Abundance of plant species and groups from before experimental manipulation (1994) through four years of manipulation (1995-1998). Values are cover (%) in treatments as a proportion of cover in unmanipulated control plots. a. Total vascular plant cover. b. *Arrhenatherum elatius*. c. Other non-native grasses. d. *Danthonia californica*. e. *Festuca idahoensis* var. *roemeri*. f. Non-native forbs. g. Moss. Native forbs were too infrequent to plot.



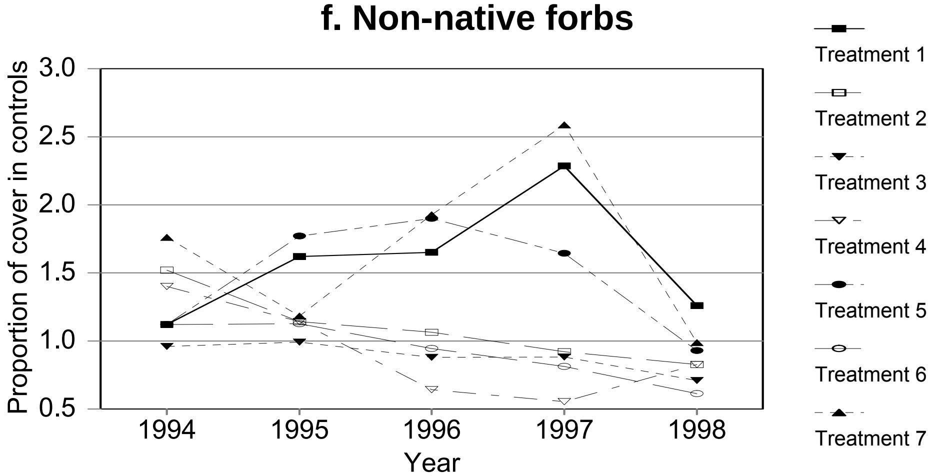



c. Other non-native grasses
Proportion of cover in controls
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
1994
1995
1996
1997
1998
Year
Treatment 1
Treatment 2
Treatment 3
Treatment 4
Treatment 5
Treatment 6
Treatment 7


d. Danthonia californica
Proportion of cover in controls
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1994
1995
1996
1997
1998
Year
Treatment 1
Treatment 2
Treatment 3
Treatment 4
Treatment 5
Treatment 6
Treatment 7


e. Festuca idahoensis var. roemeri
Proportion of cover in controls
30.0
25.0
20.0
15.0
10.0
5.0
0.0
1994
1995
1996
1997
1998
Year
Treatment 1
Treatment 2
Treatment 3
Treatment 4
Treatment 5
Treatment 6
Treatment 7

f. Non-native forbs



g. Moss

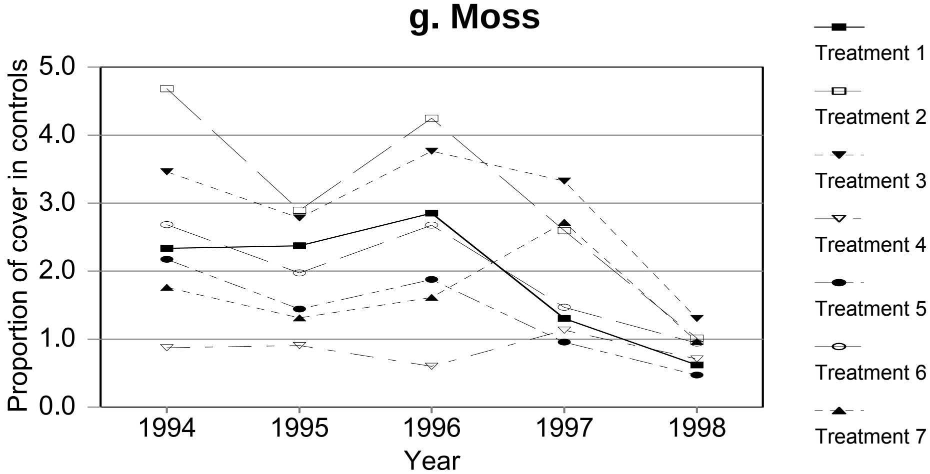
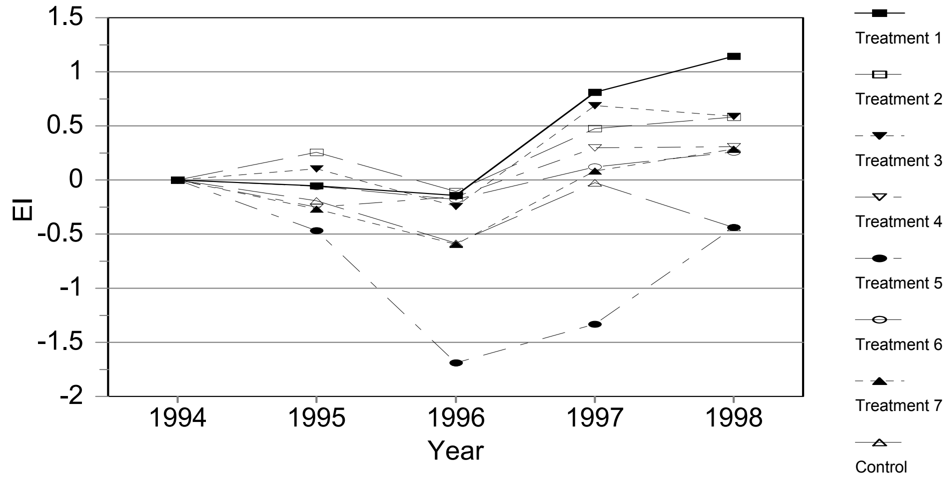


Figure 2. Effectiveness index (EI) for each year of experimental manipulation. Values for 1994 are set to 0.0, for comparison. Positive values show success in attaining management objectives; negative values show decreases in vegetation quality.



Appendix 1. Schedule of treatments.

Treatment	Year 1	Year 2	Year 3	Year 4
1	May 27, 1994	June 5, 1995	May 29, 1996	June 9, 1997
2	June 22, 1994	June 21, 1995	June 26, 1996	June 19, 1997
3	September 15, 1994	September 14, 1995	September 23, 1996	October 6, 1997
4	April 21, 1995	April 23, 1996	April 18, 1997	April 18, 1998
5	June 22, 1994	June 21, 1995	June 26, 1996	June 19, 1997
6	June 22, 1994	June 21, 1995	June 26, 1996	June 19, 1997
7	May 27, 1994 and April 21, 1995	June 5, 1995 and April 23, 1996	May 29, 1996 and April 18, 1997	June 9, 1997 and April 18, 1998

Appendix 2. Species encountered in the study. Dominant species within each category (with relatively high cover or frequency in sampling quadrats) are in bold. Nomenclature follows Hitchcock and Cronquist (1973) unless otherwise noted.

Native grasses

***Danthonia californica* (perennial)**
***Festuca idahoensis* Elmer var. *roemeri* Pavlick[1] (perennial)**

Native forbs

Agoseris sp. (perennial)
***Brodiaea coronaria* (perennial)**
***Clarkia* sp. (annual)**
Eriophyllum lanatum (perennial)
Fragaria virginiana (perennial)
Lotus micranthus (annual)
Ranunculus occidentalis (perennial)
Sanicula bipinnatifida (perennial)

Mosses

***Brachythecium albicans* (Hedw.) B.S.G.**
***Racomitrium canescens* (Hedw.) Bred. var. *ericoides* Hampe.**

Non-native grasses

***Arrhenatherum elatius* (perennial)**
***Bromus mollis* (annual)**
***Bromus rigidus* (annual)**
***Elymus caput-medusae* (annual)**
Dactylis glomerata (perennial)
***Festuca megalura* or *myuros* (annual)**
Festuca arundinacea (perennial)

Non-native and cosmopolitan forbs

Achillea millefolium (perennial)
Cerastium viscosum (annual)
Cirsium sp. (biennial)
***Daucus carota* (biennial)**
***Galium aparine* (annual)**
Geranium carolinianum (annual)
Geranium dissectum (annual)
Hieracium sp. (perennial)
***Hypericum perforatum* (perennial)**
Lathyrus sphaericus (annual)
***Myosotis discolor* (annual)**
Plantago lanceolata (perennial)
***Sherardia arvensis* (annual)**
Sonchus sp.
Unknown Apiaceae
***Vicia hirsuta* (annual)**
***Vicia sativa* (perennial)**
Vicia cracca (perennial)

[1]Recent taxonomic work suggests that within the study area *Festuca idahoensis* var. *roemeri* populations might include individuals of *Festuca rubra* (B. L. Wilson, pers. comm.)