Effects of Fire Retardant Chemical and Fire Suppressant Foam on Shrub Steppe Vegetation in Northern Nevada

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Abstract
The objectives of this study were to determine the effects of fire retardant chemical (Phos-Chek G75-F*) and fire suppressant foam (Silv-Ex) application, alone and in combination with fire, on Great Basin shrub steppe vegetation. We measured growth, resprouting, flowering, and incidence of galling insects on *Chrysothamnus viscidiflorus* and *Artemisia tridentata*. These characteristics were not affected by any chemical treatment. We measured community characteristics, including species richness, evenness, and diversity, and number of stems of woody and herbaceous plants in riparian and upland plots. Of these characteristics, only species richness and number of stems/m^2 clearly responded to the chemical treatments, and the response was modified by fire. In general, species richness declined, especially after Phos-Chek application. However, by the end of the growing season, species richness did not differ between treated and control plots. A canonical variate analysis suggested that burning had a greater influence on community composition than did the chemical treatments. In general, riparian areas showed more significant responses to the treatments than did upland areas, and June applications produced greater changes in species richness and stem density than did July applications.

Keywords:
Fire retardant
Class A foam
Great Basin
Shrub steppe
Wildland fire.

Introduction
Fire suppressant foams and fire retardant chemicals are used to contain wildland fires and control prescribed burns for habitat management. In 1988 alone, more than 19 million L of retardant were dropped from aircraft on wildland fires in the western United States (Guth and Cohen 1989). Class A foams receive widespread use in constructing fire lines for both wildfires and prescribed burns. Some 795 000 L of concentrate—enough to make 159 million L of foam—were sold in 1992 (C. Johnson, U.S.D.A. National Fire Sciences Laboratory, pers. comm.). These chemicals are often applied in environmentally sensitive areas that may contain endangered, threatened, or economically significant plant and animal species.

* Use of Trade Names does not imply endorsement by the U.S. Government.

Table 1. Plant species and the number of plot–sample period combinations on which they occurred in riparian and upland habitat at Cabin Creek and North Fork study areas in Nevada. Taxonomy follows Hickman (1993). There were 8 plots/treatment, 8 treatments/application, 2 applications (June and July), and 5 sample periods (1 pre-treatment and 4 post-treatment), for a possible total of 640 plot–sample period combinations in each habitat type.

			Number of plot–sample periods		
Genus	Species	Family	Upland	Riparian	Total
Achillea	*millefolium*	Asteraceae	22	288	310
Agoseris	*glauca*	Asteraceae	20	12	32
Arnica	*chamissonis*	Asteraceae	0	46	46
Artemisia	*ludoviciana*	Asteraceae	0	47	47
Artemisia	*tridentata*	Asteraceae	193	0	193
Chrysothamnus	*nauseosus*	Asteraceae	12	0	12
Chrysothamnus	*viscidiflorus*	Asteraceae	284	0	284
Cirsium	*foliosum*	Asteraceae	31	107	138
Cirsium	*vulgare*	Asteraceae	0	24	24
Crepis	*acuminata*	Asteraceae	1	0	1
Erigeron	spp.	Asteraceae	69	0	69
Senecio	*intergerrimus*	Asteraceae	9	0	9
Taraxacum	*officinale*	Asteraceae	11	337	348
Descurainia	*richardsonii*	Brassicaceae	5	0	5
Thlaspi	*arvense*	Brassicaceae	0	1	1
Stellaria	*longipes*	Caryophyllaceae	0	29	29
Arabis	*glabra*	Cruciferae	1	1	2
Carex	*douglassii*	Cyperaceae	45	0	45
Carex	*microptera*	Cyperaceae	0	36	36
Carex	*nebraskensis*	Cyperaceae	0	78	78
Carex	*praegracilis*	Cyperaceae	0	287	287
Equisetum	*arvense*	Equisetaceae	0	41	41
Astragalus	*curvicarpus*	Fabaceae	32	0	32
Lupinus	*caudatus*	Fabaceae	47	18	65
Thermopsis	*montana*	Fabaceae	0	213	213
Gentiana	*affinis*	Gentianaceae	0	4	4
Iris	*missouriensis*	Iridaceae	0	3	3
Juncus	*balticus*	Juncaceae	69	298	367
Juncus	*ensifolius*	Juncaceae	0	6	6
Mentha	*arvensis*	Lamiaceae	0	8	8
Prunella	*vulgaris*	Lamiaceae	0	1	1
Scutellaria	*angustifolia*	Lamiaceae	0	1	1
Allium	spp.	Liliaceae	1	0	1
Smilacina	*stellata*	Liliaceae	0	4	4
Linum	*perenne*	Linaceae	113	132	245
Sidalcea	*neomexicana*	Malvaceae	0	25	25
Epilobium	*glaberrimum*	Onagraceae	0	63	63
Agropyron	*trachycaulum*	Poaceae	142	102	244
Bromus	*inermis*	Poaceae	0	1	1
Bromus	*tectorum*	Poaceae	0	5	5
Deschampsia	*elongata*	Poaceae	0	8	8
Elymus	*cinereus*	Poaceae	30	0	30
Hordeum	*pusillum*	Poaceae	0	52	52
Koeleria	*cristata*	Poaceae	6	2	8
Poa	*pratensis*	Poaceae	0	352	352

Table 1. (*Continued*)

Genus	Species	Family	Number of plot–sample periods Upland	Riparian	Total
Poa	*secunda*	Poaceae	159	10	169
Sitanion	*hystrix*	Poaceae	62	0	62
Stipa	*thurberiana*	Poaceae	4	0	4
Ipomopsis	*aggregata*	Polemoniaceae	2	0	2
Leptodactylon	*pungens*	Polemoniaceae	10	0	10
Phlox	*hoodii*	Polemoniaceae	24	0	24
Phlox	*longifolia*	Polemoniaceae	1	0	1
Eriogonum	*ovalifolium*	Polygonaceae	7	0	7
Rumex	*crispus*	Polygonaceae	0	1	1
Rumex	*salicifolius*	Polygonaceae	0	20	20
Lewisia	*rediviva*	Portulacaceae	1	0	1
Ranunculus	*cymbalaria*	Ranunculaceae	0	19	19
Geum	*macrophyllum*	Rosaceae	0	50	50
Potentilla	*glandulosa*	Rosaceae	0	12	12
Potentilla	*gracilis*	Rosaceae	41	247	288
Rosa	*woodsii*	Rosaceae	0	4	4
Galium	*aparine*	Rubiaceae	0	5	5
Ribes	*cereum*	Saxifragaceae	6	0	6
Mimulus	*guttatus*	Scrophulariaceae	0	4	4
Penstemon	*rydbergii*	Scrophulariaceae	2	37	39
Verbascum	*thapsus*	Scrophulariaceae	0	1	1

Relatively little is known about the toxicity of these chemicals to terrestrial plants and animals; even less information is available concerning effects at the community and ecosystem levels. Here, we address responses of terrestrial vegetation to fire retardant chemical and fire suppressant foam application in the Great Basin of North America.

Previous work on a mixed-grass prairie site in North Dakota (Larson and Newton 1996) indicated that the primary effect of both retardant and foam on prairie vegetation is a reduction in plant species richness. Several aspects of the Great Basin environment suggest that results may vary from those obtained in the more mesic Midwest. The Great Basin growing season tends to be divided into two peaks: an early, large response to moisture from melting snow, and a second, smaller response to precipitation from late summer storms (West 1988). Vegetation in the Great Basin is often water-limited. Many species are dormant during the hottest summer months when natural fires are most likely to occur and thus when retardant is used. Like the mixed-grass prairie, vegetation cover in the Great Basin can be nearly 100% in riparian areas. In contrast, upland areas of the Great Basin tend to be dominated by sparse bunch grasses and shrubs, with large areas of exposed soil (Daubenmire 1978, West 1988).

Fire retardant chemicals and fire suppressant foams may influence vegetation in several ways. Because fire retardants are composed largely of nitrogen and phosphorus fertilizers, we can make predictions about their effects on vegetation based on studies of fertilizers. Like fertilizers, fire retardants may encourage growth of some species at the expense of others, resulting in changes in community composition and species diversity (James and Jurinak 1979, Larson and Duncan 1982, Wilson and Shay 1990, Tilman 1987, Wedin and Tilman 1996). Differential growth may also influence herbivory; both insect and vertebrate herbivores tend to favor new, rapidly growing shoots (Stein et al. 1992). Fire suppressant foams, which are most closely aligned with soaps, have no analogous studies from which to make predictions of effect.

The objectives of this study were to determine effects of fire retardant chemical and fire suppressant foam on (1) plant growth; (2) plant species richness, evenness, and diversity; (3) plant community composition; (4) resprouting and (5) flowering of burned and unburned vegetation; and (6) activity of galling insects on that vegetation.

Materials and Methods

Description of Study Site

The study was conducted along two similar drainages, the North Fork of the Humboldt River (T45N R41E, Sec. 19) and Cabin Creek (T44N R40E, Sec. 5), within the Santa Rosa Mountains in northern Nevada, in the western USA. Elevation of the two drainages was approximately 1800 m. Woody vegetation was predominantly *Artemisia tridentata* and *Chrysothamnus nauseosus* and *C. viscidiflorus* in the uplands, grading into low-stature riparian vegetation (mainly *Salix* spp.) near the rivers. *Juncus balticus, Carex microptera, C. nebraskensis* and *C. praegracilis*, and *Poa pratensis* were most common in the riparian zones; predominant upland species included *Poa secunda* and *Agropyron trachycaulum* (Table 1). Soils were loamy, with gravel inclusions on stream terraces. Average annual precipitation is 30.8 cm (12 in.); the frost-free season averages 80 days.

Description of Chemicals

We used one Class A (i.e. applied to Class A fuels, such as wood) fire suppressant foam, Silv-Ex*, and one fire retardant, Phos-Chek G75-F, in our field tests. Silv-Ex concentrate is a proprietary mixture of sodium and ammonium salts of fatty alcohol ether sulfates, higher alcohols, and water, as well as butyl carbitol and ethyl alcohol (Ansul, Incorporated 1994). It functions as a surfactant (i.e. detergent), allowing water to penetrate and expand over the surface of fuels to both cool and smother the fire (Pyne 1984). Silv-Ex, like other Class A foams, is applied operationally either from ground tankers or helicopters. Silv-Ex is supplied by the manufacturer as a liquid concentrate, which is mixed with water to the desired concentration before application.

Phos-Chek G75-F is a proprietary formulation composed of monoammonium phosphate and ammonium sulfate, fugitive coloring agent, and small amounts of gum-thickener, bactericide, and corrosion inhibitor (National Wildfire Coordinating Group, Fire Equipment Working Team 1991). Phos-Chek is typically applied from helicopter bucket or ground tanker in advance of a fire; other retardants with higher viscosity are applied from fixed-wing aircraft. The ammonium salts retard fire by chemically combining with cellulose as fuels are heated, as well as through evaporative cooling of the fuels (Lyons 1970, Pyne 1984). Phos-Chek is supplied by the manufacturer as a powder, which is mixed with water to the desired concentration before application.

Plot-based Treatments

Treatments were applied to plots in a stratified random design, divided equally between riparian and upland habitats and between North Fork and Cabin Creek drainages. Treatments included: (1) Phos-Chek; (2) Phos-Chek/burned; (3) 0.5% Silv-Ex; (4) 0.5% Silv-Ex/burned; (5) 1% Silv-Ex; (6) 1% Silv-Ex/burned; (7) water, equivalent in volume to chemical application; (8) water/burned. Because each chemical was mixed with water, water was used on the control plots so we could distinguish the effects of added moisture from the effects of the chemicals in this moisture-limited environment. We applied the treatments to 1-m^2 plots, which is an appropriate size for vegetation analysis in the habitats under investigation (Bonham 1989); because wildfire was of concern in this arid region, the small plots also afforded us better control of experimental burns. Cattle exclosures measuring 1 $m^2 \times 1$ m high were placed around each plot. Exclosures were made of 6-cm woven wire fencing and were anchored with steel rods. Each of the eight treatments was applied to each of four randomly located plots in the riparian zone and four randomly located plots in the upland zone on 28 June–1 July 1994. The procedure was repeated on different plots on 19–20 July to determine the effect of time of application within the growing season on vegetation response.

Chemicals were mixed with water as appropriate for operational use on sagebrush communities. Phos-Chek was applied at coverage level 3 (115 L/ha). Silv-Ex was mixed at two concentrations, 0.5% and 1.0%, and applied at the rate of 1410 L/ha. We used motorized 25.37-L backpack pumps to apply the chemicals. We did not quantify expansion of the foam. When treatment included burning, plots were ignited with a propane torch; all vegetation within the plot was burned, although not all was reduced to ash. Chemicals or water were applied to extinguish the fire, depending on treatment.

Prior to treatment, we marked five individual shoots (terminal segment of a branch) on each *Chrysothamnus viscidiflorus* within the upland vegetation sampling plots. We measured current year's growth (leaders) of these shoots, and counted the number of stems (ramets) and the number of post-burn resprouts of *Chrysothamnus* (total number of new ramets sprouting from each marked *Chrysothamnus* plant after treatment). We counted number of stems and number of species on each plot and calculated species diversity (H') and evenness (J') for each plot (Ludwig and Reynolds 1988). Total live stems on burned plots and total species on all plots were counted within 2 weeks before treatments were applied (pre-treatment), at 4, 6, 8 and 13 weeks after June applications, and at 2, 4, 6, and 11 weeks after July applications. Total live stems were counted on unburned plots before treatment and at the last two sampling periods after treatment. The last sampling period corresponded to the end of the growing season at our study sites.

Statistical Analysis for Plot-based Treatments

We used analysis of variance (ANOVA) techniques to assess the effects of the treatments on the change in number of stems, plant species richness, diversity (H'), and evenness (J'; where species richness > 1), from pre-treatment to post-treatment sampling periods. We conducted separate ANOVAs for each habitat type (riparian, upland) because species varied between them; separate analyses were also performed for the June and July applications because of phe-

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nological differences among plant species. The ANOVA model was of the form:

$$y_{ijkl} = \mu + \beta_i + \tau_j + \beta\tau_{ij} + \gamma_{k(ij)} + \delta_l + \beta\delta_{il} + \tau\delta_{jl} + \beta\tau\delta_{ijl} + \varepsilon_{ijkl},$$

with y_{ijkl} the response (change in number of stems, species richness, J′, or H′) at each plot within sampling period, treatment, and location; μ the overall mean; β_i a random location effect (North Fork, Cabin Creek); τ_j a fixed treatment effect; $\gamma_{k(ij)}$ a random plot effect; δ_l a fixed sampling period (repeated measures) effect; and ε_{ijkl} a random error effect. All other terms in the ANOVA model were fixed effect interactions, unless crossed with random terms which were then considered random effects (Littell et al. 1996). We used the mixed model procedure (PROC MIXED) of SAS (SAS 1997) to conduct the ANOVAs.

We used ANOVA techniques to assess the effects of the four burn treatments (water/burn, 0.5% Silv-Ex/burn, 1.0% Silv-Ex/burn, and Phos-Chek/burn) on total *Chrysothamnus viscidiflorus* plants per plot. Separate ANOVAs were done for June and July applications. For number of plants per plot, the ANOVA was a simple one-way in a randomized block design with location (North Fork, Cabin Creek) considered as random blocks. The ANOVA was a simple one-way with subsampling (Steel and Torrie 1980) for stems/plant and stem length; individual plants within plots were the subsamples, with a mean stem length estimated for each plant within each plot. Only plots that had *C. viscidiflorus* prior to treatments were used in the ANOVAs for number of stems per plant and stem length. Sample size for these variables ranged from 2 to 4. Because we had few plots in which we were able to assess treatment effects on stems per plant and stem length, we pooled plots across the two locations for these response variables.

We used canonical variate analysis (CVA) (Jongman et al. 1987, Gittins 1985), also called linear discriminant ordination (Green 1979, Pielou 1984), to compare the vegetative community among treatments and examine shifts in the community across sampling periods. We used CVA as an ordination procedure because it permits the differences among treatment groups and sampling periods to be displayed with maximum separation (Pielou 1984:235). We were able to use CVA as an ordination technique because the number of plots sampled exceeded substantially the number of species encountered (Jongman et al. 1987:149). We excluded from the CVA rare species (i.e., species occurring in fewer than 5% of the plots; Gauch 1982:214). Separate CVAs were done for each habitat zone (riparian and upland) and for each application time (June and July). We used Pearson correlation coefficients to correlate the canonical variates with each of the species abundances to interpret the canonical variates and describe the type of community they reflect. All species abundance values were $\ln(y+1)$ transformed prior to the CVA. We used the Canonical Discriminant procedure (PROC CANDISC) of SAS (SAS 1989) to conduct the CVA.

*Big Sagebrush (*Artemisia tridentata*) Response*

Non-burn treatments (i.e. 0.5% Silv-Ex, 1.0% Silv-Ex, Phos-Chek, and water) were applied to 40 randomly selected *Artemisia* plants (not located on vegetation plots), 10 per treatment. The volume of chemical applied to each plant was scaled according to the approximate volume of the plant, using 1.41 L/m^3. We applied the chemical using the same motorized backpack pumps we used for the vegetation plots.

We randomly selected and tagged four branches on each plant. Current annual growth (terminal leader and four subsequent leaders), and number of galls per branch were recorded prior to treatment and at the end of the growing season, 5–6 October. When flowers were present, we measured inflorescence length at the end of the season.

We used separate one-way ANOVAs to test for pre-treatment differences among the four groups in plant height, plant volume, and amount of solution to be applied. We used repeated measures ANOVA (Diggle et al. 1994) to assess differences among the four treatments and any change over time from pre-treatment to post-treatment with respect to mean leader length and mean number of galls adjusted for leader length. Mean leader length and mean number of galls used in the repeated measures ANOVAs were first averaged across the five leaders from each of four branches for each of the 40 plants. A one-way ANOVA was also used to test for differences among the four non-burned treatments with respect to inflorescence length at the end of the season. A mean inflorescence length was computed for each plant by averaging across individual flowers and across the four branches.

We used the general linear models procedure (PROC GLM) of SAS (SAS 1989) to conduct all ANOVAs except the mixed model described above. For all ANOVAs, we used Fisher's protected LSD test to isolate differences among least squares means for significant main effects or significant interaction effects, if any (Milliken and Johnson 1984). Significance was set at $P = 0.05$.

Results

Plot-based Treatments

Chrysothamnus viscidiflorus

We found no significant effects of Phos-Chek or Silv-Ex on number of *C. viscidiflorus* plants per plot for either June or July applications (Table 2). Growth and resprouting were also unaffected by any chemical application (Table 2).

Change in Number of Stems/m²

We found significant treatment by sample period interactions in the change in number of stems/m^2 between pre- and post-treatment for both June and July applications in the riparian zone ($F = 7.05$; df = 7, 6; $P = 0.01$ and $F = 4.39$; df = 7, 6; $P = 0.04$ for June and July, respectively; Figure 1). Plots treated with 1.0%

Table 2. Results of analysis of variance for characteristics of *Chrysothamnus viscidiflorus* plants after burning followed by treatment with water, Silv-Ex (0.5% or 1.0%), or Phos-Chek (see Methods).

Variable	Least squares mean (S.E.M.)	F	df	*P*
Total plants/m^2, June application				
Treatment effect	1.6(0.5)		3, 3	0.46
Location effect	—		1, 3	0.77
Total plants/m^2, July application				
Treatment effect	0.5 (0.1)	1.99	3, 3	0.29
Location effect	—	0.01	1, 3	0.99
Stems/plant, June application	3.5 (0.5)	0.55	3, 8	0.66
Stems/plant, July application	2.5 (0.5)	1.22	3, 4	0.41
Stem length (cm), June application	1.9 (0.4)	3.35	3, 8	0.08
Stem length (cm), July application	1.3 (0.3)	0.51	3, 4	0.70

Silv-Ex had significantly fewer stems than the control on burned and unburned plots through 13 weeks after June applications. All other treatments were indistinguishable from the control at 13 weeks post-treatment. Number of stems on upland plots did not differ significantly in response to any chemical treatment ($F = 1.23$; df = 7, 6; $P = 0.41$ and $F = 1.02$; df = 7, 6; $P = 0.50$ for June and July applications, respectively).

Change in Species Richness, Evenness, and Diversity

We found a significant treatment by sample period effect for species richness for both June and July applications in the riparian zone ($F = 7.27$; df = 21, 18; $P = 0.0001$ and $F = 2.56$, df = 21, 18; $P = 0.02$ for June and July applications, respectively; Figure 2). Overall, burned plots tended to gain species over the course of the study, while species richness on unburned plots remained relatively stable. Plots treated with Phos-Chek were an exception, however. Species richness declined more in plots treated with Phos-Chek, but not burned, than in plots subjected to any other non-burned treatment. Although species richness in Phos-Chek plots showed a significantly greater decline than either the Silv-Ex or control treatments at intermediate sampling periods, no differences were observed among any treatments by the 13th week after June applications. The same trend was evident in Phos-Chek plots after July applications (Figure 2b), but chemically treated plots did not differ significantly from control plots in any sampling period.

We found a significant treatment by sample period interaction in change in species richness on upland plots after June ($F = 2.29$; df = 21, 18; $P = 0.04$) but not July ($F = 1.29$; df = 21, 18; $P = 0.29$) treatments. Unburned plots showed little trend through the season, and chemically treated plots were never statistically different from control plots at any sampling period (Figure 2c). Burned plots showed a slight tendency to gain species over the course of the study, particularly on plots treated with 0.5% Silv-Ex.

Shannon's index of species diversity (H') and Pielou's index of evenness (J') did not differ among treatments in either upland or riparian habitats after either June or July applications (Table 3).

Community Characteristics

The canonical variate analysis suggested that the chemical treatments had relatively little effect on the community composition (Figures 3 and 4). In each of the four analyses, the first axis tended to separate pre-treatment from post-treatment samples, with pre-treatment conditions associated with higher values of axis one. This axis accounted for 48% of the variation in riparian plots after June application and 47% after July application, 85% in upland plots after June application, and 63% after July application. In riparian habitat, the first axis was most strongly correlated with *Poa pratensis* ($r = 0.86$ for June and $r = 0.89$ for July applications), *Carex praegracilis* ($r = 0.75$ for June and $r = 0.72$ for July), and *Juncus balticus* ($r = 0.75$ for both June and July). In upland habitat, the first axis was most strongly correlated with *Poa secunda* ($r = 0.84$ for June and $r = 0.70$ for July) and *Agropyron trachycaulum* ($r = 0.72$ for June and $r = 0.68$ for July).

The second axis, which accounted for 14% and 13% of the variation in riparian plots after June and July applications, respectively, separated post-treatment burned from post-treatment unburned plots, although the unburned 0.5% Silv-Ex plots were more similar to burned plots than to other unburned treatments after June applications (Figure 3a). For June applications, the second axis was most strongly correlated with *Taraxacum officinale* ($r = 0.56$) and *Thermopsis montana* ($r = 0.50$); for July applications, the second axis was correlated with *Agropyron trachycaulum* ($r = 0.62$). By the 11th week after July applications, riparian plots all had similar communities, as defined by the first two axes of the CVA, although unburned plots were all > 1 and burned plots

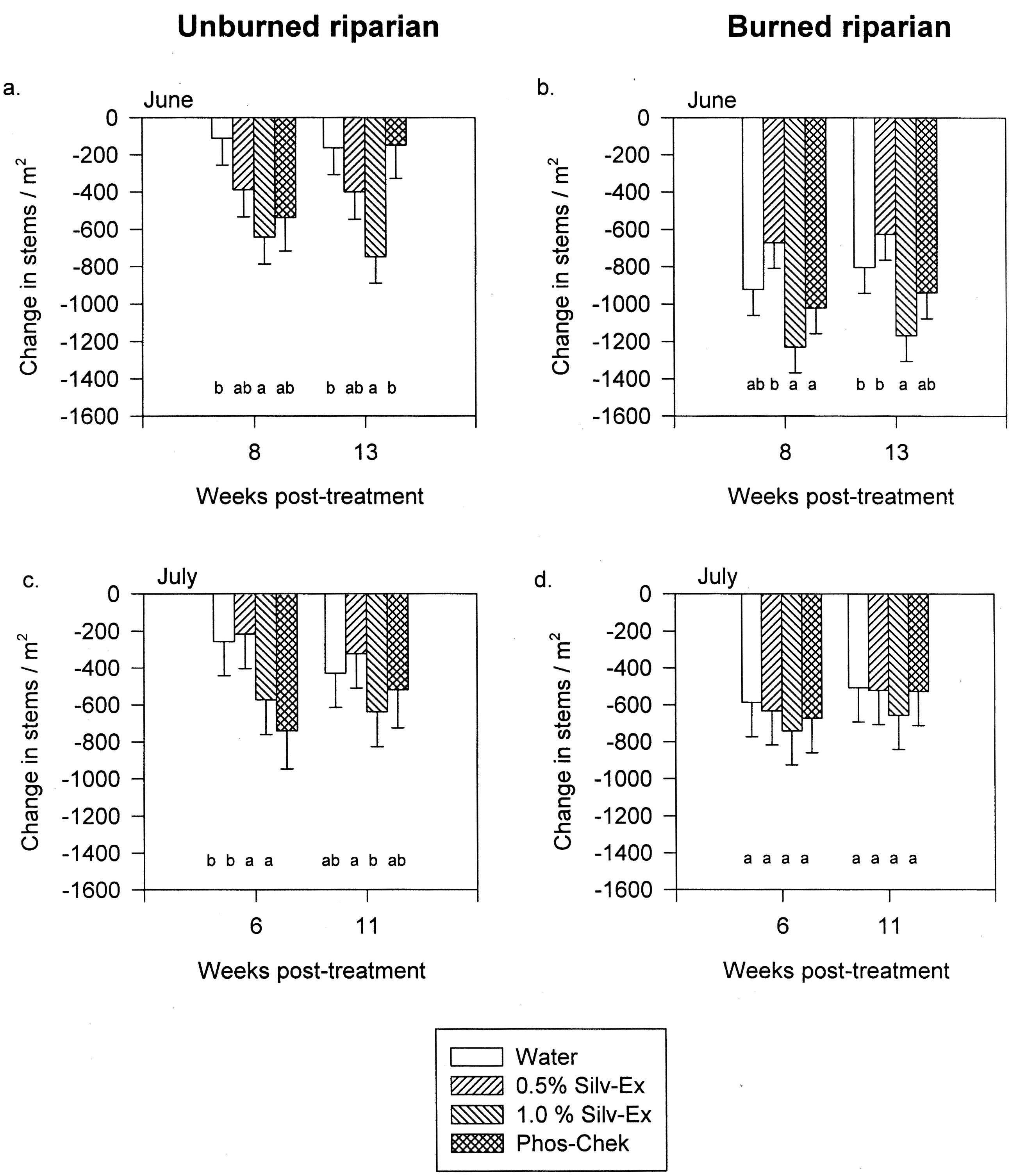

Figure 1. Change in stems/m^2 between pre-and post-treatment on unburned and burned riparian vegetation plots. Shown are least square means + one standard error of the mean for each chemical treatment. Means with the same letters do not differ significantly from other means at that sampling period using Fisher's LSD test.

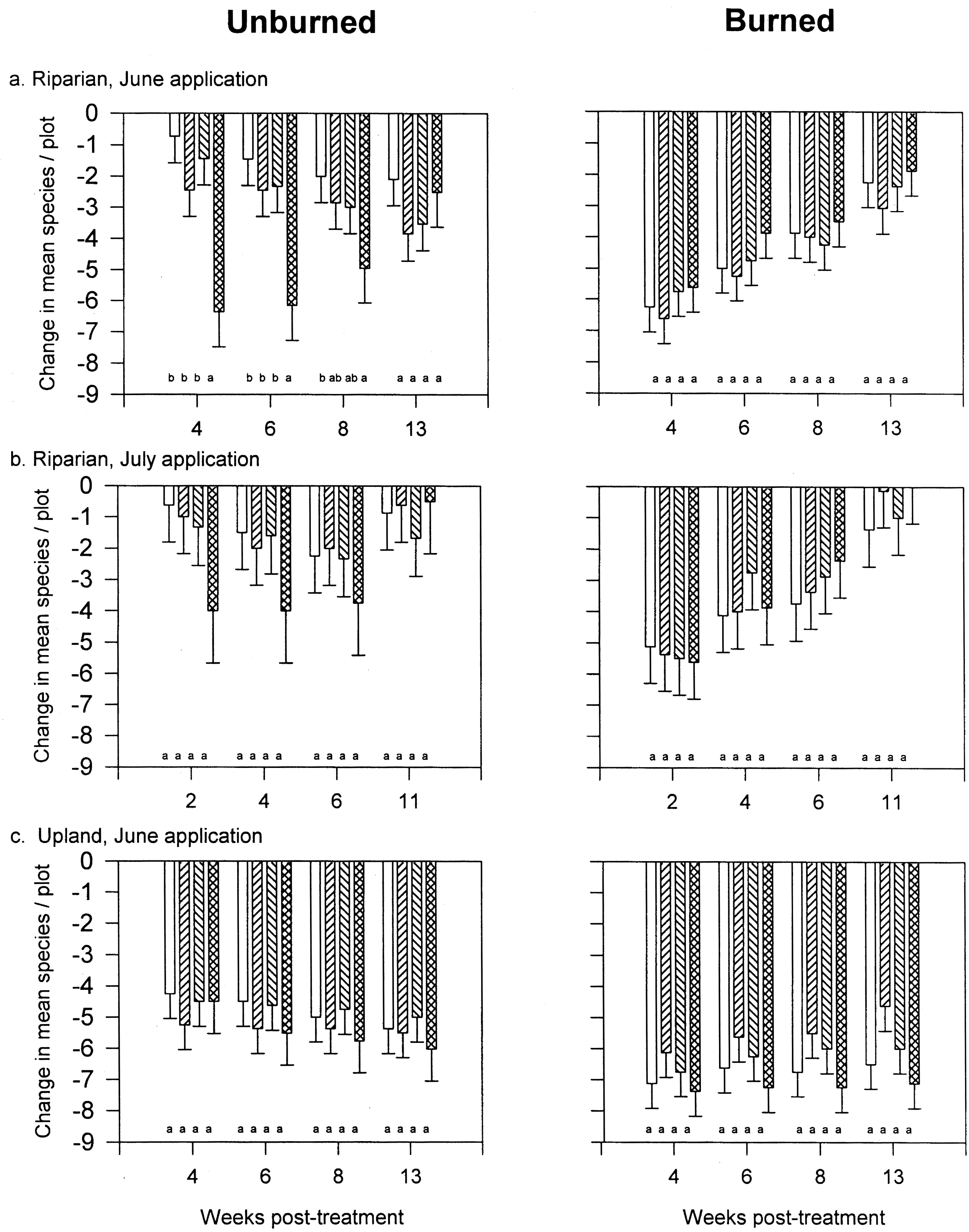

Figure 2. Change in species richness between pre- and post-treatment on unburned and burned vegetation plots. Shown are least square means + one standard error of the mean for each chemical treatment. Means with the same letters do not differ significantly from other means at that sampling period using Fisher's LSD test. See legend in Figure 1 for key to treatments.

Table 3. Results of analysis of variance for change in species diversity (H′) and evenness (J′) between pre- and post-treatment on riparian and upland plots (see Methods).

Variable	Least squares mean (S.E.M.)	*F*	df	*P*
H′, riparian habitat, June application	–0.16 (0.08)	1.32	7, 6	0.29
H′, riparian habitat, July application	–0.07 (0.11)	0.26	7, 6	0.95
H′, upland habitat, June application	–0.93 (0.07)	1.27	7, 6	0.39
H′, upland habitat, July application	–0.87 (0.08)	2.03	7, 6	0.20
J′, riparian habitat, June application	0.06 (0.03)	3.89	7, 6	0.06
J′, riparian habitat, July application	0.13 (0.06)	0.80	7, 6	0.61
J′, upland habitat, June application	0.17 (0.06)	0.65	6, 2[1]	0.71
J′, upland habitat, July application	0.04 (0.06)	0.56	7, 2	0.76

[1] There were no species richness values > 1 for Phos-Chek/burned treatment, so J′ could not be computed.

were all < 1 on CV1, implying somewhat greater recovery of the dominant grass and sedge species on unburned plots (Figure 3b). In contrast, burned and unburned plots were still mainly separated on both axes at 13 weeks after June applications (Figure 3a).

In upland habitat, the second axis accounted for 5% and 15% of the variation in plots after June and July applications, respectively. The second axis was most strongly correlated with *Achillea millefolium* ($r = –0.66$) and *Artemisia tridentata* ($r = 0.46$) for June applications, and with *Achillea millefolium* ($r = 0.53$) for July applications. As in the riparian zone, the second axis tended to separate burned from unburned treatments, although more completely for June applications (Figure 4a) than for July applications (Figure 4b); 11 weeks after July applications, 1.0% Silv-Ex plots were more similar to burned plots than to other unburned treatments.

Artemisia *Study*

The 40 *Artemisia tridentata* shrubs that we treated did not vary significantly in height ($F = 1.45$; df = 3, 36; $P = 0.24$), volume ($F = 0.04$; df = 3, 36; $P = 0.98$), or amount of chemical applied ($F = 0.44$; df = 3, 36; $P = 0.72$). We found no significant effect of any chemical treatment on growth, flower production, or galling insect activity (Table 4).

Discussion

Comparison of Chemical Effects

In most respects, the effects of Phos-Chek, and 0.5% or 1.0% Silv-Ex on vegetation in our Great Basin study sites did not vary substantially from each other or from the control. The lack of difference among treatments is best illustrated by the CVA, which tended to separate plots based on phenology and burning, rather than chemical treatment (Figures 3 and 4). With few exceptions, effects we observed did not persist to the end of this 1-year study. Effects that did persist were related to Silv-Ex applications. Unburned and burned riparian plots treated with 1.0% Silv-Ex in June still had a greater deficit in total live stems than any other treatment at the end of the study (Figure 1a and 1b). At the community level, after July applications on unburned upland plots, 1.0% Silv-Ex plots remained distinct from other unburned plots with respect to the second CVA axis (Figure 4b); 0.5% Silv-Ex plots remained distinct from other unburned riparian plots at the 13th week after June applications (Figure 3a).

Burning itself had a much greater influence on community-level changes than did any of the chemical treatments (Figures 3 and 4). Pre-treatment plots varied little with respect to CV1 in either habitat type; burning tended to result in declines in the dominant grasses and sedges represented by this axis, especially in riparian habitat and after July application in upland habitat. Not surprisingly, burned plots remained distinct from unburned plots in uplands with respect to CV2 after June applications (Figure 4a); in this analysis, CV2 was positively correlated with *Artemisia tridentata*, which is harmed by fire (Young and Evans 1978).

Comparison of Habitat Types

Riparian habitat was marginally more sensitive to chemical treatments than upland habitats. Of the 10 vegetative characteristics we measured, only species richness showed a significant treatment effect in upland habitat (Figure 2c), and this effect was a subtle change in trend between burned and unburned treatments. Change in stems/m^2 (Figure 1) and change in species richness (Figure 3) both showed significant treatment effects in riparian habitat. The reason for greater response on riparian plots may be related to moisture availability. Because moisture is limiting in the Great Basin (West 1988), the capacity for response is greater in the more mesic (i.e. riparian) compared to the more xeric (i.e. upland) sites.

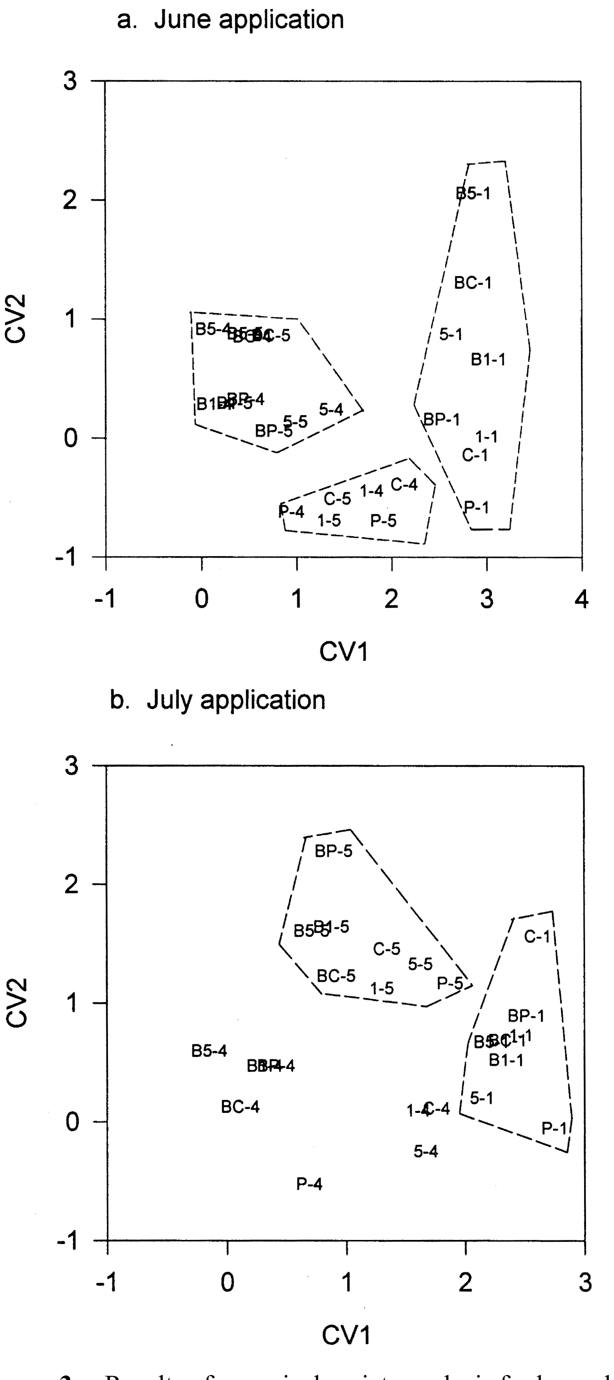

Figure 3. Results of canonical variate analysis for burned and unburned riparian vegetation treated with 0.5% Silv-Ex, 1.0% Silv-Ex, Phos-Chek, or water. Symbols on the graph refer to treatment (B = burned, 5 = 0.5% Silv-Ex, 1 = 1.0% Silv-Ex, P = Phos-Chek) and sample period (–1 = pre-treatment sample; –4 = fourth sample period, 8 weeks after June applications and 6 weeks after July applications; and –5 = fifth sample period, 13 weeks after June applications and 11 weeks after July applications). Dashed lines enclose (a) pre-treatment, post-treatment burned and post-treatment unburned plot means; and (b) pre-treatment and final post-treatment plot means.

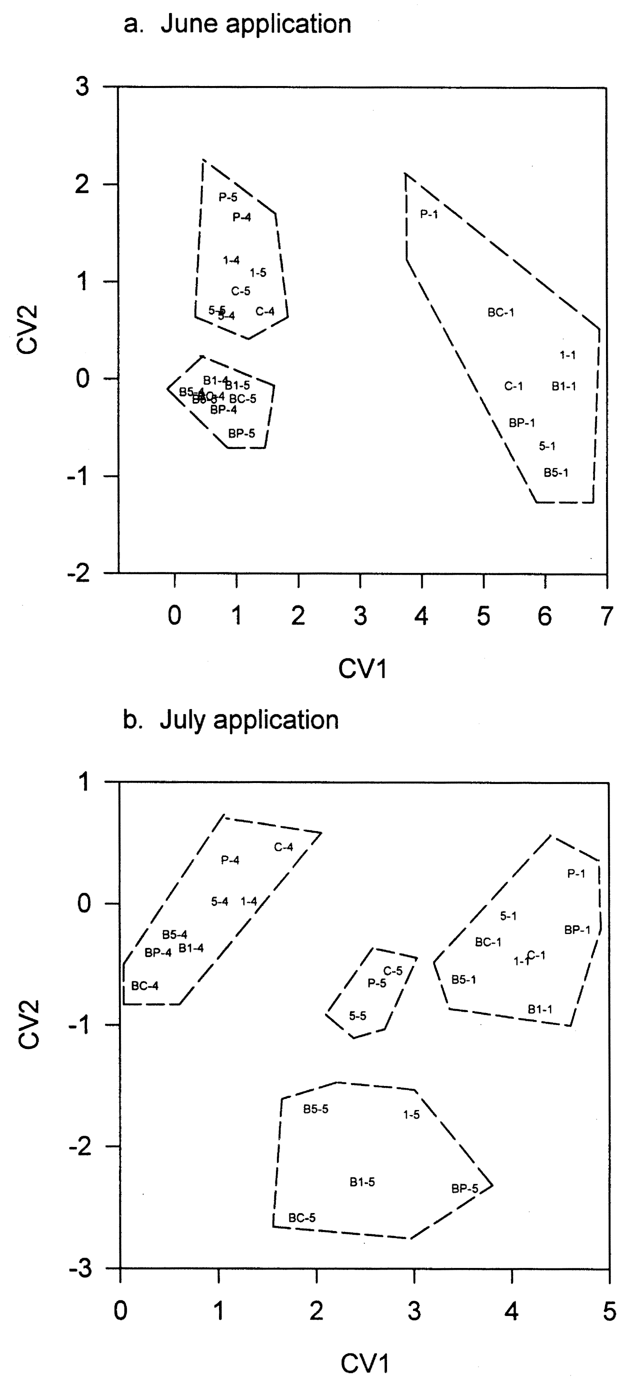

Figure 4. Results of canonical variate anlysis for burned and unburned upland vegetation treated with 0.5% Silv-Ex, 1.0% Silv-Ex, Phos-Chek, or water. Symbols are as in Figure 3. Dashed lines enclose (a) pre-treatment, post-treatment burned, and post-treatment unburned plot means; and (b) pre-treatment, fourth post-treatment, final post-treatment burned, and final post-treatment unburned plot means.

Table 4. Results of analysis of variance for characteristics of *Artemisia tridentata* after application of water, Silv-Ex (0.5% or 1.0%), or Phos-Chek (see Methods)

Variable	Least squares mean (S.E.M.)	*F*	df	*P*
Leader length (cm)	7.46 (0.35)	0.83	3, 36	0.48
Galls (*n*) / leader length (cm)	0.014 (0.003)	0.90	3, 36	0.45
Inflorescence length (cm)	7.93 (0.39)	0.59	3, 35	0.62

Time of Application

In general, chemical effects that appeared after June applications also appeared after July applications in riparian habitat, although statistical significance tended to be greater in June applications. The only effects that persisted at the end of the study were the result of June applications (Figures 1a and 2c). Because the final sampling for both June and July applications were completed within a 2 week period, it is unlikely that this difference can be accounted for by a later final sample for July applications. More likely, some cool-season species that had yet to senesce when June treatments were applied had done so by the July applications, making the July experiment inherently less powerful.

Lack of Response

The majority of vegetative characteristics we measured showed no response to chemical application over the course of the growing season in which the chemicals were applied. We detected no treatment effect on species diversity or evenness, or on any characteristic of the two woody plants we examined (Tables 2, 3 and 4). Flowering progressed normally in *Artemisia* (Table 5). Chemicals did not disrupt the well-known (Young and Evans 1974) post-fire sprouting of *Chrysothamnus* (Table 2). Activity of galling insects was not influenced by either chemical (Table 4), which suggests either that structural components and nutrients of leaves and stems were unaffected by Silv-Ex and Phos-Chek, or that they were affected in ways not detected by galling insects. The chemically treated communities were generally similar to the control communities (Figures 3 and 4).

Unlike a similar study in North Dakota in which *P. pratensis* increased its growth dramatically, apparently in response to fertilization by nitrogen in Phos-Chek (Larson and Newton 1995), no single species (including *P. pratensis*, which was common in riparian plots; Table 1) seemed to respond out of proportion to any other in this study (i.e. evenness was unaffected by chemical treatments). In addition, the only effects that persisted at the end of the study were the result of June applications (Figures 1a and 2c). We suspect these differences were related to lack of precipitation at the Nevada study sites. Precipitation was less than half the 30-year mean near our study sites in 1994 (2.03 cm for June–September 1994 compared with a yearly average of 4.90 cm for 1966-1995; NOAA National Climatic Data Center, U.S. Surface Data for Paradise Valley, NV). The lack of precipitation likely limited late-season growth of most species, and may have dampened fertilization effects. James and Jurinak (1979), working in Great Basin desert vegetation, found that response to experimental nitrogen fertilization was smaller when conditions were drier. Working in an annual grassland in California, Larson and Duncan (1982) also found that annual and seasonal weather patterns and soil moisture affected vegetation more than did treatment with air-dropped diammonium phosphate fire retardant.

The lack of significant differences among most chemical treatments applied after burning may reflect the short duration of the study rather than an actual lack of effect. Responses to burning in the sagebrush steppe are more appropriately measured over the course of several years (Young and Evans 1978), or even decades (Harniss and Murray 1973). Early-season annuals, in particular, could not be expected to grow on plots until the following season (West 1988). Many upland species, after early-spring growth that largely occurred before roads were passable to the study site, were dormant through most of the study. It should be kept in mind, however, that most natural fires also occur during this dormant season; if chemicals do not persist in the soils until the next growing season, there may, in fact, be little long-term effect of their use.

Management Implications

The few effects we detected on vegetation suggest that either Phos-Chek or Silv-Ex, applied as directed, can be used to control wildland fire in this area of the Great Basin without major disruption of terrestrial vegetation. One caveat, however, is the short duration of this study. We cannot say with certainty what changes may occur in species that were dormant until the next growing season. The fact that most immediate responses returned to control levels by the end of the study suggests that effects are likely transitory. Even fertilization experiments, in which far greater amounts of nitrogen are added than were added by Phos-Chek application in this study, document rapid return to pre-fertilization conditions in the absence of additional nitrogen (Kellner 1993, Wikeem et al. 1993). However, effects that were not apparent a year or two after treatment may be seen if plots are revisited decades hence (Milchunas and Lauenroth 1995, Vinton and Burke 1995).

Assuming that these chemicals are effective fire-fighting tools, consequences of chemical application are most appropriately compared with the effect of additional area burned in a more slowly controlled wildfire when chemicals are not used. Since the introduction of invasive exotic plants such as *Bromus tectorum* and *Taeniatherum caput-medusae*, fires in the Great Basin can have devastating and long-lasting ecological results as the native *Agropyron–Artemisia* association is replaced by a virtual monoculture of quick-burning annual grasses (West 1988; Billings 1993). Not only do these grasses drastically reduce species diversity (Knapp 1996), they can increase fire frequencies from the pre-invasion intervals of 60–110 years to post-invasion intervals of less than 5 years (Whisenant 1990). Effects we observed in the current study were minor by comparison. If *B. tectorum* or *T. caput-medusae* are present in the vicinity of a wildfire, far less ecological damage is likely to be done by application of retardants or foams than by allowing the fire to burn unchecked.

Managers intending to use these chemicals to control prescribed burns may wish to consider effects on species richness or on individual species of interest. Most significant treatment effects on species richness occurred in the riparian zone; care should be exercised in riparian areas (see also Gaikowski et al. 1996, McDonald et al. 1996), especially if they harbor particular species of concern.

Finally, this study did not adequately address the interaction between burning and chemical application. Studies of longer duration, in which plots can be followed for several seasons after treatment, are essential in assessing these interactions.

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Summary

We studied the effects of fire retardant chemical (Phos-Chek G75-F) and fire suppressant foam (Silv-Ex), alone and in combination with fire, on Great Basin shrub steppe vegetation. Plots treated with Phos-Chek initially had greater declines in species richness than other treatments, but these differences vanished by the end of this one-year study. A larger community response was observed to burning than to any chemical treatment. The few effects we detected on vegetation suggest that either Phos-Chek or Silv-Ex, applied as directed, can be used to control wildland fire in this area of the Great Basin without disrupting vegetative communities.