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Fire Effects on Prairies and Oak Woodlands on Fort Lewis, Washington

Abstract

Before 1800, frequent fires maintained Idaho fescue prairies and Garry oak woodlands on Fort Lewis. Fire exclusion in the 1900s, however, has allowed Scot's broom, Douglas-fir, and numerous herbaceous aliens to invade native prairies and oak woodlands. Since 1978, a management program using prescribed fires on 3-5 yr rotations has been used in an effort to maintain the open communities. We evaluated the role of fire on fescue prairies, oak woodlands, and broom thickets using prescribed fires in fall 1994 and spring 1995, and compared preburn/postburn species frequency to identify fire maintainers, increasers, and decreasers. Fall fires were more effective than spring fires, and best promoted native species and communities. Prescribed fires had no effect on Idaho fescue frequency, which maintained dominance in the postfire prairie. Other native prairie graminoids and forbs, and hairy cats-ear, a prominent alien, were maintained by fire. Prescribed fires also maintained open Garry oak woodlands, reduced Scot's broom cover in broom thickets, and killed small Douglas-firs. These fires, however, tended to favor alien species instead of native species. A large prairie subjected to >50 yr of broadcast burns ignited annually by artillery fire has been converted from fescue prairie to an open meadow dominated by hairy cats-ear and alien grasses, such as sweet vernal grass. Of the three regimes we investigated, fire intervals shorter or longer than the 3-5 yr fire rotation now employed on Fort Lewis are detrimental to fescue prairie and oak woodland. Excessive burning or fire exclusion causes loss of prairie and oak woodland.

Introduction

In regions where recurring fire is an important environmental factor, many plant species have fire-tolerant characteristics and persist despite repeated fires. Some plant communities are fire-dependent, persisting only where fires prevent more competitive, fire-sensitive species from displacing them. Fire-stable communities are maintained by frequent, low intensity, low severity ground fires that exclude invasive, fire-avoiding species (Anderson and Brown 1986, Agee 1993, Fonda et al. 1998). Fire-stable communities include prairies (Kucera and Ehrenreich 1962, Anderson 1964, Ewing and Engle 1988, Wilson and Shay 1990), oak woodlands (Plumb and McDonald 1981, White 1983, Guerin 1993), chaparral (Horton and Krabel 1955, Vogl and Shorr 1972, Conrad et al. 1986), ponderosa pine (*Pinus ponderosa*) forests (Weaver 1964, Covington et al. 1997), and longleaf pine (*P. palustris*) forests (Greene 1931, Rebertus et al. 1989).

Most native prairie species endure fire extremely well (Anderson 1964, Old 1969, Heady 1972, Antos et al. 1986, Ewing and Engle 1988, Wilson and Shay 1990). Fires maintain prairies by killing invading trees and shrubs (Thilenius 1964, Griffin 1977, Nimir and Payne 1978, Gruell et al. 1986). Both Nimir and Payne (1978) and Antos et al. (1986) quantified the effects of fires on Montana prairies with species composition similar to prairies on Fort Lewis, Washington, the location of this study. Prescribed fires set in spring by Nimir and Payne (1978) initially changed the cover of some prairie species, but those differences decreased throughout the first growing season. Antos et al. (1986) observed that a summer wildfire initially reduced Idaho fescue (*Festuca idahoensis*) cover and increased total forb cover, although the community returned to preburn cover values within three years. Neither of these studies provided data on species frequency, however, which would have clarified to what extent the species endured fire.

The effects of fire on communities dominated by oaks have been studied extensively (Boerner 1981, White 1983, Myers 1985, Guerin 1993, Glitzenstein et al. 1995), especially in California (Heady 1972, Green 1979, Plumb and McDonald 1981, Sugihara and Reed 1987, Allen-Diaz and Bartolome 1992). Some oaks are fire resisters (Rowe 1983), protected from fire damage by thick bark (Plumb 1979), but more commonly they are fire endurers (Rowe 1983), relying on postfire resprouting after top-kill (Boerner 1981, Plumb and McDonald 1981, White 1983, Myers 1985, Allen-Diaz and Bartolome 1992, Keeley 1992, Guerin 1993). Prescribed fires maintain open Garry

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oak (*Quercus garryana*) woodlands by reducing shrub cover, killing invading conifers, and top-killing oak sprouts (Plumb and McDonald 1981, White 1983). Sugihara and Reed (1987) set fall fires in California to maintain Garry oak woodlands. Fires killed Douglas-fir (*Pseudotsuga menziesii*), but mature Garry oaks were not damaged. Fires top-killed all oak stems <3 m tall, but all damaged stems resprouted vigorously.

Since the late 1800s, fire exclusion has reduced fire incidence in many fire-stable communities, so that fire-dependent plant communities have been invaded by fire-sensitive species (Cooper 1961, Weaver 1964, Myers 1985, Agee 1993). Fire exclusion also permits high fuel levels to develop, which ultimately may lead to high intensity, high severity fires that threaten normally fire tolerant communities (Gartner and Thompson 1972, Habeck and Mutch 1973, Griffin 1977, Gruell et al. 1982).

Prescribed fires, similar to those we used in this research, are designed to reduce fuels, remove invasive species, and maintain fire-dependent communities. Prescribed fires commonly are set in prairies (Heady 1972, 1977; Nimir and Payne 1978; Anderson and Brown 1986; Gruell et al. 1986), oak woodlands (Sugihara and Reed 1987), ponderosa pine forests (Weaver 1964, Ffolliott and Guertin 1988), longleaf pine forests (Guerin 1993), and giant sequoia (*Sequoiadendron giganteum*) forests (Kilgore 1972, Parsons and Nichols 1985).

Douglas-fir is a commonly targeted species of prescribed fire, because Douglas-fir benefits from fire exclusion on prairies and open woodlands throughout its range. Since the advent of fire exclusion, Douglas-fir has invaded prairies in Montana and Washington (Cooper 1961, del Moral and Deardorff 1976, Agee and Dunwiddie 1984, Gruell et al. 1986), and oak woodlands in Washington, Oregon, and California (Sprague and Hansen 1946, Lang 1961, Thilenius 1964, Franklin and Dyrness 1973, Kertis 1986, Sugihara and Reed 1987). The effectiveness of prescribed fire at removing invading Douglas-fir from prairies and oak woodlands has been studied in Montana (Gruell et al. 1986) and California (Sugihara and Reed 1987), but not in western Washington. Gruell et al. (1986) noted that spring and fall fires caused high mortality among small Douglas-firs. Fall fires burned more thoroughly, and they tended to kill larger trees. Sugihara and Reed (1987) concluded that fall burning every 5 yr, coupled with mechanical removal of occasional Douglas-fir survivors, maintained Garry oak woodlands.

The study site for this research was Fort Lewis, a 34,865 ha military installation ~20 km south of Tacoma, Washington. Idaho fescue prairies, Garry oak woodlands, and Douglas-fir forests are dominant community types on Fort Lewis (Figure 1). The prairies and oak woodlands of Fort Lewis exist on gravelly, glacial outwash plains deposited ~14,000 yr ago (Ugolini and Schlichte 1973). The soils are classified as Spanaway gravelly sandy loam, a nearly level to undulating, somewhat excessively drained soil (Zulauf 1979). The surface layer is black gravelly sandy loam, with a dark grayish brown very gravelly sandy loam subsoil (Zulauf 1979). This soil type, with only a few minor inclusions, forms the broad plain between Lakewood and Roy, on which Fort Lewis is located. Early explorers and settlers reported frequent, late-season fires on the prairies and oak woodlands in this region, suggesting that Native Americans set fires to enhance the growth of edible prairie plants and to aid in hunting (Lang 1961, Norton 1979, Boyd 1986).

Fort Lewis is one of several prairies on outwash plains in western Washington. The basic floristic composition of these prairies has been known for years (Jones 1936). The Mima Mound prairie, ~10 km south of Fort Lewis, was studied by del Moral and Deardorff (1976). The flora of this prairie is similar to the prairie on Fort Lewis, although it appears more modified than Fort Lewis prairies. Both prairies are dominated by native Idaho fescue and several native forbs. Camas (*Camassia quamash*) is an indicator species. Both prairies support prominent populations of aliens, especially hairy cats-ear (*Hypochaeris radicata*) and Kentucky bluegrass (*Poa pratensis*). Hairy cats-ear is noteworthy, since it already was conspicuous and abundant in western Washington prairies by the 1930s (Jones 1936).

On Fort Lewis, fire exclusion has allowed 6,560 ha of the original 16,800 ha fescue prairie to be converted to forest since 1870 (Figure 2). Before 1870, fescue prairies were large and interconnected. Currently, only a fraction of the original fescue prairie remains as small, isolated grasslands (Figures 1, 2). Large areas of oak woodland also have been lost to invading Douglas-firs, but past records did not distinguish oak woodlands from conifer forest.

Figure 1. The fescue grassland on Wier Prairie in May 1999. In the left background is a Garry oak woodland and encroaching Douglas-fir forest. In front of these wooded stands is a band of Scot's broom, encroaching on the fescue grassland.

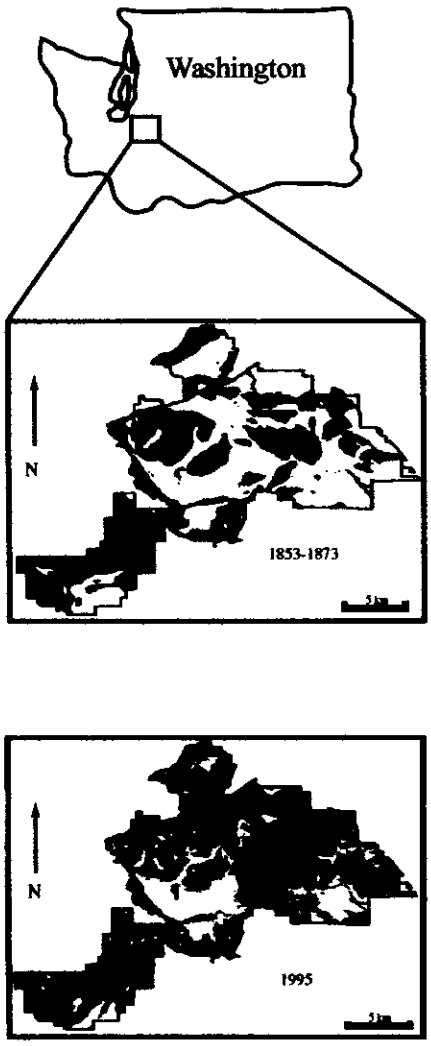

Figure 2. Land cover maps on Fort Lewis, from data provided by Teresa Hansen and Brandy Riche of Fort Lewis. Black depicts the extent of forested areas; white represents prairies. Top: based on 1853-1878 land records. Bottom: based on 1995 land surveys.

Scot's broom (*Cytisus scoparius*) has benefited from fire exclusion by invading many of the remaining prairies and oak woodlands on Fort Lewis (Figure 1). This alien shrub rapidly degrades prairies by forming dense, 1-3 m tall canopies that shade prairie species. Mature broom stands also support high intensity, high severity fires by generating large amounts of woody fuel. Scot's broom is a resprouter, thus all control methods must account for broom persistence after treatment. Broom sprouts are least successful if the treatment is applied during maximum growing season stress (Ussery and Krannitz 1998).

Three fire-management regimes exist on Fort Lewis. The first, and most widespread, is fire exclusion on ~28,000 ha. The second regime comprises a prescribed fire program applied predominantly in spring. Fort Lewis began lighting prescribed fires in the 1960s, and since 1978 has managed a comprehensive prescribed fire program on 3000 ha of prairies and oak woodlands with 3-5 yr rotations. Most prescribed fires are set in February/March, but fires occasionally are set in fall. Wier Prairie, in the southwest corner of Fort Lewis, is in this management regime. The fescue grassland on Wier Prairie is presumed to be the closest approximation to the original prairie community at Fort Lewis, although it contains alien species (Figure 1). Various oak woodlands associated with the prairies are considered to represent a former original component on Fort Lewis. The third fire regime is a 3000 ha artillery impact area on the Ninety-first Division Prairie, where frequent training fires within the prescriptions of the fire management plan are allowed to burn. Bombing is concentrated in a central 1000-1200 ha area, which we call Artillery Prairie. This site has been subjected to broadcast burns ignited by artillery fire nearly annually for 50 yr. Despite the heavy use of fire, no studies have been published on the effects of fire on Fort Lewis prairies and oak woodlands.

Fort Lewis is an excellent site to examine species and community responses to prescribed fire on prairies and oak woodlands. Fort Lewis has three widely divergent, documented fire regimes in a small area with uniform soils, it is the only site in western Washington with a long-standing program of consistent prescribed burning, and it contains many of the largest, highest quality fescue prairies and oak woodlands in western Washington. This study was designed to answer four research questions: 1) what is the current composition of prairies and oak woodlands on Fort Lewis? 2) will prescribed fires maintain the status of prairie and oak woodland species? 3) do species frequency, cover, and recruitment vary between spring and fall prescribed burns? 4) does prescribed fire reduce frequency and density of

invading Douglas-fir, Scot's broom, and other alien species?

Methods

Community Composition

We set prescribed fires in fescue grasslands and oak woodlands, currently managed under the 3-5 yr fire regime, and in broom thickets where prairie fires had partially succeeded in removing Scot's broom. We used the annual broadcast burn at Artillery Prairie as the fire treatment in the cats-ear meadow. Fire effects on herbaceous species were evaluated on alternate 1 x 1 m microplots arranged along transects that varied in length depending on community type. The buffer zones between the 1 m^2 microplots were used to separate the prescribed fire treatments. The distribution of burned microplots in each community is shown in Table 1.

TABLE 1. Distribution of burned plots for understory species in each community exposed to different burn treatments. These plots also contributed to the data on preexisting composition in Table 3.

Community	Fire regime	Burn date		
		Aug 94	Sep 94	Mar 95
Fescue grassland	3-5 yr	-	30	60
Oak woodland	3-5 yr			
Herbaceous		-	33	29
Woody		-	17	13
Cats-ear meadow	Annual	90	-	-
Broom thicket	3-5 yr			
Herbaceous		-	28	5
Woody		-	17	13

Fescue grassland composition was surveyed using 90 microplots on four 40-60 m transects, arranged as two pairs of parallel transects. The 90 cats-ear meadow microplots were placed along one randomly located 180 m transect, 200 m inside the artillery impact area, as dictated by safety restrictions. Microplots for sampling herbaceous species in oak woodlands and broom thickets were located on 3-15 m transects within 44 10 x 20 m macroplots (see below). These transects were short because stands were discontinuous. All oak woodland macroplots were located within 5 m of tree trunks to ensure they measured the maximum effect of tree cover on the understory. All macroplots in broom thickets were located within 5 m of open prairie to ensure that the site had been invaded recently by Scot's broom and that prairie species were still present in the stand.

Fire effects on woody species were determined using 10 x 20 m macroplots in oak woodlands and broom thickets. Garry oak and Scot's broom were surveyed together on the same 44 macroplots placed along a kilometer of prairie-oak woodland ecotone. Nomenclature for vascular species follows Hitchcock and Cronquist (1973). Voucher specimens are housed by the Land Condition Trend Analysis Program on Fort Lewis.

Data on preexisting composition were gathered May-August 1994 on all microplots shown in Table 1, and postfire data were gathered on the same microplots May-July 1995. No 1995 data were gathered in the cats-ear meadow. The site has been subjected to annual broadcast burns for many years, and we presumed that composition has been unchanged for years. We estimated weighted cover, because fire often reduces the thickness of the foliage without changing the canopy spread of the plants. Cover (C′, as canopy coverage) was estimated to the nearest 1%. Foliage density (D) was estimated to the nearest 5%, expressed as a decimal. Weighted cover (C) was calculated as $C = C' * D$. Cover, height, and diameter at breast height were recorded for all oaks and Douglas-firs. After the final inventory, species were classified as fire increasers, fire maintainers, or fire decreasers, based on changes in frequency. Fire increasers gained at least 10 percentage points in frequency from preburn frequency, fire maintainers were within ±10 percentage points of preburn frequency, and fire decreasers lost at least 10 percentage points in frequency from preburn frequency. We chose 10 percentage points so that species with frequencies up to 90% had latitude to increase on the site, and species with frequencies as low as 10% had latitude to decrease. In either case, maintainers were not automatically favored by this choice.

Fire Treatments

We burned 1 m^2 microplots in the grasslands on Wier and Artillery prairies, and 10 x 20 macroplots in the oak woodlands and broom thickets, in September 1994 and March 1995. The 1 m^2 microplots were assigned randomly to the fire treatments (Table 1). Microplots not scheduled to be burned were soaked with water. Scratch

lines were placed around some of the oak and broom macroplots because of high fuel loads. All prescribed fires were set with 10-20°C ambient temperatures and 20-50% relative humidity. Wind speeds were <5 km/h during all fires, except over the fescue grassland in March 1995 when gusts reached 10 km/h, causing fires to escape and burn 60 microplots, rather than the intended 30. Cats-ear meadow microplots were randomly placed in a single broadcast fire set by bombing in August 1994. Fire weather for spring fires was well within the normal weather patterns for prescribed fires. Fall fires, however, were delayed later than planned because summer 1994 was hot and dry for longer than normal. Prescription weather and conditions were met a few days after light rain in early September.

All prairie microplots burned completely. Fires were patchy in the oak woodlands and broom thickets. Most of the unburned area was under a thick broom canopy, where grass cover was low and fuel moisture was high. Flame heights were <1 m in prairie and oak plots, <2 m in broom plots.

Temperatures of Prescribed Fires

Peak fire temperatures were measured using OMEGALAQ temperature-indicating paints that melt at 142°, 246°, 343°, 427°, 538°, and 649°C (Table 2). The range of paints was striped on 3 x 10 cm aluminum plates, then the plates were placed on the ground in each community just before fires were set. The range of temperatures is consistent with low intensity fires. In general, 60-80% of the plates reached 246° to 343° (Table 2). No plate reached 538° or 649°.

Fuel Sampling

Samples of the fuel loads were collected in May 1995 from randomly selected unburned and burned microplots created for the baseline composition survey. Fuel samples were collected from 12 microplots for each treatment in each community. Because of the escaped fire in the fescue grassland in March 1995, however, unburned prairie fuels were collected from 12 microplots randomly placed in an adjacent unburned area. Fuels were separated into live fine fuels (i.e., all live grasses and forbs), dead fine fuels, and dead wood. In the broom thickets, however, it was not feasible to separate dead fine fuels and dead wood because broom produced abundant brittle twigs. All fuel samples were oven-dried at 105°C for 48 hr in a forced-air oven, then weighed. Fuel loads are expressed in kg/ha.

Experimental Design and Statistical Analysis

The data for preburn/postburn treatment comparisons were gathered in a randomized complete block ANOVA design; individual microplots defined the blocks. The data for fall/spring and unburned/burned treatment comparisons were gathered in a completely randomized design ANOVA. For all statistical analyses, the significance level was set at $P = 0.05$ before the research began. Data reported in the tables as percentages were transformed by arcsine before analysis.

TABLE 2. Percent of heat sampling paints burned at different fire temperatures by community type and fire season. Fire temperatures were measured using OMEGALAQ fire sensitive paints on metal plates placed on the ground in each community before the fires were set. No fires reached 538° C

Community	Season	Plates	Temperature (°C)				
			142°	246°	343°	427°	538°
Fescue grassland	Spring	30	43	54	3	-	-
	Fall	30	3	77	20	-	-
Oak woodland							
Tree base	Spring	43	33	39	26	2	-
	Fall	23	16	68	16	-	-
Understory	Spring	34	23	44	30	3	-
	Fall	23	22	65	13	-	-
Cats-ear meadow	Summer	27	71	29	-	-	-
Broom thicket	Spring	15	33	60	7	-	-
	Fall	30	13	44	33	10	-

Results

Preexisting Composition

The fescue grassland on Wier Prairie was dominated by native prairie species, with the exception of hairy cats-ear, English plantain (*Plantago lanceolata*), and colonial bentgrass (*Agrostis tenuis*). Frequencies for the dominant species were high on the prairie, and total cover was >80% (Table 3). Under the current 3-5 yr fire rotation, the bunchgrass Idaho fescue dominated. Hairy cats-ear was the most important prairie forb, but with considerably less cover. Both species were continuously distributed throughout the sample area. Cryptogams, mainly the mosses *Rhacomitrium canescens* and *Polytrichum juniperinum*, were continuously distributed in the prairie, accounting for ~23% cover. Oregon sunshine (*Eriophyllum lanatum*), prairie lupine (*Lupinus lepidus*), field wood-rush (*Luzula campestris*), long-stoloned sedge (*Carex pensylvanica*), and English plantain were nearly continuously distributed with frequencies greater than 80%, but all had low cover values (Table 3). Hounds-tongue hawkweed (*Hieracium cynoglossoides*) and western witchgrass (*Panicum occidentale*) grew contagiously.

Understory cover was <30% in the oak woodlands, and most was accounted for by alien species (Table 3). Under the current 3-5 yr fire rotation, rhizomatous graminoids dominated the understory (Table 3). The four most prominent species, Kentucky bluegrass, long-stoloned sedge, colonial bentgrass, and red fescue (*Festuca rubra*), are rhizomatous. These four species plus suckling clover (*Trifolium dubium*) and English plantain had greater cover in the oak woodlands than in the fescue grasslands (Table 3). Idaho fescue, hairy cats-ear, and Oregon sunshine, the dominant fescue grassland species, were greatly reduced under oaks (Table 3). Except for long-stoloned sedge, frequencies of the species named above differed noticeably between fescue grasslands and oak woodlands. Many other prairie species, such as hounds-tongue hawkweed, prairie lupine, pine

TABLE 3. Percent frequency (F) and mean percent cover (C) of preexisting composition of fescue grassland, oak woodland, cats-ear meadow, and broom thicket species with at least 1% cover in one of the communities. N|A = Native or Alien species.

		Fescue grassland		Oak woodland		Cats-ear meadow		Broom thicket	
Species	N|A	F	C	F	C	F	C	F	C
Festuca idahoensis	N	100	39.9	8	+	8	+	-	-
Hypochaeris radicata	A	100	7.8	51	+	100	19.1	-	-
Luzula campestris	N	98	+	-	-	98	1.3	-	-
Eriophyllum lanatum	N	94	1.7	-	-	-	-	-	-
Lupinus lepidus	N	92	1.4	-	-	-	-	-	-
Plantago lanceolata	A	90	+	44	1.0	-	-	43	+
Carex pensylvanica	N	89	+	92	5.2	20	+	43	1.7
Agrostis tenuis	A	81	+	53	3.7	58	2.1	71	3.0
Panicum occidentale	N	71	1.0	-	-	6	+	-	-
Hieracium cynoglossoides	N	66	2.0	-	-	21	+	-	-
Festuca rubra	N	41	+	24	2.0	98	2.6	-	-
Panicum scribnerrianum	N	12	+	-	-	58	2.0	-	-
Lupinus albicaulis	N	12	1.1	-	-	-	-	-	-
Poa pratensis	A	-	-	98	10.0	-	-	57	2.0
Trifolium dubium	A	-	-	49	1.3	-	-	-	-
Anthoxanthum aristatum	A	-	-	-	-	100	9.8	-	-
Galium parisiense	A	-	-	-	-	-	-	66	2.8
Cytisus scoparius	A	-	-	-	-	-	-	100	61.6
Cryptogams		100	22.6	15	+	100	9.4	43	1.9
Total number of species		52		61		34		37	
Total vascular cover		61.1		25.1		39.0		12.2	
Total cryptogam cover		22.6		0.4		9.4		1.9	

+: <1% cover

lupine (*Lupinus albicaulis*), and western witchgrass, were absent. Few woody species grew in the oak woodlands, and cryptogams were a minimal component of the understory (Table 3).

The annual training-caused fires on the cats-ear meadow have resulted in <50% total plant cover. Most of the cats-ear meadow cover consisted of alien species, but many native species were present as subordinate members of the community. Hairy cats-ear and sweet vernal grass (*Anthoxanthum aristatum*) dominated, and both were continuously distributed in the community (Table 3). Sweet vernal grass is an alien annual, absent in the fescue grasslands and uncommon anywhere on Fort Lewis except Artillery Prairie. Several native, but subordinate graminoids, including red fescue, Scribner witchgrass (*Panicum scribnerianum*), and field wood-rush were favored by annual burning, as indicated by high frequencies. They were contagiously to continuously distributed in the prairie. Frequency of most prairie species was significantly lower in the cats-ear meadow than the fescue grassland, and many species were absent. Idaho fescue was merely a minor component in the cats-ear meadow.

Scot's broom invasion decimates native prairie cover, because canopy cover is so high. Scot's broom was the only continuously distributed species in these thickets (Table 3). All native prairie species were significantly reduced or absent in the broom thickets. Except for long-stoloned sedge, all other understory species were alien grasses and forbs (Table 3). Colonial bentgrass, Kentucky bluegrass, and long-stoloned sedge were the dominant graminoids; wall bedstraw (*Galium parisiense*), an alien annual, was the dominant forb. All had inordinately low cover. Many bare areas existed in the thickets, because of the dense broom canopy.

Prescribed Fire in Fescue Grassland

Six species prominent in the fescue grassland (Table 3) were fire maintainers (Table 4). Idaho fescue, hairy cats-ear, and Oregon sunshine, the three most important species, and the cryptogams maintained high frequency in both fall and spring burns. Cryptogam cover increased significantly in both burns, whereas cover for Idaho fescue and hairy cats-ear decreased significantly (Table 4). Although both burn treatments significantly reduced the cover of the dominant fescue, no plants were killed. Conversely, hairy cats-ear individuals were killed. The high frequency and cover values (Table 4) are accounted for by dense postfire seed germination and growth. Field wood-rush and prairie lupine were classified as decreasers in response to the spring fire only. After both treatments, cover for field wood-rush increased as a result of a flush of post-fire growth. Nearly all prairie lupine plants were killed by the fires, so that the postfire values shown in Table 4 were contributed by recent germinants. Subordinate species in the fescue grassland, but unlisted in Tables 3 or 4, were not affected by fire. They maintained their prefire status, regardless of fire season. Camas, despite low mean cover, is in this category.

TABLE 4. Percent frequency and mean percent cover of fescue grassland species with at least 1% cover in one of the treatments, in response to fall and spring prescribed burns. Species cover values with unlike superscripts between pre- and postburn, by fall or spring burn, are significantly different. Similarly, cover values lacking superscripts are not significantly different. N|A = Native or Alien species.

		Frequency				Cover			
		Fall burn		Spring burn		Fall burn		Spring burn	
Species	N|A	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Maintainers									
Cryptogams		100	100	100	100	25.1[a]	37.5[b]	21.5[a]	26.4[b]
Festuca idahoensis	N	100	100	100	100	40.8[a]	11.7[b]	39.4[a]	9.1[b]
Hypochaeris radicata	A	100	100	100	100	7.9[a]	4.5[b]	7.7[a]	5.7[b]
Eriophyllum lanatum	N	93	97	93	95	1.8	1.4	1.7	1.2
Panicum occidentalis	N	73	63	70	65	0.9	0.6	1.0	0.8
Hieracium cynoglossoides	N	70	70	63	58	2.4	3.1	1.8	2.0
Decreasers in spring burn									
Luzula campestris	N	100	100	98	80	0.6[a]	1.1[b]	0.4[a]	0.7[b]
Lupinus lepidus	N	87	97	95	78	1.3[a]	0.4[b]	1.5[a]	0.3[b]

TABLE 5. Percent frequency and mean percent cover of oak woodland species with at least 1% cover in one of the treatments, in response to fall and spring prescribed burns. Species cover values with unlike superscripts between pre- and postburn treatments, by fall or spring burn, are significantly different. Similarly, cover values lacking superscripts are not significantly different. N|A = Native or Alien species.

		Frequency				Cover			
		Fall burn		Spring burn		Fall burn		Spring burn	
Species	N|A	Pre	Post	Pre	Post	Pre	Post	Pre	Post
					Maintainers				
Poa pratensis	A	91	100	100	90	9.7[a]	6.0[b]	8.2	6.3
Trifolium dubium	A	48	58	59	55	1.9	1.7	1.2	0.6
Hypochaeris radicata	A	48	48	69	72	0.8	1.0	0.8	1.0
Plantago lanceolata	A	39	42	62	66	0.5	1.0	0.8	1.0
Festuca rubra	N	24	27	38	35	0.9	0.9	1.4	1.7
Vicia sativa	A	21	30	41	38	0.1	1.1	0.4	0.4
					Increaser in fall burn				
Carex pensylvanica	N	88	100	100	90	6.4	9.1	4.6	4.7
					Decreaser in spring burn				
Agrostis tenuis	A	61	58	76	59	3.1	1.9	9.0	7.1

Prescribed Fire in Oak Woodlands

Five of the six maintainers in oak woodlands were aliens (Table 5). Two understory species in the oak woodlands responded appreciably to fire, but only in terms of changes in frequency. Colonial bentgrass was a decreaser in the spring burn treatment, whereas long-stoloned sedge was an increaser in the fall burn treatment (Table 5). Kentucky bluegrass, in the fall burn treatment, was the only species with a significant change (decrease) in cover for either treatment.

Prescribed Fire in Broom Thickets

The fall fire burned significantly more of the stand, caused significantly greater mortality, and resulted in significantly less resprouting of broom plants than the spring fire (Table 6). The fall fire resulted in significantly less density and cover of mature broom plants, had no significant effect on seedling density (Table 6), and significantly reduced postfire cover of small broom plants (Table 7). The patchy spring fire significantly reduced postfire seedling density, but had no other significant effects (Table 6). We classified Scot's broom in the understory as a decreaser, although postfire frequency was merely four percentage points less than prefire frequency (Table 7). When all data from Tables 6 and 7 are viewed together, Scot's broom prominence on the site decreased because of fire.

TABLE 6. Effects of Sep 94 and Mar 95 burns on Scot's broom. Postfire data were gathered in May 95 for both burns. Values with unlike superscripts (a-b) are significantly different between fall and spring burns. Values with unlike subscripts (c-d) are significantly different between pre- and postburns, by fall or spring burns. Similarly, values lacking superscripts are not significantly different.

	Fall burn		Spring burn	
Category	Pre	Post	Pre	Post
Area burned (%)		90[a]		78[b]
Stem density per m^2	52.9[c]	11.4[d]	58.2	51.0
Cover (%)	24.8[c]	3.5[d]	13.8	12.0
Seedling density (per m^2)	8.2	5.9	6.3[c]	3.0[d]
Mortality (%)		87.0[a]		47.2[b]
Basal sprouting (%)		1.8[a]		30.8[b]

Cryptogams also were decreasers, losing 30 percentage points of prefire frequency. Except for the maintainer Kentucky bluegrass, all other understory species in the broom thickets were increasers with fall fire (Table 7). Five of the six increaser species were aliens, and all occupied areas that had been bare under the complete broom canopy before the fire. Other species in the broom thickets, unlisted in Table 7, maintained their status with the fall burn treatment.

Fire Effects on Trees

Fire dramatically affected oak stems <1 m tall or <2 cm dbh. The fall fires top-killed more oaks

TABLE 7. Percent frequency and mean percent cover of broom thicket species with at least 1% cover, in response to a Sep 94 prescribed burn. Species cover values with unlike superscripts between pre- and postburn are significantly different. Similarly, cover values lacking superscripts are not significantly different. N|A = Native or Alien species.

Species	N|A	Frequency Pre	Frequency Post	Cover Pre	Cover Post
			Maintainer		
Poa pratensis	A	44	41	2.0	1.4
			Increasers		
Teesdalia nudicaulis	A	19	93	<0.1[a]	1.5[b]
Agrostis tenuis	A	81	100	1.8	5.2
Galium parisiense	A	57	93	1.2	1.5
Carex pensylvanica	N	44	56	2.7	3.0
Hypericum perforatum	A	81	93	1.1	1.9
Plantago lanceolata	A	44	64	0.6	0.4
			Decreasers		
Cryptogams		56	26	2.0	0.5
Cytisus scoparius	A	100	96	62.8[a]	1.9[b]

TABLE 8. Height and diameter classes of Garry oaks top-killed by fall and spring prescribed fires.

	Fall		Spring	
	Prefire density	Number top-killed	Prefire density	Number top-killed
Stem height (m)				
< 1	82.5	77.4	54.8	44.5
1-2	5.7	2.4	6.7	1.6
2-3	3.9	0.7	4.1	0.2
3-4	1.2	0.1	8.0	0
> 4	8.4	0	8.0	0
Stem diameter (cm)				
< 2	85.9	76.1	60.8	35.7
2-5	3.4	0.1	4.4	0.2
5-10	4.3	0.1	3.8	0
> 10	5.6	0	5.4	0

than the spring fires in these height/diameter classes (Table 8). Oak mortality from fire was trivial. Of the prefire densities shown in Table 8, only three <1 m tall sprout clumps, with 5-10 stems each, and two of the 5-10 cm dbh trees were killed by fire. Otherwise, all top-killed stems resprouted. Taller and larger diameter trees were unaffected by fire.

Spring fire significantly reduced Douglas-fir from 13.9 to 4.5 stems/ha for saplings <1 m tall, and from 21.3 to 10.6 stems/ha for saplings <2 cm diameter. No Douglas-firs >3 m tall or >5 cm diameter were killed by fire.

Fire Effects on Fuels

Compared to the unburned condition, both fall and spring fires significantly reduced total fuel loading (Table 9). Fuel loadings were lowest in fescue grasslands and highest in oak woodlands. There was no significant difference in fuels after fall and spring fires in fescue grasslands. Fall and spring fires significantly reduced total fuels in the oak woodlands, mainly by reducing dead fine fuels. Fall fires in the broom thickets significantly reduced total fuels, but spring fires failed to carry through broom thickets.

TABLE 9. Fire effects on total fuel loading (kg/ha) in fescue grassland, oak woodland, and broom thicket. Both fall and spring burns significantly reduced the total fuel loading in each community, compared to the unburned condition.

	Unburned	Fall	Spring
Fescue grassland	1702	0	0
Oak woodland	3694	2345	1929
Broom thicket	2804	1847	-

Discussion

All fires in this study favored prairies and oak woodlands by killing invading Scot's broom and Douglas-fir (Tables 4-7). Prairie species are fire endurers, so that prescribed fires did not damage the fescue grassland, regardless of fire season (Tables 3, 4). The present species composition in the fescue grassland has been maintained using prescribed fires for 20 yr. Prescribed fires temporarily reduced Idaho fescue cover, had no significant effect on frequency, and did not remove Idaho fescue as the dominant prairie species. Prescribed fires caused no significant changes to most native or alien subordinates, nor to community composition. Furthermore, prescribed fires maintained open Garry oak stands by top-killing Garry oak saplings and seedlings, reducing Scot's broom cover, and killing young Douglas-firs.

Fire regimes shorter or longer than the 3-5 yr fire rotation on Fort Lewis have been shown to be deleterious to prairies and oak woodlands (Table 3). Excessive burning harms most native prairie

species. Fifty years of annual broadcast burning changed 1000-1200 ha of Artillery Prairie from a community dominated by perennial bunchgrasses to one dominated by alien forbs and annual grasses (Table 3). Compared to the fescue grassland, native plant cover was significantly lower, and community composition was dramatically altered. The displacement of Idaho fescue as the dominant species and the presence of many alien species indicated that the native prairie community is not adapted to prolonged annual burning. Annual burning, however, has maintained graminoid and forb dominance by eliminating Scot's broom and restricting invasion/establishment by Douglas-fir.

Compared to excessive burning, however, fire exclusion affects a much greater area on Fort Lewis. Fire exclusion has allowed Scot's broom and Douglas-fir to invade prairies and oak woodlands (Figure 1). Closed stands of Scot's broom and Douglas-fir eliminate nearly all native prairie species; closed canopies within Douglas-fir forests eliminate both prairie and oak woodland species.

Most prescribed fire programs strive to promote grassland and savannah structures by limiting the stem density of woody species. In general, prairie fires initially reduce graminoid cover (Nimir and Payne 1978, Antos et al. 1986) or biomass (Ewing and Engle 1988), promote rapid herbaceous postfire growth (Antos et al. 1986), and have positive effects (or no effect) on frequency of the native prairie species (Anderson and Bailey 1980, White 1983, Wilson and Shay 1990). The prairies on Fort Lewis responded exactly in this manner to prescribed fires.

Prescribed fires on Fort Lewis resulted in topkill and triggered resprouting for small Garry oak individuals, but caused no damage to mature trees. These responses to fire are common in many oaks. Some of the well-known oak species that endure fire by resprouting are blue oak (*Quercus douglasii*), scrub oak (*Q. dumosa*), and interior live oak (*Q. wislizenii*) in California (Allen-Diaz and Bartolome 1992, Keeley 1992); Gambel oak (*Q. gambelii*) in Arizona (Harrington 1985); myrtle oak (*Q. myrtifolia*), sand live oak (*Q. geminata*), turkey oak (*Q. laevis*), bluejack oak (*Q. incana*), and sand post oak (*Q. margaretta*) in Florida (Guerin 1993, Glitzenstein et al. 1995); jack oak (*Q. ellipsoidalis*) and bur oak (*Q. macrocarpa*) in Minnesota (White 1983); and white oak (*Q. alba*), black oak (*Q. velutina*), and chestnut oak (*Q. prinus*) in New Jersey (Boerner 1981).

Some fire effects on Fort Lewis differed from results observed elsewhere. Fires were followed by higher forb cover in California prairies and oak woodlands (Heady 1972, Sugihara and Reed 1987), Montana prairies (Antos et al. 1986), and Minnesota oak savannas (White 1983), but not in corresponding communities on Fort Lewis. Likewise, cryptogam cover was lower after fire in Montana prairies (Antos et al. 1986), compared to higher cryptogam cover after fires in fescue grassland.

Our research indicates that fire is essential in maintaining prairie and oak woodland communities in western Washington. Early explorers and settlers noted a high incidence of fire on prairies (Lang 1961, Norton 1979, Boyd 1986), and prairie covered more area in the mid-1800s than currently (Figure 2). Excluding fires since the early 1900s has allowed Douglas-fir to invade prairies and oak woodlands, suggesting that fire once helped maintain the more open communities (Figures 1, 2). The situation at Fort Lewis is identical to the Mima Mound prairie, where Douglas-fir invasion has changed prairie species adapted to xeric, low fertility soils to forest species adapted to mesic, more fertile soils (del Moral and Deardorff 1976). At least one of the contributors to better nutrient inventory is Scot's broom, a known nitrogen-fixer (Ussery and Krannitz 1998).

On Fort Lewis, only frequently burned areas have continued to support large prairies and open oak woodlands (Tables 3-5). The current prescribed burning program, however, must be expanded to reverse prairie loss to Scot's broom and Douglas-fir. This study has shown that fall fires killed more Scot's broom and Douglas-fir than spring fires, but fall fires had nearly the same beneficial effects (e.g., reducing fuels, maintaining species) as spring fires on prairies and oak woodlands. A program based on fall fires could help remove Scot's broom and Douglas-fir from heavily invaded sites. The exact timing of fire in broom thickets determines how successfully the program will work. Although Scot's broom resprouts, stems of all diameters resprout less successfully after mid-summer cutting (Ussery and Krannitz 1998). On the other hand, broom seeds mature in mid-summer (Ussery and Krannitz 1998), so that postfire germination in response

to a late-summer or early-fall fire could repopulate the site with broom seedlings. Using a model of fire in California mixed-conifer forest, van Wagtendonk (1983) showed that more than one prescribed fire cycle is likely to be required to restore the balanced fire regime. We anticipate that multiple fires will be necessary on Fort Lewis. Already, second fires are needed to kill dense broom reproduction before seed crops can be produced in the second postfire growing season. A strategy of aggressive mechanical or chemical removal of Scot's broom, Douglas-fir, and other prominent invaders should supplement prescribed burning to help restore prairies and oak woodlands to the open, historical condition. Given the number of alien species on the prairies (Tables 3-6), many of which have been around for decades (Jones 1936), supplemental seeding and planting of native species may be needed. Once the balanced condition of native prairie species has been achieved, both fall and spring prescribed fires should effectively maintain these communities.

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