Fire Effects on Wetland Prairie Plant Species

FINAL REPORT

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SUMMARY

Wetland prairies of the Willamette Valley, considered among the rarest of Oregon's ecosystems, are threatened by invasion of woody species and non-native species. Because of its historical importance, fire is a top choice of managers for preventing the encroachment of woody species. However, the effects of prescribed burning on present day wetland communities, with their mix of native and non-native species, are not clear. The present study investigated some of the mechanisms--survival, growth, and reproduction--that determine the response of plants to fire for seven dominant wetland species. The approach was to compare survival, aboveground vegetative biomass, reproductive biomass, and flowering intensity between burned and unburned plots one growing season after the burn treatment, using before-burning measurements as a covariate in the analysis. The experiment was conducted in the Willamette Floodplain Research Natural Area of the William L. Finley National Wildlife Refuge, Oregon.

The responses of seven study species show four patterns of response to burning:

- *Poor survivors:* Species with reduced survival, aboveground vegetative biomass, and reproduction (*Rosa* spp., *Veronica scutellata*).
- *Decreasers:* Species with no change in survival but reduced aboveground vegetative biomass and reproduction (*Deschampsia cespitosa, Carex unilateralis*).
- *Unaffected:* Species with little changes in survival, aboveground vegetative biomass, and reproduction (*Hordeum brachyantherum, Holcus lanatus*).
- *Increasers:* Species with increases in survival, aboveground vegetative biomass, and reproduction (*Beckmannia syzigachne*).

Management strategies for conservation of Willamette Valley native wetlands require the reduced abundance of woody species, the reduction or prevention of increase in non-native pest plant abundance, and the increase or at least the maintenance of native species' abundance.

The results of this study indicate that prescribed burning can achieve the first objective of decreasing the abundance of woody species (*Rosa* spp.). Long-term rose control would require repeated burning. Fire neither reduced nor promoted the abundance of the non-native herbaceous species measured (*Holcus lanatus*). **The results were mixed for the native species.** The abundance of two native species was maintained (*Hordeum brachyantherum*) or promoted (*Beckmannia syzigachne*). The abundance of the other three native species measured was reduced (*Veronica scutellata, Deschampsia cespitosa, Carex unilateralis*).

These results are for first year responses to a single fire. Responses of plants may change with timing of burning (e.g., fall vs. summer burn), with frequency of fires, and may not be evident the first year after burning. More definite management recommendations can be made after long term effects become clear from continuing research programs

INTRODUCTION

Native prairies, remarkable for their biodiversity, once dominated the landscape of the Willamette Valley. Before the mid- 1800's the Kalapuya, indigenous people of the Willamette Valley, maintained these prairies by setting annual fires, facilitating hunting and gathering of food plants (Boyd 1986, Boag 1992). These fires reduced the abundance of shrubs and trees, favored the abundance of grasses such as tufted hairgrass, *Deschampsia cespitosa,* and promoted a rich variety of native forbs. Today, however, native prairies are considered among the rarest of Oregon's ecosystems and are in critical need of conservation (ONHP 1983). Factors that contributed to the destruction of these unique wetland prairies include urban and agricultural development, threats that are also prominent today (Hammond and Wilson 1993). Succession to shrublands and forests threaten most of the few remnants of undeveloped prairie. With suppression of large-scale fires in the early 1800's, trees and shrubs increased in abundance, changing the environment to the detriment of the prairie grasses and forbs (Habeck 1961, Johannessen et al. 1971, Towle 1982). In addition, weedy exotic species introduced with settlement have spread rapidly often dominating and suppressing native vegetation.

This encroachment of woody species and invasion of non-native pest plants are of great concern to agencies and managers responsible for conserving these remnant prairies. Prescribed fire is a top choice for management because of its ability to slow or prevent the invasion of woody plants during natural succession (Wilson and Clark 1995, 1997a, Clark and Wilson 1996, Pendergrass 1996). 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. One hundred years ago, reinstitution of periodic fire may have been sufficient to maintain these grasslands as native-dominated systems. Today, however, widespread invasion of exotic species has significantly altered the remaining prairies. Moreover, strict smoke management regulations generally require mangers to burn in early fall, which may not coincide with historical timing of burning.

Only a handful of studies have investigated the effect of fire on Willamette Valley wetland prairie species and these studies have often presented conflicting or inconsistent results (Connelly and Kauffman 1991, Clark and Wilson 1996, Pendergrass 1996, Streatfeild and Frenkel 1997). The present study takes a different approach: rather than examining net effects of fire on abundance (often measured as cover), we investigate some of the mechanism--survival, growth, and reproduction--that determine the response of wetland plants to fire. By including *how* fire affects the plants, managers will be better able to design improved conservation strategies.

OBJECTIVE

The objective of this study was to determine the effects of prescribed fire the first growing season after burning on the survival, growth, and reproduction of seven dominant wetland prairie species. Our approach was to compare survival, aboveground vegetative biomass, and flowering intensity between burned and unburned plots, using before-burning measurements as a covariate in the analysis.

METHODS

Study area

The research site was the Willamette Floodplain Research Natural Area of the W. L. Finley National Wildlife Refuge (lat. 123º 18', long. 44º 25'), located 16 km south of Corvallis, Oregon. The study area is a portion of "space two" (Streatfeild and Frenkel 1997), which was last burned in 1979, from an accidental fire (Figure 1).

Although topography is generally level with elevation ranging from 82 m to 88 m, the site is characterized by lenticular-shaped features (approximately 150 m × 170 m) that are about 50 cm higher than the surrounding topographic matrix, leading to the terminology "mound" and "intermound" (Streatfeild and Frenkel 1997). Mounds and intermounds differ floristically and in moisture status (Streatfeild and Frenkel 1997). The study area is periodically flooded by direct rainfall from November to April, with mounds typically exposed above ponded areas (Streatfeild and Frenkel 1997). The present study was conducted in intermound vegetation.

At the time the Research Natural Area was established in 1966, refuge staff believed that the prairie was unplowed and represented a nearly native grassland ecosystem (Streatfeild and Frenkel 1997). Aerial photographs from 1936, however, show plowlike soil surface disturbance on several mounds and some shallow ditches (Streatfeild and Frenkel 1997). Intermounds do not appear to have been plowed, but probably received heavy cattle grazing and trampling (Streatfeild and Frenkel 1997).

Study species

The seven wetland species selected for this study are *Rosa* spp., *Veronica scutellata* L., *Deschampsia cespitosa* (L.) Beauv., *Carex unilateralis* Mack, *Holcus lanatus* L., *Hordeum brachyantherum* Nevski, and *Beckmannia syzigachne* (Steudel) Fern. These species represent dominant native and non-native perennials found in Willamette Valley wetland prairies (Table 1). Four of the seven study species, *Rosa eglanteria, Deschampsia cespitosa, Holcus lanatus,* and *Veronica scutellata,* are also the most abundant plants in the intermound of the Finley Research Natural Area (Streatfeild and Frenkel 1997).

Experimental design

Our experiment followed a randomized complete block design. Each of the eight blocks (approximately 20 m × 20 m) had two treatments randomly assigned: 1) prescribed burning and 2) no burning. Using metal tag stakes, we permanently marked within each treatment area six individual clumps each of *Deschampsia cespitosa* and *Carex unilateralis.* We also permanently staked within each treatment area at least six quadrats (1 m × 0.5 m) that contained each of the following species: *Beckmannia syzigachne, Holcus lanatus, Rosa* spp., *Veronica scutellata*, and *Hordeum brachyantherum.* No quadrats were located under dense rose cover, defined as when the vegetation underneath such cover could not be seen.

The measurement area within the 0.5 m^2 quadrat for *Beckmannia syzigachne, Holcus lanatus*, and *Hordeum brachyantherum* was the entire area unless the density of these species was very high. In this case, we subsampled a smaller area of the quadrat. *Rosa* spp. and *Veronica scutellata* were always measured within a smaller quadrat (0.25 m × 0.25 m) nested within the 0.5 m^2 quadrat.

Burn treatment

A few days prior to the prescribed burn, U.S. Fish and Wildlife personnel made fire breaks around the burn treatment areas by mowing buffers (approximately 4 m wide), using hand-held gasoline powered mowers. Mowed litter was then removed from the buffers. We placed pyrometers (Bentley and Fenner 1958) in each of the eight burn treatment areas to measure soil temperatures during the fire. The range of maximum surface temperatures measured at the soil surface was 73°C to 260°C. Methodological details and results are included as Appendix A.

Fire crews from the U.S. Fish and Wildlife Service, assisted crews from several other government agencies, burned the treatment areas on September 26, 1996. Initial inspection after the fire showed generally complete burns. Data showing burning times for each block and weather conditions during the fire are listed in Appendix B.

Data collection

Pre-manipulation data collection

We made pre-manipulation measurements of plant size and flowering in late July and early August 1996 after flowering was complete, but before many plant tissues began to senesce. Table 2 lists the size and flowering measurements collected for each species. These data are summarized by quadrat in Appendix C.

In addition to the listed size measurements, clumps of *Beckmannia syzigachne, Holcus lanatus*, and *Hordeum brachyantherum* located within the quadrats were marked with color-coded nails in order to measure survival one year after treatment.

Post-manipulation data collection

We collected post-manipulation data in July 1997 at the same phenological time as the 1996 pre-manipulation data were collected. The aboveground biomass of each species was harvested from the same measurement area as used to collect 1996 pre-manipulation data. Biomass was separated into vegetative and reproductive components. For the graminoid species, reproductive biomass included the flowering culm beginning at the base of the inflorescence and included all attaching structures. The remaining aboveground biomass was measured as aboveground vegetative biomass. For *Rosa* spp. and *Veronica scutellata* reproductive biomass included the peduncle and all attached structures. The remaining aboveground biomass was measured as aboveground vegetative biomass.

Dead and live vegetative biomass were separated after harvesting for *Deschampsia cespitosa*. Limited reproductive biomass was collected for *Hordeum brachyantherum* because most fruits had dispersed at the time of data collection. After harvesting, all biomass samples were dried in an oven for 48-96 hours and then weighed.

In addition to collection of reproductive biomass, post-manipulation flowering data were also collected before harvesting biomass as an additional measure or reproductive response to burn (Table 2). Seedling numbers were counted for *Holcus lanatus* and *Hordeum brachyantherum*, but not counted for to her species due to the difficulty in distinguishing a seedling from a vegetative sprout. Survival data were also collected for each species.

Survival of *Carex unilateralis* and *Deschampsia cespitosa* was determined using the existing staked clumps. Survival of *Rosa* sp. and *Veronica scutellata* was determined as presence or absence within the measurement quadrat.

All post-manipulation data are summarized by quadrat in Appendix C.

Data analysis

Treatment effects were tested with analysis of covariance using type III sum of squares. *Statgraphics* ver 3.0 was used for the statistical analysis. Untransformed data best met the various assumptions of the analysis of covariance. The analysis included subsampling, which allows testing for block × treatment interactions (Underwood 1997). In every case where treatment had a significant effect on a response variable ($P \leq 0.05$), the block × treatment interaction was non-significant. Block × treatment mean-squares were used in the denominator of F-ratios for testing treatment effects (Steele and Torrie 1960, Newman et al. 1997, Underwood 1977).

The covariates used in the ANCOVA were vegetative and reproductive size measurements of unburned plants that had a high correlation with plant biomass (Table 3). A series of size measurements was made on approximately 20 unburned plants found at the study site for each of the seven study species (Fischer, Wilson, and Clark, unpublished data). After the measurements were made, the plants were harvested, the biomass separated into vegetative and reproductive parts, and then weighed after drying in an oven for 48-96 hours. Multiple regression was used to determine which size measurements had the best correlation with plant biomass.

RESULTS AND DISCUSSION

Species responses

Rosa spp.

Survival of *Rosa* spp., as measured by presence or absence in the measurement plots, decreased in the burn treatment compared to the unburned treatment (Table 4). Aboveground vegetative biomass, reproductive biomass, and number of flowers or fruits significantly decreased in burn treatment compared to the unburned treatment (Table 4).

Survival of fire depends on protection of regenerative buds. Aerial buds of *Rosa* spp. are exposed with little protection from fire and thus can be readily killed during a fire. The reduction in aboveground vegetative biomass and reproduction of *Rosa* spp. the first year after burning is likely a consequence of this increased mortality of aboveground buds. Although *Rosa* spp. have aerial buds that are easily killed by fire, they also have buried root crowns, which are protected from fire and from which roses can survive and readily resprout (Noste and Bushey 1987).

Past studies of rose responses to fire in Willamette Valley prairies have measured vegetative cover, with inconsistent results. Some studies show significant reductions of woody cover (Clark and Wilson 1996, Wilson and Clark 1997a), while others show reductions in shrub height without reductions in cover (Pendergrass 1996, R. E. Frenkel, personal communication). The smaller size of rose shrubs probably indicates smaller aboveground biomass. Thus, in terms of the more sensitive and ecologically meaningful characteristic of biomass, fire seems to have a consistent effect of immediately reducing rose abundance.

Since post-fire regrowth from buried root crowns is common in rose, long-term reduction of rose abundance requires mortality. In another study of survival of roses and other shrubs through prescribed fire in a Willamette Valley wetland, fire reduced survival 45% compared to unburned controls (Clark and Wilson 1996), somewhat higher than the 19% reduction in rose survival found in the present study. Ignoring changes in physiological health or growth form, 19% mortality per fire event would lead to a 95% overall reduction in rose survival after 14 prescribed fires. These results suggest long-term control of rose is possible with a management program of repeated prescribed burning.

Veronica scutellata

Prescribed fire was uniformly detrimental to the native forb *Veronica scutellata*, with statistically significant decreases in survival, aboveground vegetative biomass, reproductive biomass, and number of inflorescences compared to unburned treatment (Table 4).

Veronica scutellata spreads vegetatively with runners that are located on the soil surface just underneath the litter layer (D. L. Clark, personal observation). Though they are not exposed aerially as with *Rosa* spp., these regenerative buds are still relatively unprotected and susceptible to high temperatures from fire. The observed reduction in aboveground vegetative biomass and reproduction of *Veronica scutellata* is likely a consequence of this increased mortality.

Other studies also report negative response of *Veronica scutellata* to fire. For example, in another study at the Finley RNA, *Veronica scutellata* cover was lower in more recently burned areas (Streatfeild and Frenkel 1997). Following prescribed burning of the Danebo wetland in west Eugene, *Veronica scutellata* cover was less than that of controls, although the variability was high (Clark and Wilson 1996). In contrast to these results, *Veronica scutellata* was one of eight perennials that established or significantly increased in frequency in burned areas of west Eugene wetland prairies (Pendergrass 1996).

Deschampsia cespitosa and Carex unilateralis

Deschampsia cespitosa and *Carex unilateralis* both had nearly 100% survival after fire (Table 4). Even though survival was not affected by burning, aboveground vegetative and reproductive biomass decreased after fire compared to the unburned treatment (Table 4). Inflorescence numbers for both species also greatly decreased in the burn plots, but there were block × treatment interactions (Table 4), which make treatment effects more difficult to interpret (Underwood 1997).

Graminoids characteristically have meristems at the bases of their leaves providing greater protection from fire compared to many dicots with aerial meristems (Whelan 1995). Moreover, densely packed stems and leaves characteristic of many clump and tussock graminoids can insulate the meristems buried inside the clump (Whelan 1995). Densely clumped grasses with abundant senesced leaves can also be severely harmed because the dense culms can continue to burn after a fire passes (Wright and Bailey 1982). Although rarely did entire clumps of either *Carex unilateralis* or *Deschampsia cespitosa* die following the burn, a substantial number of individual tillers of the clumps may have died, thus reducing aboveground vegetative biomass and reducing resources for reproduction. Additionally, because plants had not completely senesced at the time of burning (D. L. Clark, personal observation), loss of minerals and photosynthate to fire might be more severe.

Similar results were reported in another study at Finley RNA where both *Deschampsia cespitosa* and *Carex unilateralis* cover was less in the more recently burned areas (Streatfeild and Frenkel 1997). Following prescribed burning of the Danebo wetland in west Eugene, the number of flowering stems for both *Carex unilateralis* and *Deschampsia cespitosa* was less than that of controls with a contrasting increase in cover of *Deschampsia cespitosa*, although the variability was high (Clark and Wilson 1996).

In other west Eugene wetlands, *Deschampsia cespitosa* frequency increased immediately after burning, but cover declined significantly, suggesting a shift from fewer large plants to a greater number of smaller plants (Pendergrass 1996). Cover, however, returned to preburn abundance the following year (Pendergrass 1996). A similar patter was observed in Horkelia Prairie (west Eugene) where *Deschampsia cespitosa* cover decreased almost 50% after the first year after burning and then increased to slightly more than in the controls two years after the burn (Wilson et al. 1995).

Hordeum brachyantherum and Holcus lanatus

Survival for both *Hordeum brachyantherum* and *Holcus lanatus* in the burn plots was similar between the burned and unburned treatments, with a small non-significant increase for *Holcus lanatus* in the burn plots compared to the unburned plots (Table 4). Burning also had little effect on aboveground vegetative biomass, reproductive biomass, and inflorescence number and size, with only slight increases (Table 4).

Both *Hordeum brachyantherum* and *Holcus lanatus* are rhizomatous grass species, characterized by underground vegetative buds that are well protected by the soil from high temperatures, in contrast to the more elevated meristems of the bunch grasses and sedges (Ewing and Engle 1988, Wright and Bailey 1982). Thus, with increased protection of vegetative buds, mortality rates remained the same between the burn and unburned treatments and likely contributed to no decreases in aboveground vegetative biomass and reproduction for *Hordeum brachyantherum* and *Holcus lanatus.*

Other wetland fire studies, however, show negative responses of *Hordeum brachyantherum* and *Holcus lanatus* to fire. *Hordeum brachyantherum* cover in the Finely RNA was lower in areas most recently burned (Streatfeild and Frenkel 1997). The number of flowering stems from *Holcus lanatus* following fire at the Danebo Wetland in west Eugene was less than that of controls, although variability was high (Clark and Wilson 1996). *Holcus lanatus* decreased initially after burning in west Eugene wetland prairies but increased in the following years, even with additional fires (Pendergrass 1996). The cover of *Holcus lanatus* in an upland prairie also decreased after burning, though the large reductions were not statistically different (Wilson and Clark 1997a).

The results of these studies, including the present study, are in contrast to the expected response of increased growth of the rhizomatous grasses after fire. The expectation was that with protected vegetative buds little mortality would occur after burning, and growth would increase due to increased resource availability with decreased rose biomass. However, trends in vegetative changes in response to fire may not be evident immediately following burning (Wilson and Clark 1997a, b).

Beckmannia syzigachne

Beckmannia syzigachne was the only study species to show increased responses to the burn treatment as compared to the unburn treatment (Table 4). Survival significantly increased as did aboveground vegetative biomass and reproduction as measured by inflorescence length and number of inflorescences. *Beckmannia syzigachne's* increase in survival, growth, and reproduction might be caused by increased resource availability because of the reduction in abundance of competitors. On the other hand *Hordeum brachyantherum* and *Holcus lanatus,* with similar growth forms and perennating buds as *Beckmannia syzigachne,* showed no similar increases.

Increased aboveground vegetative biomass in the burn plots may be due instead to the significant (P = 0.003) increase in establishment of *Beckmannia Syzigachne* seedlings in the burn plots (3.89 seedlings/m^2) compared to the unburn plots (-1.33 seedlings/m^2). In contrast, the seedling establishment of *Holcus lanatus* was lower in the burn plots (23.1 seedlings/m^2 in unburned plots, 7.7 seedlings/ m^2 in burn plots). Seedling establishment rates in west Eugene wetland showed only two seedlings out of 9,600 sowed seeds (K.J. Davis, personal communication).

Patterns of species response to fire

The responses of seven wetland species measured in this study show four patterns (Table 5):

- *Poor survivors* with reduced survival, aboveground vegetative biomass, and reproduction,
- *Decreasers* with no change in survival but reduced aboveground vegetative biomass and reproduction,
- *Unaffected* with little changes in survival, aboveground vegetative biomass, and reproduction,
- *Increasers* with increases in survival, aboveground vegetative biomass, and reproduction.

Low survival and decreases in aboveground vegetative biomass and reproduction after fire appeared to be a function of how well protected the regenerative buds were. The species with lowest survival (*Rosa* spp. and *Veronica scutellata*) had the least protected regenerative buds from fire. Species with no decreases in survival, aboveground vegetative biomass and reproduction (*Holcus lanatus, Hordeum brachyantherum*, and *Beckmannia syzigachne*) had buds well protected from the soil from fire. Both *Deschampsia cespitosa* and *Carex unilateralis* with moderately protected buds decreased in aboveground vegetative biomass and reproduction with little change in survival.

Fire can cause the direct reduction of biomass and survival through the combustion of plant tissues, as seen in *Rosa* spp. and *Veronica scutellata*. Indirect promotion of growth is possible through lower resource demand and higher resource availability. Reduction in cover the first year after burning, especially the taller shrubs, can increase light to the lower, largely herbaceous community. There is little information on whether reduced cover also translates into lower demand for soil nutrients. Fire can increase phosphorus availability to plants (Seastedt and Ramundo 1990). In contrast, volatilization during burning generally reduces nitrogen availability in the first year after burning (Ojima et al. 1994, Turner et al. 1997). There was no evidence of increased aboveground biomass after fire for any of the four species with aboveground penetrating buds (*Rosa* spp., *Veronica scutellata*, *Carex unilateralis*, *Deschampsia cespitosa*), probably because tissue loss outweighed any increased growth rate from reduced competition or enhancing growing conditions. Moreover, growth responses in perennial prairie plants can take several years to become measurable (Wilson and Clark 1997a,b).

Fire can indirectly promote reproduction through increased soil temperatures, leading to earlier growth, and through increased light and nutrients from reduced competition (Rundel 1981, Hulbert 1988). For six of our study species, there was no significant increase in reproductive biomass or size or number of inflorescences, suggesting that these mechanisms are unimportant for these Willamette Valley wetland prairie species.

Management Implications

Management strategies for conservation of Willamette Valley native prairies require the reduction in abundance of woody species, the reduction or prevention of increase in abundance of non-native pest species, and the increase or at least maintenance of native species' abundance (Table 6). The results from this study indicate that prescribed burning can achieve the first objective of decreasing the abundance of woody species (*Rosa* spp.). Unless burns are repeated, however, roses are likely to recover due to their ability to resprout. Fire did not reduce the abundance of *Holcus lanatus*, the only non-native herbaceous species measured, but neither did fire promote its abundance. Fire maintained or promoted the abundance of two of the five native species measured (*Hordeum brachyantherum, Beckmannia syzigachne*). The other three native species decreased the first growing season after burning in this study, but other investigations (Wilson et al. 1995, Pendergrass 1996) suggest that one of these species, *Deschampsia cespitosa*, may recover if fires are not repeated annually. More data are necessary to determine if this recovery will occur for the other native species that decreased abundance the first year after fire (*Carex unilateralis, Veronica scutellata*).

It is important to remember that these management implications are based on first year responses to a singe fire, one with specific characteristics. Responses of plants may change with timing of burning (for example, fall vs. summer burn) and with frequency of fires, and may not be evident the first year after burning. More definite management recommendations can be made after long-term effects become clear from continuing research programs (Wilson and Clark 1995, 1997a,b).

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Figure 1. Map showing the research site at the Willamette Floodplain Research Natural Area of the W. L. Finley National Wildlife Refuge located 16 km South of Corvallis, Oregon. The study area, marked by an X, is located in an area that was last burned, by an accidental fire, in 1979

Table 1. Description of the seven study species.

Species	Family	Functional group	Position of perennating buds	Life-span	Native or non-native
Beckmannia syzigachne	Poaceae	short-rhizomatous grass	below ground	annual or short-lived perennial	native
Carex unilateralis	Cyperaceae	tufted sedge	aboveground	perennial	native
Deschampsia cespitosa	Poaceae	bunchgrass	aboveground	perennial	native
Holcus lanatus	Poaceae	rhizomatous grass	belowground	perennial	non-native
Hordeum brachyantherum	Poaceae	rhizomatous grass	belowground	perennial	native
Rosa spp.	Rosaceae	shrub	above and belowground	perennial	native and non-native
Veronica scutellata	Scrophu-lariaceae	creeping forb	aboveground	perennial	native

Table 2. Summary of plant size and flowering measurements made on the seven study species before and after the burn treatments in September 1996. See Appendix C for units and measurement areas for each species.

Species	Pre-manipulation measurement	Post-manipulation measurement
Beckmannia syzigachne	total length of inflorescences number of inflorescences	total length of inflorescences number of inflorescences
Carex unilateralis	total length of inflorescences number of inflorescences length of longest leaf circumference	total length of inflorescences number of inflorescences
Deschampsia cespitosa	total length of inflorescences number of inflorescences circumference cover	total length of inflorescences number of inflorescences
Holcus lanatus	total length of inflorescences number of inflorescences	total length of inflorescences number of inflorescences
Hordeum brachyantherum	total length of inflorescences number of inflorescences total stem height	total length of inflorescences number of inflorescences
Rosa spp.	number of flowers and fruits cover height of tallest branch	number of flowers and fruits
Veronica scutellata	number inflorescences number of branches total stem height	number of inflorescences

Table 3. Covariates used in the analysis of covariance for each response variable for each of the seven study species. See Appendix C for units and measurement areas for each species.

Species	Response variable (after treatment measurement)	Covariate (before treatment measurement)
Beckmannia syzigachne	Vegetative biomass	Total length of inflorescences
	Reproductive biomass	Total length of inflorescences
	Total length of inflorescences	Total length of inflorescences
	Number of inflorescences	Number of inflorescences
Carex unilateralis	Vegetative biomass	Length of longest leaf × total length of inflorescences
	Reproductive biomass	Length of longest leaf × total length of inflorescences
	Total length of inflorescences	Number of inflorescences
	Number of inflorescences	Number of inflorescences
Deschampsia cespitosa	Vegetative biomass	Cover × total number of inflorescences
	Reproductive biomass	Number of inflorescences
	Number of inflorescences	Cover × total number of inflorescences
Holcus lanatus	Vegetative biomass	Total number of inflorescences
	Reproductive biomass	Total length of inflorescences
	Total length of inflorescences	Total length of inflorescences
	Number of inflorescences	Number of inflorescences
Hordeum brachyantherum	Vegetative biomass	Sum of squares of stem height
	Number of inflorescences	Number of inflorescences
Rosa spp.	Vegetative biomass	Cover × height of tallest branch
	Reproductive biomass	Total number of flowers and fruits
	Number of flowers and fruits	Number of flowers and fruits
Veronica scutellata	Vegetative biomass	Number of inflorescences
	Reproductive biomass	Number of inflorescences
	Number of inflorescences	Number of inflorescences

Table 4. Responses of seven dominant wetland plants the first growing season after burning treatment (September 1996) measured in terms of survival, aboveground vegetative biomass, reproductive biomass, size of inflorescences, and number of reproductive units. See Table 2 for the specific reproductive units measured for each species after burning. Values are least-square means from the analysis of covariance. P is the probability that values differed significantly between burn and unburn treatment just by chance. Values in bold differed significantly from each other ($P \leq 0.05$). *indicates that the block × treatment interaction was significant ($P \leq 0.05$)

Species	Responses to fire				
	survival	aboveground vegetative biomass	reproductive biomass	length of inflorescence	number of reproductive units
	%	*g/m²*	*g/m²*	*cm/m²*	*no./m²*
Beckmannia syzigachne					
Burn	**77.4**	**11.0**	2.3	**154.4**	**19.0**
No burn	**36.9**	**4.1**	1.2	**76.1**	**6.8**
	P = 0.03	**P = 0.01**	P = 0.20	**P = 0.01**	**P =0.00**
Holcus lanatus					
Burn	80.0	30.2	2.8	343.6	60.6
No burn	66.7	29.1	2.0	332.6	52.0
	P = 0.64	P = 0.90*	P = 0.37	P = 0.91	P = 0.61
Hordeum brachyantherum					
Burn	82.6	29.1			12.8
No burn	80.7	24.8			9.8
	P = 0.76	P = 0.54			P = 0.61
Rosa spp.					
Burn	79.2	**76.8**	**1.4**		**9.6**
No burn	98.2	**376.0**	**12.5**		**73.6**
	P = 0.06	**P = 0.00**	**P = 0.02**		**P = 0.02**
Veronica scutellata					
Burn	**47.1**	**2.9**	**0.2**		**32.0**
No burn	**85.7**	**10.2**	**0.8**		**150.4**
	P = 0.00	**P = 0.01**	**P = 0.02**		**P = 0.03**
	%	*g/clump*	*g/clump*	*cm/clump*	*no./clump*
Carex unilateralis					
Burn	100.0	**25.5**	**1.6**	50.1	*32.9*
No burn	100.0	**36.7**	**3.8**	93.1	*54.2*
		P = 0.03	**P = 0.02**	P = 0.09	*P = 0.10**
Deschampsia cespitosa					
Burn	97.5	**8.5**	0.2		*0.7*
No burn	100.0	**16.7**	0.6		*4.7*
	P = 0.36	**P = 0.02**	P = 0.13		*P = 0.07**

Table 5. Response patterns of seven dominant wetland species to burn treatment (September 1996) at Finley Research Natural Area.

Poor Survivor	**Decreaser**	**Unaffected**	**Increaser**
with reductions in survival, aboveground vegetative biomass, and reproduction	with no change in survival, but decreases in aboveground vegetative biomass, and reproduction	with little changes in survival, aboveground vegetative biomass, and reproduction	with increases in survival, aboveground vegetative biomass, and reproduction
Rosa spp. *Veronica scutellata*	*Deschampsia cespitosa* *Carex unilateralis*	*Hordeum brachyantherum* *Holcus lanatus*	*Beckmannia syzigachne*

Table 6. Effectiveness of prescribed burning for conservation management of the Finley Research Natural Area, based on results of this study.

Conservation Goal	**Goal achieved**	**Comments**
Reduce abundance of woody species	Yes	Repeated burns will be necessary to maintain reduction of *Rosa* spp.
Reduce or not promote abundance of non-native herbaceous species	Yes	Fire did not increase the abundance of the single non-native herbaceous species measured in this study
Promote or maintain the abundance of native species	Yes and no	Fire promoted or maintained the abundance of two of the five native species measured. The abundance of the other three species was reduced.

Appendix A Soil temperatures during the burn treatment at the Willamette Floodplain Research Natural Area of W. L. Finley National Wildlife Refuge, Oregon.

The maximum soil temperatures for the burn treatment September 1996 at Finley Research Natural Area are listed in Table A1. Two measurements were made for each burn treatment in each of the eight blocks. Temperatures were assessed using pyrometers made from sheets of ceramic fiber backing (5 cm × 3.5 cm × 0.25 cm) stapled to the same size mica sheets (modified from Bentley and Fenner 1960). The side of the mica sheets facing the ceramic fiber backing was painted with six parallel strips of paint designed to melt at the following temperatures: 73C, 104C, 121C, 149C, 204C, and 260C (R. E. Frenkel, personal communication).

The pyrometers were inserted into the soil with vertical stripes of paint at right angles to the soil surface using a steel plate (5 cm × 15 cm × 0.3 cm) created by Robert Frenkel, Oregon State University. The steel plate was hammered into the soil about 5 cm and then fully extracted from the soil at the same time that the pyrometer was carefully inserted into the slit created by the steel plate. The pyrometers were exposed above the soil layer about 0.5 cm. Soil flanking the inserted pyrometer was tapped gently with a wooden block to pack the soil tightly against the pyrometer, stimulating soil original density. Pyrometers were inserted immediately before the burn to avoid deterioration caused by soil moisture. Immediately after the burn, pyrometers were carefully extracted from the soil with a trowel.

After the burn, a darkened mark on the pyrometers indicated that portion of the pyrometer above the soil surface. Melting of paint in this portion of the pyrometer gave the approximate temperature at the ground surface. Melting of paint below this darkened area gave the temperature profile below the soil surface.

Table A1. Soil temperatures in the burn treatments September 1996 at the Willamette Floodplain Research Natural Area of the W. L. Finley National Wildlife Refuge, Oregon. The values are the distance (mm) from the top of the pyrometer at which the paint melted.

Block	Replicate	Temperature (C)					
		73	104	121	149	204	260
1	1	15	12	12	7	3	1
1	2	13	6	6	3	1	0
2	1	22	16	16	13	8	5
2	2	5	0	0	0	0	0
3	1	14	11	9	6	2	0
3	2	5	1	0	0	0	0
4	1	10	9	8	7	5	3
4	2	missing	14	13	13	9	6
5	1	5	1	0	0	0	0
5	2	7	6	6	3	0	0
6	1	10	2	0	0	0	0
6	2	5	2	1	1	0	0
7	1	6	6	7	7	6	3
7	2	missing					
8	1	2	0	0	0	0	0
8	2	7	4	0	0	0	0

Appendix B Burn time and weather conditions during the prescribed burns, September 1996, at the Willamette Floodplain Research Natural Area of W. L. Finley National Wildlife Refuge, Oregon.

Table B1. Burn time for each of the eight blocks during the prescribed burn September 26, 1996.

Block number	Ignition	No flames, smoke only
6,8	11:00 a.m.	11:15 a.m. (11:09 a.m. big flames out)
7	11:37 a.m.	11:42 a.m.
2, 3, 4, and 5	12:05 p.m.	12:15 p.m.
1	12:25 p.m.	12:30 p.m.

Table B2. Weather conditions prior, during, and following the prescribed burn on September 26, 1996. The mixing layer prior to the fire was at 1600 feet.

Conditions	Time					
	10:45	11:27	11:55	12:35	13:30	14:00
Wind speed (mph) and direction	5 NW	4 E	3 NW	2-3 NW	5 N	3 W
Relative humidity (%)	46*	40	35	34	35	31
Dry bulb temperature(F)	66	72	74	73	74	76
Wet bulb temperature	56	58	58	57	58	59

*This measurement was calculated. The humidity read 34%.

Appendix C Pre-manipulation (1996) and post-manipulation measurements (1997) of survival, biomass, size, and flowering intensity for seven dominant wetland prairie species in the Willamette Floodplain Research Natural Area of W. L. Finley National Wildlife Refuge, Oregon. This appendix summarizes over 100,000 collected number. Blanks indicate missing values. The code for the variable labels for each species is as follows:

Beckmannia syzigachne (Besy)

Blk	Block number (8 blocks)
Tmt	Treatment (0 = unburn, 1= burn)
Tag	Tag (identification number of measurement area)
Quad	Quadrat (identification number of measurement area)
InflTN96	Total number of inflorescences per m^2 in 1996
InflTL96	Total length (cm) of inflorescences per m^2 in 1996
InflTN97	Total number of inflorescences per m^2 in 1997
InflTML97	Total length of mature inflorescences per m^2 in 1997
InflTDL97	Total length (cm) of partially dispersed inflorescences per m^2 in 1997
Surv	Survival (0 = no measurement, 1 = survival, 2 = no survival)
SdlN	Number of seedlings per m^2 in 1997
TillerN	Number of tillers per m^2 in 1997
Rwgt	Biomass (g) of reproductive structures per m^2
Vwgt	Biomass (g) of vegetative structures per m^2
VwgtRank	Transformed reproductive biomass data using rank transformation
RwgtRank	Transformed vegetative biomass data using rank transformation

Carex unilateralis (Caun)

Blk	Block number (8 blocks)
Tmt	Treatment (0 = unburn, 1 = burn)
Tag	Tag (identification number of measurement area)
Quad	Quadrat (identification of measurement area)
Cir96	Circumference (cm) of clump in 1996
LfL96	Length (cm) of longest leaf per clump in 1996
InflTN96	Total number of inflorescences per clump in 1996
InflTL96	Total length (cm) of inflorescences per clump in 1996
Surv	Survival (0 = no measurement, 1 = survival, 2 = no survival)
InflTL97	Total length (cm) of inflorescences per clump in 1997
InflTN97	Total number of inflorescences per clump in 1997
Rwgt	Biomass (g) of reproductive structures per clump
Vwgt	Biomass (g) of vegetative structures per clump

Deschampsia cespitosa (Dece)

Blk	Block number (8 blocks)
Tmt	Treatment (0 = unburn, 1 = burn)
Tag	Tag (identification number of measurement area)
Quad	Quadrat (identification of measurement area)
Cir96	Circumference (cm) of clump in 1996
Cvr96	Cover (%) live tissue per clump in 1996
InflTN96	Total number of inflorescences per clump in 1996
InflTL97	Total length (cm) of inflorescences per clump in 1997
Surv	Survival (0 = no measurement, 1 = survival, 2 = no survival)
Rwgt	Biomass (g) of reproductive structures per clump
BWgt	Biomass (g) of vegetative structures still alive per clump
Vwgt	Biomass (g) of dead vegetative structures per clump

Holcus lanatus (Hola)

Blk	Block number (8 blocks)
Tmt	Treatment (0 = unburn, 1= burn)
Tag	Tag (identification number of measurement area)
Quad	Quadrat (identification number of measurement area)
InflTN96	Total number of inflorescences per m^2 in 1996
InflTL96	Total length (cm) of inflorescences per m^2 in 1996
InflTN97	Total number of inflorescences per m^2 in 1997
InflTL97	Total length (cm) of inflorescences per m^2 in 1997
Surv	Survival (0 = no measurement, 1 = survival, 2 = no survival)
SdlN	Number of seedlings per m^2 in 1997
Rwgt	Biomass (g) of reproductive structures per m^2
Vwgt	Biomass (g) of vegetative structures per m^2

Hordeum brachyantherum (Hobr)

Blk	Block number (8 blocks)
Tmt	Treatment (0 = unburn, 1 = burn)
Tag	Tag (identification number of measurement area)
Quad	Quadrat (identification of measurement area)
SSStemH96	Sum of squared stem heights per m^2 in 1996
InflTN96	Total number of inflorescences per m^2 in 1996
InflTN97	Total number of inflorescences per m^2 in 1997
Surv	Survival (0 = no measurement, 1 = survival, 2 = no survival)
MRWgt	Biomass of mature reproductive structures per m^2
DRWgt	Biomass of partially dispersed reproductive structures per m^2
Vwgt	Biomass (g) of vegetative structures per m^2

Rosa spp. (Rosa)

Blk	Block number (8 blocks)
Tmt	Treatment (0 = unburn, 1 = burn)
Tag	Tag (identification number of measurement area)
Quad	Quadrat (identification of measurement area)
Cvr96	Cover (%) per 0.625 m^2 in 1996
Hgt96	Height (cm) of tallest branch in measurement area in 1996
FN96	Total number of flowers and fruits per 0.625 m^2 in 1996
FN97	Total number of flowers and fruits per 0.625 m^2 in 1997
Surv	Survival (0 = no measurement, 1 = survival, 2 = no survival)
Rwgt	Biomass (g) of reproductive structures per 0.625 m^2 in 1996
Vwgt	Biomass (g) of vegetative structures per 0.625 m^2 in 1997

Veronica scutellata (Vesc)

Blk	Block number (8 blocks)
Tmt	Treatment (0 = unburn, 1 = burn)
Tag	Tag (identification number of measurement area)
Quad	Quadrat (identification of measurement area)
BrTN96	Total number of branches per 0.625 m^2 in 1996
Hgt96	Total height per 0.625 m^2 in 1996
InflTN96	Total number of inflorescences per 0.625 m^2 in 1996
InflTN97	Total number of inflorescences per 0.625 m^2 in 1997
Surv	Survival (0 = no measurement, 1 = survival, 2 = no survival)
Rwgt	Biomass (g) of reproductive structures per 0.625 m^2 in 1996
Vwgt	Biomass (g) of vegetative structures per 0.625 m^2 in 1997