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Effects of Fire, Mowing, and Mowing with Herbicide on Native Prairie of Baskett Butte, Baskett Slough NWR

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SUMMARY

We report results from a field experiment evaluating the effectiveness of mowing, mowing and herbicides, and burning on woody plants, key native and non-native grasses and forbs, and the Fender's blue butterfly. The goal was to find a technique that controlled woody pest plants without harming native species or promoting non-native species.

Three years after the initial manipulations, all treatments significantly reduced woody plant cover. Mowing promoted the group of measured native grasses without promoting non-native species. In contrast, burning had mixed effects on herbaceous species, promoting growth for some species and decreasing growth for others. Each treatment, particularly mowing, caused local increases in numbers of Fender's blue butterfly egg masses, probably because lupines invigorated by treatments attracted ovipositing females. Although prescribed burning seemed to kill larvae, treated areas still accumulated more eggs masses than in controls.

Three years after the start of manipulations, mowing was the most effective overall treatment for controlling woody plants, increasing native species abundance without promoting non-native species, and increasing Fender's blue butterfly numbers. We recommend mowing for restoring similar habitats. Prescribed burning would also be an effective choice for habitat restoration.

INTRODUCTION

The problem

The rare Fender's blue butterfly (*Icaricia icarioides fenderi*) is found only in the Willamette Valley of Oregon (Hammond and Wilson, 1993) and is a candidate for listing under the federal Endangered Species Act. The low abundance of the butterfly makes it a high priority for conservation and management for recovery. Native upland prairies support the largest populations of this butterfly and its host plants, Kincaid's lupine (*Lupinus sulphureus* ssp. *kincaidii*) and spur lupine (*L. arbustus*). These remnant prairies supply the butterfly with food plants, egg-laying sites, and proper flight conditions. The prairies 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 prairies (Wilson et al., 1992).

The native prairies 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 exotic plants suppress the native vegetation, including Kincaid's lupine and plants that supply nectar for Fender's blue butterfly adults. The tall foliage of 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 woody plant succession is a threat to 12 of 13 Fender's blue butterfly sites.

Potential management manipulations

Individuals concerned with protecting the Fender’s blue butterfly agree that protecting and improving suitable habitat is a high priority for butterfly conservation. Yet little is known about how to apply control techniques or how effective they might be. Three control techniques widely applied in prairie management are prescribed burning, mowing, and herbicide application.

Burning is a favored management tool for many of the native prairies in the Willamette Valley. A prime reason for the use of prescribed fire is its ability to slow or prevent the invasion of woody plants during natural succession (Wright and Bailey, 1980; Wilson and Clark, 1995; Clark and Wilson, 1996; Pendergrass et al., 1997). Frequent fires are necessary to accomplish this goal, because trees allowed to grow for several years can survive prairie fires. A second motivation for the use of fire in management is the historical role of fire in the Willamette Valley (Johannessen et al., 1971; Towle, 1982; Boyd, 1986). Returning the natural disturbance process of fire is thought to aid in habitat restoration. Prescribed fires can stimulate the growth or flowering of some native species in Willamette Valley wetland prairies (Connelly and Kauffman, 1991; Wilson et al., 1993; Kaye et al., 1994). The effect of burning at different sites and on herbaceous non-native species is still unclear or variable (Wright and Bailey, 1980; Ewing and Engle, 1988; Glenn-Lewin et al., 1990; Wilson and Shay, 1990; Wilson and Ingersoll, 1993; Macdonald, 1993; Mitchell et al., 1996), however, and in some circumstances might be detrimental to native vegetation (Grilz and Romo, 1994; Maret, 1996).

Mowing, like burning, is widely used for vegetation management in the Willamette Valley. Although anecdotal reports show beneficial effects of mowing (e.g., O’Keefe, 1995), few studies document the success or failure of mowing in controlling pest plants (but see Bobbink and Willems, 1993).

Herbicide use has the twin advantage of relatively low expense and relatively high effectiveness (Grilz and Romo, 1995). Herbicides are often applied once; control methods like fire and mowing often require repeated application to effect pest plant control.

The studies reported here were designed to evaluate the efficacy of specific techniques of burning, mowing, and herbicide application in controlling pest plant species threatening the Fender’s blue butterfly and in promoting important native prairie species.

Study area

We conducted the study 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 prairies dominated by the fescue *Festuca idahoensis* var. *roemeri*, disturbed prairies dominated by non-native weeds and poison oak, 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 (Hammond and Wilson, 1993; Schultz, 1996; Hammond, 1997).

The study area for the experiment was located to the southeast of the south peak (Mt. Baldy) of Baskett Butte, a promontory within the Baskett Slough National Wildlife Refuge. The prairie vegetation in this area is being invaded by the woody species *Rhus diversiloba*, *Rosa eglanteria*, *Rubus discolor* and *Crataegus* sp. We selected this area because of the abundance of invading woody plants, the presence of many native grasses and forbs, the presence of Fender’s blue butterfly, and the availability of enough area to conduct prescribed burns.

METHODS

Experimental design and manipulations

We used a replicated before-after-control-intervention design, with five complete blocks. Each block (approximately 19 m x 20 m) was a section of the experimental area with a complete set of the following four treatments:

- Burn in October 1994 and September 1996
- Mow in October 1994, September 1995, and September 1996
- Mow with herbicide applied to cut stems in October 1994, September 1995, and September 1996
- No manipulation

A buffer (0.5 - 1 m wide) was placed around each treatment area to reduce problems with edge effects. An additional mowed buffer (2 m) was placed around the burn treatment for safety.

The prescribed burns were ignited with drip torches along the edges of plots and then allowed to burn on their own. The convection fires produced by this technique even in small plots have fire characteristics typical of broadcast burning (Maret, 1996). In the 1996 prescribed burns, flame lengths were typically 1 m - 2 m, with maximum lengths of 3 m - 4 m. Burning consumed all existing litter over the 85% - 95% of the plots burned.

Mowing was accomplished with a tractor-driven rotary cutter, set to cut about 6 cm above the soil surface. We applied the herbicides glyphosate (in 1994 and 1995) and Crossbow™ (in 1996) manually with a wicking wand to the cut stems of woody plants within the mowing with herbicide treatment areas. Herbicide concentrations were set at label recommendations.

The planned prescribed burn for 1995 was canceled because high humidity and low temperatures prevented ignition.

Set-up procedures

Three permanent quadrats (1.0 m × 0.5 m) containing *Festuca* were randomly located within each of the treatment areas (60 quadrats, total). The diagonal corners of quadrats were marked with stakes labeled with the coordinates of the quadrat. Metal stakes were used in the burn treatment, small wooden stakes in the mow and mow with herbicide treatments, and wire flag stakes in the no manipulation treatment.

Areas with dense cover of shrubs surrounding the blocks were mowed May 9, 1994 to encourage new growth of vegetation that could help support a fire in the fall. Trees just outside the blocks were removed to improve fire safety.

Measurement procedures: treatment areas

Pre-manipulation data were collected June 3-14, 1994. We used the following phenological events to match manipulation sampling dates in subsequent years with the pre-manipulation sampling dates in 1994:

- *Calochortus tolmei* has completed blooming, but vegetative parts are still green
- *Dactylis glomerata* is in anthesis
- Flowers are appearing on *Agrostis diegoensis*
- *Lupinus* spp. are still flowering but past peak

Post-manipulation data were recorded June 7-12, 1995, June 10-18, 1996, and June 9-20, 1997, at the same phenological time as in 1994.

The cover of shrubs and trees small enough to mow were measured within the entire treatment area by dividing each treatment area into four cells and estimating cover in each cell. Cover of the shrubs and trees was measured as a group and not by individual species. Species counted as shrubs were *Rhus diversiloba*, *Rosa eglanteria*, *Amelanchier alnifolia*, *Rubus discolor* and *Crataegus* sp. The same method for measuring cover of shrubs and small trees was used to measure the cover of *Lupinus sulphureus* ssp. *kincaidii*, *Lupinus arbustus* and *Erigeron decumbens* var. *decumbens*. We also collected post-manipulation data on the height and number of inflorescences of *L. suplureus* ssp. *kincaidii* and *L. arbustus*, a secondary host for Fender's blue butterfly larvae.

In all estimates of cover, two investigators reached a consensus value, using calibrated templates as standards. In subsequent years, at least one investigator had collected cover in the previous year, to promote consistency among years.

Measurement procedures: quadrats

The vegetative cover of each of the following species was measured in each quadrat:

- *Agrostis diegoensis, Danthonia californica, Elymus glaucus*, and *Festuca idahoensis* var. *roemeri* (native grasses)
- *Calochortus tolmei, Fragaria virginiana*, and *Potentilla gracilis* (native forbs)
- *Dactylis glomerata* and *Holcus lanatus* (non-native grasses)
- *Daucus carota, Plantago lanceolata*, and *Vicia* spp. (non-native forbs).

These species were selected because as a group they account for most of the herbaceous cover and they may also be important indicators of the ratio of native to non-native species in the community. In addition, we measured total herbaceous vegetative cover within quadrats.

At the time of manipulations, most of the herbaceous plants were dormant, although leaves and stems of many were still present.

After the pre-manipulation measurements were made, large trees (too big to mow, greater than 5 cm basal diameter) were removed by a fire crew in June. Three trees were removed from the burn treatment area within block E: *Acer macrophyllum, Pseudotsuga menziesii* and *Prunus* sp. One tree, *Malus* sp., was removed from the burn treatment area within block C. A clump of *Amelanchier alnifolia* and two *Quercus garryana* were removed from the burn treatment area within block B. The limbs and other woody debris were removed from the blocks and then chipped on site. At the same time, woody debris from the earlier mowing on May 9, 1994 was chipped.

Measurement procedures: Fender's blue butterfly

The abundance of Fender's blue butterfly larvae and eggs were recorded each year by C. B. Schultz. In April, the presence of larvae was recorded by direct search on host lupines and by noting lupine tissue damage characteristic of Fender's blue butterfly larvae. In June, relative egg abundance was recorded by counting Fender's blue butterfly egg masses on lupine leaves. All lupines within each treatment area were examined for larvae and eggs. Adult densities were not recorded because their mobility was greater than the sizes of each treatment area.

Analysis

Treatment effects were calculated as proportional changes: the change in abundance after the manipulation, divided by the initial abundance. For example, the response variable for the first year after treatment was $\frac{Abundance_{95} - Abundance_{94}}{Abundance_{94}}$. Positive values show increases in abundance after the manipulation; negative values show declines. This formula balances differences among areas in pre-manipulation abundance. If the denominator equaled 0 but the numerator was non-zero (which happened rarely), 1.0 was added to both numerator and denominator.

Treatment effects were tested with analysis of variance, using the rank transformation (Conover, 1980) to meet statistical assumptions of homogeneity and independence of errors. For the quadrat data, the analysis included subsampling, which allows testing for block × treatment interactions, which can make treatment effects difficult to interpret (Underwood, 1997). In every case where treatments had a significant affect on a response variable ($\alpha = 0.05$), the block × treatment interaction was non-significant. When main effects were significant, pairwise treatment comparisons were examined using Tukey’s HSD (Steel and Torrie, 1980; Eberhardt and Thomas, 1991) at the 0.05 level

To better depict the effects of treatments on vegetation over time, both year-to-year variation unrelated to treatments (as reflected in changes in the controls) and initial differences between control and treatment areas were algebraically eliminated. The formula we used was

$\tilde{Y} = \frac{Y_{ij} / Y_{i,94}}{Y_{control,j} / Y_{control,94}}$, where $\tilde{Y}$ is the transformed response variable, Y is the untransformed response variable, i is the treatment, and j is the year.

RESULTS AND DISCUSSION

Pre-manipulation community composition

Woody plants were a dominant component of the study site. Average cover of woody plants ranged between 13% and 36% within treatment areas (Table 1). *Rhus diversiloba* and *Rosa eglanteria* were the most common shrubs measured at the study site.

Kincaid's lupine and spur lupine had overall vegetative cover within treatment areas between 0.1% and 1.2% (Table 1), because they were abundant only along the northern sections of most blocks. The Willamette daisy was present in low abundance.

The measured group of native herbaceous plant species had coverages averaging between 18% and 29% before manipulations. *Danthonia* was the most abundant measured native grass species; *Fragaria* was the most abundant measured native forb species (Table 1).

The measured group of non-native herbaceous plant species had average coverages between 10% and 19%. *Daucus* was the most abundant measured exotic plant species (Table 1).

Average total herbaceous cover within quadrats ranged between 45% and 56%. The 12 herbaceous species measured accounted for most (over two-thirds) of this cover.

Effects of experimental manipulations

Woody plants. Each experimental manipulation was effective at reducing woody plant cover to less than half pre-manipulation levels (Figure 1). Shrubs resprouted each year after treatment. In the case of the prescribed burning treatment, resprouting led to an increase in woody plant cover in 1996 after the year without burning (1995). As a consequence, the two mowing treatments led to better final control of woody plant cover than prescribed burning (Table 2). The presence of vigorous resprouting also means that both burning and mowing treatments need to be repeated regularly until shrubs are killed.

The application of herbicide cut stems had no statistically important additional effect on controlling woody plant cover.

Some previous studies of prescribed burning in Willamette Valley prairies reported a reduction in shrub stature (Pendergrass et al., 1997) without necessarily a reduction in shrub cover (R. E. Frenkel, pers. comm.; K. L. Pendergrass, pers. comm.). Clark and Wilson (1996) found both a reduction on woody cover and decreased survival with mowing and burning treatments applied to a Willamette Valley wetland prairie.

Common herbaceous plants. Total herbaceous cover was relatively constant in all treatments and controls over the course of the experiment (Figure 2). Therefore, changes in the abundance of individual species or species groups are likely to be reflect important effects of experimental treatments.

Measured native grass species were significantly promoted by the mowing and mowing with herbicide treatments (Figure 2 and Table 2). *Danthonia californica* was most responsible for this trend, increasing twice as much in mowed plots as in control plots (Table 2). *Danthonia* cover declined significantly in burned plots compared to control plots. Changes in measured non-native grasses either matched (mowing and mowing with herbicide) or were significantly lower (burning) than in controls (Figure 2 and Table 2). The species group of exotic annual grasses was not measured before treatments began in 1994, but trends in cover with treatment (Table 1) suggest that mowing promotes the establishment of these problem species.

Both native and non-native forbs showed little statistically significant response to treatments (Table 2). The exception was *Plantago lanceolata*, which decreased significantly in burned treatments compared to controls.

Mowing and mowing with herbicide might be promoting native grasses because of differences in stature among species. In upland prairies, *Danthonia californica*, the native grass that increased most strongly to mowing, grows with most of its leaf biomass within 5 cm of the soil surface. Mowing would thus have little direct effect on *Danthonia*. In contrast, the non-native grasses *Dactylis glomerata* and *Holcus lanatus* have most of their foliage relatively evenly distributed along plants that typically reach 150 cm; mowing would cut the dormant stems and leaves of these species, reducing shading of *Danthonia* during the fall and spring growing periods.

Fire can have many effects on herbaceous vegetation (Hurlbert, 1988). Fall burning is unlikely to kill plants outright (Clark and Wilson, in preparation; Wilson and Maret, unpubl. data). In tallgrass prairie, important effects were increased light and soil temperatures after the fire (Hulbert, 1988). It is unclear why these changes would suppress non-native grasses in particular. An intriguing idea is that burning leads to lower availability of soil nitrogen (Ojima et al., 1994; Turner et al, 1997), through direct volatilization and decreased nitrogen mineralization. The resulting impoverished soil can hinder growth of weedy non-native plants (Aerts and Berendse, 1988; Davis and Wilson, unpublished data). Additional studies are needed to clarify how fire affects these prairie ecosystems.

In summary, this is the first time for Willamette Valley prairies that mowing and prescribed burning have been shown to promote groups of native herbaceous species relative to non-native species.

Rare plants. The cover of *Lupinus sulphureus* spp. *kincaidii*, *Lupinus arbustus*, and *Erigeron decumbens* var. *decumbens* was generally low and showed no consistent pattern with treatments (Tables 1 and 2). As is typical with many plants (Whelan, 1995), the effect of burning and mowing was more pronounced on lupine flowering intensity and height (Table 3). Irregular occurrences of these plants in treatment area prevented statistical analysis, but some trends are clear. *L. s*. spp. *kincaidii* never flowered in the controls (Table 3). The burning treatment caused the highest rates of inflorescences per cover for both *L. s.* spp. *kincaidii* and *L. arbustus*, over twice that found in other treatments. Highest flowering rates were in the years following prescribed burning. *L. s.* spp. *kincaidii* was somewhat taller in the treatments than in controls (Table 3).

Two factors are likely to have caused this increase in lupine vigor. The leaves of the lupines in this study are close to the ground (typically < 20 cm) and easily shaded by taller plants, such as shrubs and weedy, non-native grasses. Such competitive pressures can reduce lupine growth and flowering (Wu and Torres, 1990). Burning significantly reduced the cover of these taller plants. Although mowing and mowing with herbicide did not reduce the cover of weedy grasses, they seemed to slow the growth of these taller, non-native plants (pers. obs.), perhaps permitting lupine growth to continue longer into the season than in controls.

Soil changes from prescribed burning could also contribute to enhanced lupine growth. Burning converts soil phosphorus into a form more usable by plants (Seastedt and Ramundo, 1990), and phosphorus can stimulate flowering in lupines (Wu and Torres, 1990). Burning in tallgrass prairie also reduces available soil nitrogen (Ojima, et al., 1994; Turner et al., 1997), which can lead to slower plant growth. The ability of legumes like *Lupinus* to fix N can give them a competitive edge (Towne and Knapp, 1996).

Fender's blue butterfly. The densities of Fender's blue butterfly larvae before treatment (Table 4) varied in line with lupine cover (Table 1). Although the proportional changes in larval numbers from before treatment in 1994 to 1997 were not significantly related to treatment (Table 2), big changes in larval numbers did occur within burn plots (Figure 3). Almost no larvae remained in 1995 after the 1994 prescribed fire and in 1997 after the 1996 prescribed fire. Highest numbers of larvae were found in the burn plots in 1996. The pattern differs for Fender's blue butterfly eggs (Table 4, Figure 3). Egg densities generally increased over time in the treatments but not in the controls, leading to a significant effect on eggs for the mowing and prescribed burning treatments (Table 2).

Understanding the causes of these patterns requires information on the biological interactions of Fender's blue butterfly and its host lupines (Hammond and Wilson, 1993; Hammond, 1994; Schultz, 1996). Female adults typically lay eggs on lupine foliage in June (Figure 4). These eggs hatch into larvae, which are active and eating lupine foliage for a few weeks in June. Starting around July, larvae enter diapause, residing at the soil surface or in the litter layer (Schultz, 1996). Lupine foliage dies back in July, and the plant is dormant for the summer and into the fall. Fall rains can stimulate lupine growth, but the bulk of lupine growth occurs as temperatures increase in the early spring (Figure 4). Fender's blue butterfly larvae become active again typically in April, feeding on new lupine foliage. Larvae pupate in late spring, and adults eclose in May. Lupine flowering peaks in May and early June.

At the time of treatments in this experiment, in September and October, Fender's blue butterfly larvae are in diapause near the soil surface (Figure 4). Prescribed burning usually consumed the litter layer over 85%-95% of the treatment areas (personal observation) and would easily kill any larvae present. This direct mortality explains the precipitous decline in larval numbers after burning (Figure 3). Similar concerns about mortality of larvae with fire have been expressed for butterflies in tallgrass prairie (McCabe, 1981; Dana, 1985, cited in Panzer, 1988; Swengel, 1992). Mowing, since cutting happens around 6 cm, has little direct effect on larvae (Figure 3). The spring after treatments, flowering intensity increases in lupine plants (Table 3). We suggest that female Fender's blue butterflies are attracted by this increased flowering vigor of lupines, which leads to more ovipositing and higher egg densities. That is, post-treatment lupines act as butterfly magnets, drawing adults from unstimulated lupines outside the treatment areas. With prescribed burning, the increase in ovipositing more than compensated for loss of larvae (Figure 3). With mowing, increased ovipositing without loss of larvae led to highest proportional increase in egg numbers (Table 2).

The mowing with herbicide treatment differed from the mowing treatment in 1996-1997, with numbers of both larvae and eggs down (Figure 3). That year the herbicide was changed from glyphosate to Crossbox™, a mixture of 2,4-D and triclopyr. It is possible that the decline in number of larvae was due to direct toxicity.

This study shows the beneficial effects of prescribed burning and mowing on Fender's blue butterfly populations under experimental conditions. Long-term and larger-scale benefits require expanding treatment effects beyond an increase in lupine flowering to an increase in the resource base for the butterfly. That is, lupine populations and adult nectar sources (most of which are native species; Wilson et al., 1997) must become more abundant. The best way to reach these goals is to continue habitat restoration efforts. Increased native plant cover, decreased non-native plant cover, and increased vigor were shown in this study to occur with some habitat manipulations. We feel that the best next step is to test these results with management-scale applications, coupled with direct propagation of lupines and nectar sources through seeding or transplanting.

SUMMARY OF MANAGEMENT RECOMMENDATIONS

Key objectives for managing the Fender's blue butterfly include preventing encroachment of woody plants, promoting native herbaceous species without also promoting non-native pests species, and increasing Fender's blue butterfly populations. The results from this study lead to several recommendations for meeting these objectives.

- Mowing, mowing with herbicide application, and prescribed burning were each effective at controlling woody plants. Any of these techniques could be used to prevent invasion and increase of woody plants into native prairie. Resprouting leads to the return of woody plant cover, so treatments should be repeated regularly.
- Some treatments were able to shift the balance in favor of native herbaceous species. Mowing significantly promoted the group of measured native grasses without promoting the non-native perennial grasses. If mowing is used to promote native grasses, results should be carefully monitored to see if undesirable exotic annual grasses are also promoted. Prescribed burning, best at reducing non-native perennial grasses, could also be used to shift vegetation composition towards natives.
- Each treatment, particularly mowing, caused local increases in Fender's blue butterfly populations. We therefore recommend the application of these techniques to larger habitats, but accompanied by careful monitoring of vegetation and butterfly responses.
- The best treatment overall is mowing. Of the seven statistically significant effects on ecosystem quality, mowing had the best results in five cases (Table 2).
- Prescribed burning also had significant beneficial effects, reducing woody plant cover, reducing non-native grass cover compared to controls, and promoting the Fender's blue butterfly. In situations in which mowing is economically or logistically impractical, prescribed burning would be a good choice for habitat restoration. An alternative approach is to combine burning and mowing treatments, perhaps in alternate years.

- We recommend against using herbicides on stems cut after mowing. Little added benefits accrued from herbicide application and there are possible adverse effects on Fender's blue butterfly larvae and some non-target plants.

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Figure 1. Average woody plant cover after treatments, adjusted for premanipulation cover and year-to-year variation in the unmanipulated controls (see Methods for explanation). Mowing and mowing with herbicide treatments were applied in the fall of 1994, 1995, and 1996. Burning treatments were applied in the fall of 1994 and 1996. Cover was recorded in June of each year. Proportional changes from 1994 to 1997 of treatments sharing letters were statistically indistinguishable.

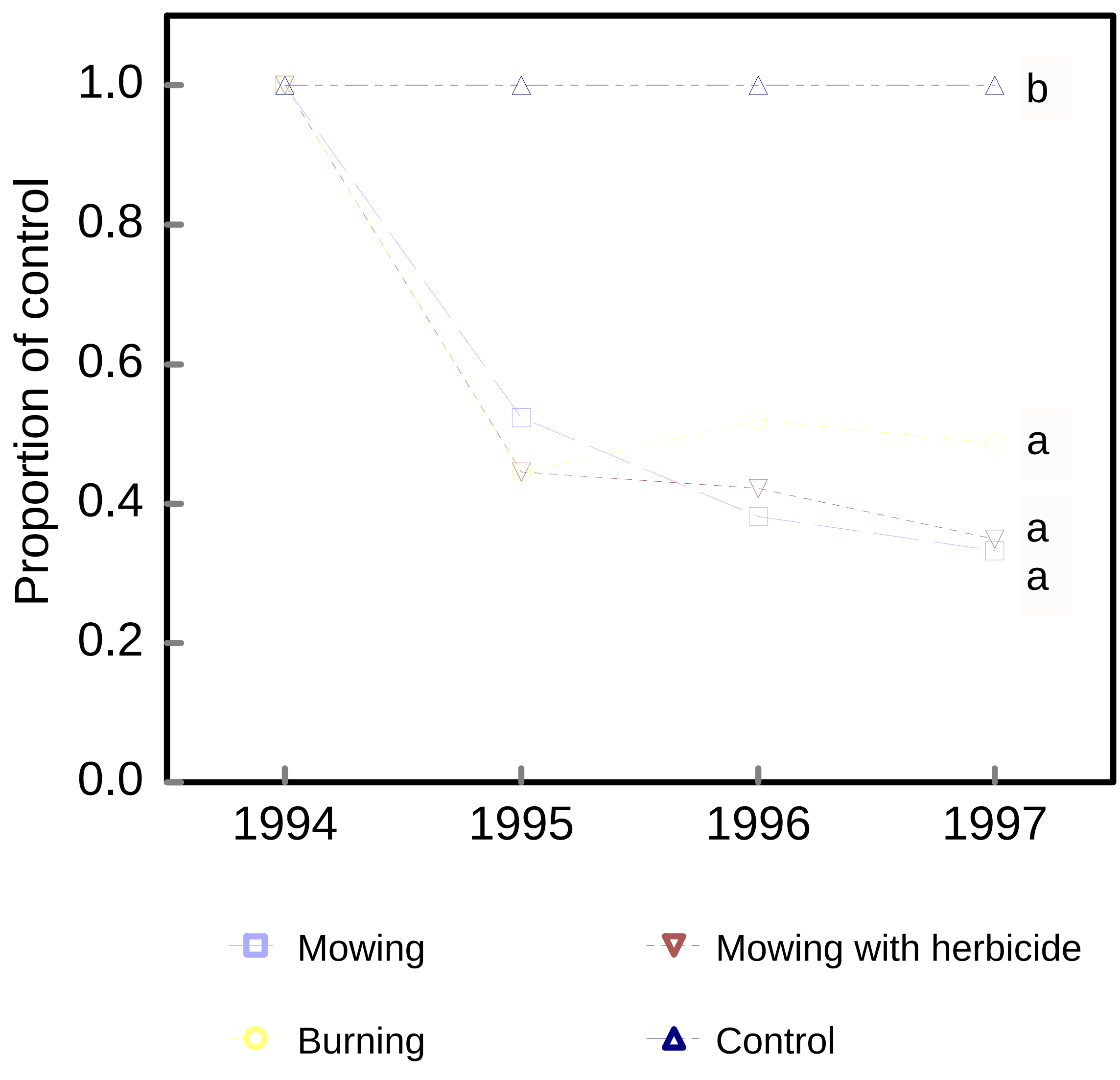
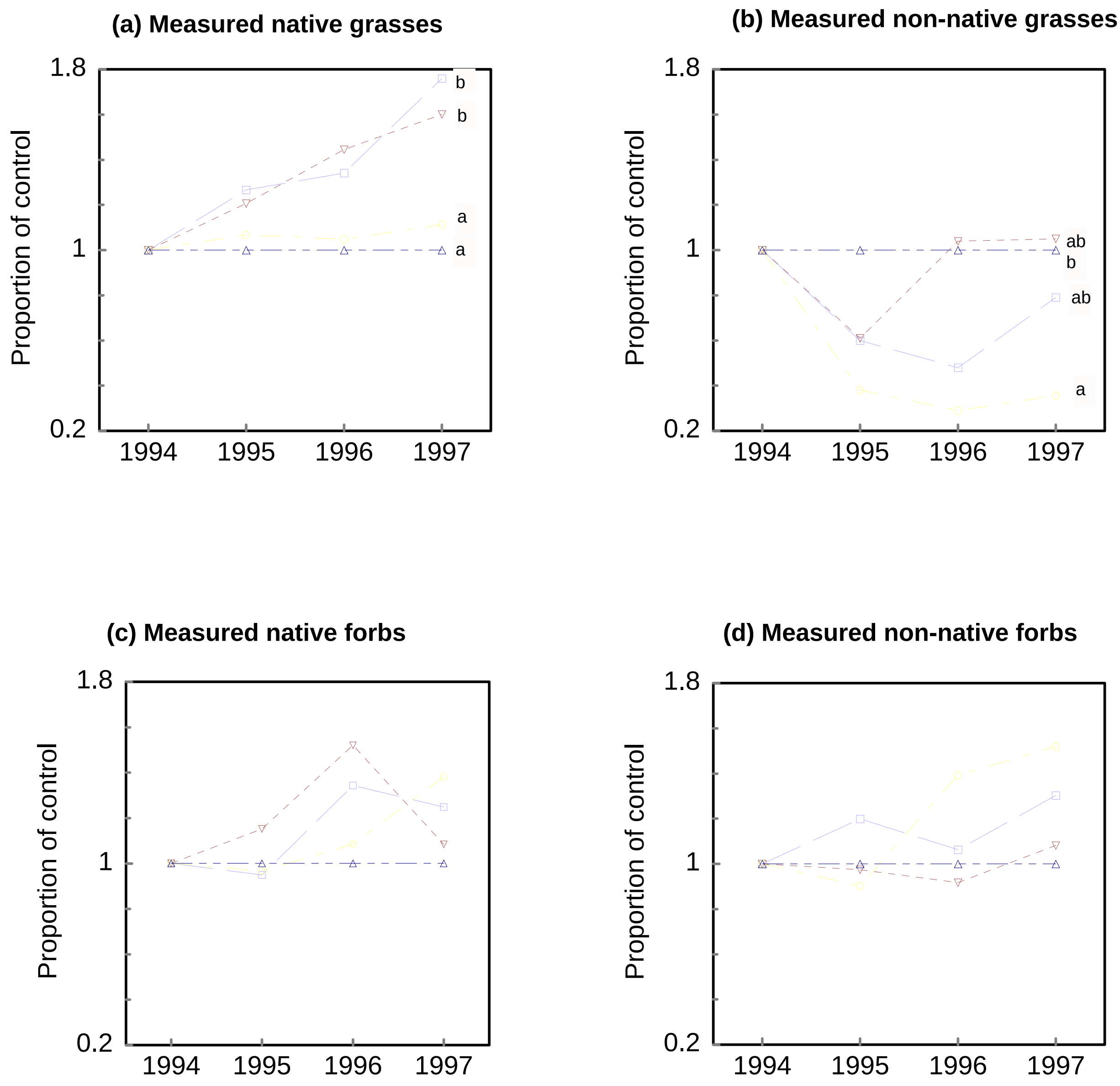


Figure 2. Average cover of species groups after treatments, adjusted for premanipulation cover and year-to-year variation in the unmanipulated controls (see Methods for explanation and next page for legend). Mowing and mowing with herbicide treatments were applied in the fall of 1994, 1995, and 1996. Burning treatments were applied in the fall of 1994 and 1996. Cover was recorded in June of each year. In those cases where proportional changes from 1994 to 1997 were significantly affected by treatments, treatments sharing letters were statistically indistinguishable. See next page for figure legend.



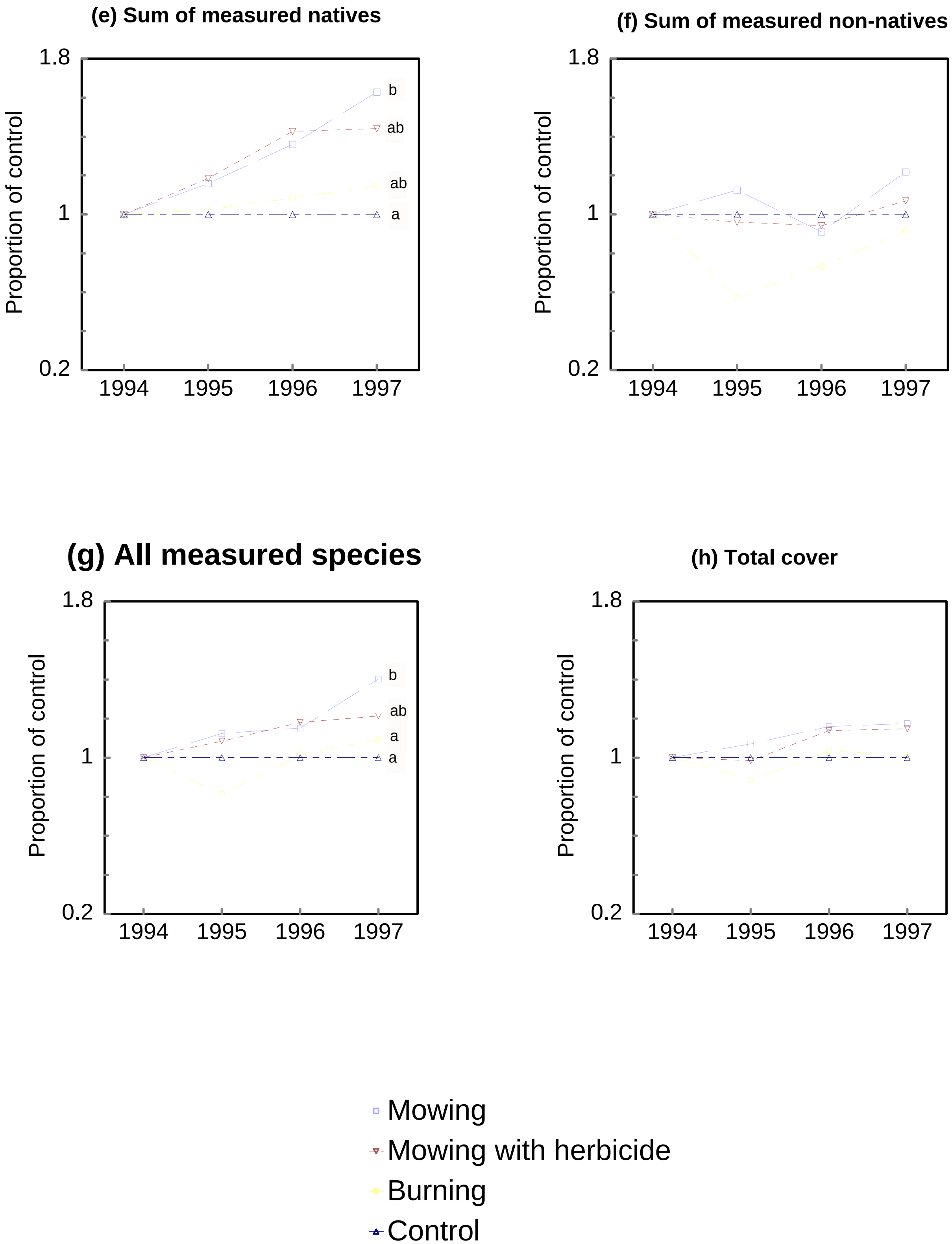
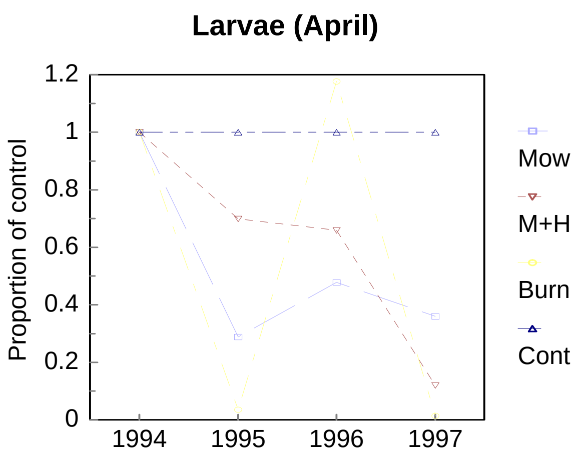

(e) Sum of measured natives
(f) Sum of measured non-natives
(g) All measured species
(h) Total cover
Proportion of control
1.8
1
0.2
1994
1995
1996
1997
b
ab
ab
a
b
ab
a
a
Mowing
Mowing with herbicide
Burning
Control

Figure 3. Average number of Fender's blue butterfly larvae and egg masses over time, adjusted for premanipulation abundance and year-to-year variation in the unmanipulated controls. Mowing and mowing with herbicide treatments were applied in the fall of 1994, 1995, and 1996. Burning treatments were applied in the fall of 1994 and 1996. Proportional changes from 1994 to 1997 in egg mass density was significantly affected by treatments.



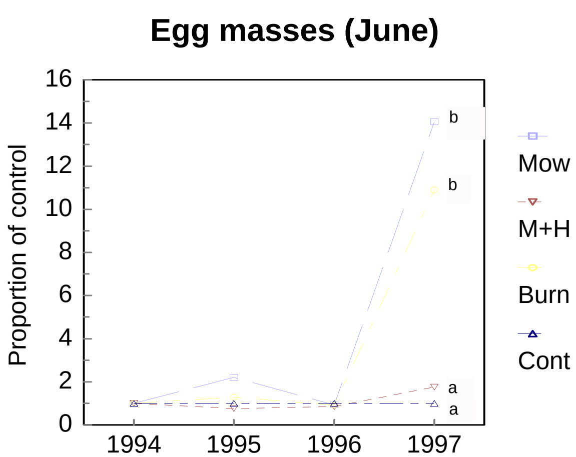


Figure 4. Approximate time line of events for the Fender's blue butterfly and host lupines. Also shown are timing of study measurements and treatments.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Butterfly	(diapause continues)		Larvae active		Adults eclose	Females lay eggs; larvae hatch	- - - - - - - - - - Larvae in diapause (in litter) - - - - - - - - - -					
Lupines			New shoots		Flowering			Senescence				
Measurement and manipulation				Density of larvae		Vegetation; egg density			Treatments: Fire and mowing			

Table 1. Average cover (%) of plants before treatment (1994) and after treatment (1995, 1996, 1997). N = native, NN = non-native, G = grass, F = forb. nr = not recorded.

	Year	Treatments			
		Mow	Mow with herbicide	Burn	Control
Woody plants	1994	13.5	18.1	35.4	24.1
	1995	6.8	6.3	12.3	22.8
	1996	4.2	6.2	12.7	19.6
	1997	5.0	6.0	16.4	22.9
Lupinus sulphureus ssp. *kincaidii* (N)	1994	0.5	0.4	0.2	0.2
	1995	0.4	0.4	0.2	0.1
	1996	0.3	0.5	0.2	0.0
	1997	0.4	0.7	0.4	0.1
Lupinus arbustus (N)	1994	0.5	0.1	1.2	0.1
	1995	0.3	0.1	0.6	0.1
	1996	0.3	0.1	0.6	0.2
	1997	0.4	0.0	0.9	0.2
Erigeron decumbens var. *decumbens* (N)	1994	0.2	0.0	0.0	0.0
	1995	0.2	0.0	0.1	0.1
	1996	0.1	0.0	0.0	0.1
	1997	0.1	0.0	0.0	0.1
Agrostis diegoensis (NG)	1994	4.1	3.2	3.3	6.5
	1995	4.2	3.4	4.8	4.9
	1996	2.0	2.0	2.7	2.6
	1997	4.3	3.6	6.8	4.7
Danthonia californica (NG)	1994	6.4	5.5	3.9	6.5
	1995	6.4	4.8	1.8	6.5
	1996	6.4	5.5	1.3	5.1
	1997	23.0	16.3	3.8	13.8
Elymus glaucus (NG)	1994	1.7	0.5	0.9	2.9
	1995	2.5	1.2	2.1	1.7
	1996	2.2	1.3	1.5	2.2
	1997	3.1	1.5	2.2	2.9
Festuca idahoensis var. *roemeri* (NG)	1994	3.4	3.6	4.5	3.0
	1995	1.7	2.1	1.7	1.6
	1996	1.6	1.2	1.9	1.1
	1997	2.4	2.9	3.9	2.6
Calochortus tolmei (NF)	1994	0.7	1.2	0.5	0.8

	1995	0.5	1.1	0.7	0.6
	1996	0.5	0.7	0.4	0.6
	1997	1.0	1.0	1.3	0.8
Fragaria virginiana (NF)	1994	2.9	4.1	6.1	8.8
	1995	2.4	4.0	6.1	8.5
	1996	2.9	4.0	4.8	6.7
	1997	4.1	5.3	7.6	11.6
Potentilla gracilis (NF)	1994	0.5	0.5	0.4	0.2
	1995	0.6	0.4	0.4	0.5
	1996	0.6	0.7	0.7	0.5
	1997	0.6	0.5	1.5	0.7
Dactylis glomerata (NNG)	1994	3.2	0.5	6.7	1.0
	1995	3.1	0.3	1.7	1.0
	1996	2.7	0.5	1.4	1.0
	1997	6.5	1.3	4.3	1.2
Holcus lanatus (NNG)	1994	0.8	0.5	0.8	0.7
	1995	0.4	0.4	1.0	0.8
	1996	0.6	1.1	1.5	1.6
	1997	1.8	1.7	2.7	3.8
Daucus carota (NNF)	1994	7.5	6.2	6.8	5.7
	1995	7.3	6.0	4.8	5.7
	1996	12.0	10.1	13.2	11.1
	1997	21.0	14.5	18.5	14.7
Plantago lanceolata (NNF)	1994	3.4	4.2	4.1	2.4
	1995	2.7	2.6	2.0	1.2
	1996	3.2	3.6	3.9	2.1
	1997	7.9	7.7	11.4	2.6
Vicia spp. (NNF)	1994	0.1	0.1	0.6	0.4
	1995	1.9	1.3	1.1	2.1
	1996	0.5	0.8	0.4	0.5
	1997	0.5	0.4	0.4	1.6
Exotic annual grasses (NNG)	1994	nr	nr	nr	nr
	1995	4.5	4.5	5.3	3.3
	1996	7.1	7.1	5.4	3.9
	1997	14.7	10.1	8.4	6.1

Table 2. Median proportional changes from before treatment (1994) to three years after treatment (1997) for measured plant species and plant groups; average proportional changes for Fender's blue butterfly larvae and eggs. *P* is the probability that differences in proportional changes among treatment occurred just by chance. Treatments sharing letters were statistically indistinguishable (Tukey's HSD, α = 0.05). Where treatments had significant effects ($P < 0.05$), the treatment best at reaching the management objectives of promoting natives or reducing non-natives is noted by underlining.

	Treatments				*P*
	Mow	Mow with herbicide	Burn	Control	
Woody plants	-0.66a	-0.66a	-0.45a	-0.07b	<0.01
Lupinus sulphureus ssp. *kincaidii*	0.00	0.00	0.00	0.00	0.33
Lupinus arbustus	0.00	0.00	-0.16	0.00	0.31
Erigeron decumbens var. *decumbens*	0.00	0.00	0.00	0.00	0.17
Agrostis diegoensis (NG)	0.00	0.00	0.00	-0.13	0.63
Danthonia californica (NG)	4.00b	1.73b	0.00a	1.38b	<0.01
Elymus glaucus (NG)	0.50	0.00	0.38	0.00	0.50
Festuca idahoensis var. *roemeri* (NG)	-0.25	-0.50	0.33	-0.25	0.65
Measured native grass species	0.87b	0.79b	0.38a	0.30a	<0.01
Calochortus tolmei (NF)	0.00	0.00	1.50	0.00	0.36
Fragaria virginiana (NF)	0.20	0.20	0.13	0.09	1.00
Potentilla gracilis (NF)	0.00	0.00	0.00	0.00	0.27
Measured native forb species	0.50	0.00	0.50	0.32	0.71
Sum of measured natives	0.85b	0.66ab	0.33ab	0.26a	0.05
Dactylis glomerata (NNG)	0.00	0.00	0.00	0.00	0.14
Holcus lanatus (NNG)	0.50	0.00	0.25	2.25	0.48
Measured non-native grass species	0.74ab	0.50ab	0.00a	1.50b	0.04
Daucus carota (NNF)	1.92	1.20	2.00	1.17	0.84
Plantago lanceolata (NNF)	1.40bc	0.33ab	1.75c	0.00a	<0.01
Vicia spp. (NNF)	0.00	0.00	0.00	0.00	0.76
Measured non-native forb species	1.63	0.94	1.38	0.88	0.43
Sum of measured non-natives	1.57	1.33	0.86	0.75	0.25
All measured species	1.19b	0.88ab	0.60a	0.56a	<0.01
Total cover	0.50	0.50	0.29	0.29	0.30
Fender's blue butterfly larvae	0.61	-0.22	-0.93	3.00	0.08
Fender's blue butterfly eggs	17.69c	1.28ab	9.16bc	0.67a	0.01

Table 3. Vigor of Kincaid's lupine (*kin*) and spur lupine (*arb*) within treatment areas in 1995, 1996, and 1997. Averages for inflorescences per cover and for height were calculated only for those blocks containing those lupines species. sd is standard deviation. — under sd means that there was only one data point.

		Inflorescences per block				Inflorescences per cover (%)				Height (cm)			
		kin		*arb*		*kin*		*arb*		*kin*		*arb*	
		mean	sd	mean	sd	mean	sd	mean	sd	mean	sd	mean	sd
Mow	1995	1.7	1.5	1.7	2.9	0.8	0.8	1.1	1.9	17.0	1.4	26.5	10.6
	1996	1.3	0.6	13.0	15.6	0.8	0.3	7.2	4.0	21.7	4.5	59.5	2.1
	1997	11.3	14.4	7.3	12.7	3.5	3.9	0.9	1.6	18.0	1.4	23.0	5.3
Mow with herbicide	1995	1.0	1.4	3.0	4.2	0.3	0.4	2.0	2.8	17.7	—	30.5	17.7
	1996	4.0	4.2	2.0	2.8	0.7	0.7	1.3	1.9	20.0	2.8	26.5	16.3
	1997	9.0	9.9	0.0	0.0	1.1	1.0	0.0	0.0	17.2	1.6	16.0	5.7
Burn	1995	10.7	15.9	45.7	64.1	6.8	7.3	9.1	9.2	17.5	0.7	44.0	7.1
	1996	8.7	11.0	34.3	42.2	5.2	5.9	8.2	3.8	21.0	6.1	50.0	9.5
	1997	28.0	18.4	74.3	62.6	6.7	1.0	13.2	5.0	20.3	4.6	35.6	5.1
Control	1995	0.0	—	3.0	4.2	0.0	—	3.0	4.2	—	—	25.5	20.5
	1996	0.0	—	3.0	1.4	0.0	—	1.8	0.6	18.0	—	52.0	11.3
	1997	0.0	—	0.5	0.7	0.0	—	0.3	0.4	13.5	—	29.5	3.5

Table 4. Average estimated numbers of Fender's blue butterfly larvae and number of egg masses before treatment (1994) and after treatment (1995, 1996, 1997). Averages are only for those treatment areas with lupines.

	Year	Treatments			
		Mow	Mow with herbicide	Burn	Control
Larvae (April)	1994	3.2	3.3	4.4	1.0
	1995	1.2	3.0	0.2	1.3
	1996	2.6	3.7	8.8	1.7
	1997	3.8	1.3	0.2	3.3
Eggs (June)	1994	6.2	17.3	16.2	3.3
	1995	49.8	47.3	76.0	12.0
	1996	37.2	94.3	96.4	21.3
	1997	87.2	30.3	176.4	3.3