Ecological Applications, 9(4), 1999, pp. 1420–1429

THE ROLE OF PRESCRIBED BURNING IN MAINTENANCE OF AN ENDANGERED PLANT SPECIES, *LOMATIUM BRADSHAWII*

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Abstract. Responses of a federally listed endangered plant species, *Lomatium bradshawii,* to the use of fire as a management tool for maintaining remnant wetland prairies were evaluated at two public land areas in the Willamette Valley of western Oregon. Areas containing *L. bradshawii* were treated with two or three fall season prescribed burns during a nine-year period. Foliar crown area, height, umbellets, and schizocarps of 150 *L. bradshawii* at Rose Prairie and 250 at Fisher Butte and the recruitment and density of *L. bradshawii* in 2-m^2 plots at both sites were documented during 1988–1996. When both sites were considered together, crown area, height, umbellets, and schizocarps per plant initially responded positively to burn treatments, but increases were not consistent across years or sites. Crown area tended to increase and then decline after each burn. Burning initially enhanced schizocarp production at both sites; schizocarps declined one or two years after burning but remained much higher in the burn treatments than in controls until 1996. Seedling production was not correlated with schizocarp production at either site. Umbellet and schizocarp production were not correlated with January–June temperatures or precipitation at the nearest weather station. Burning accentuated differences in size and reproductive capacity of *L. bradshawii* at the two sites and differentially affected recruitment and density. Random resampling of *L. bradshawii* in 1997 indicated that effects of repeated burning during the previous eight years were hard to detect. At Rose Prairie, foliar crown area, height, number of leaves, umbellets, and schizocarps in 1997 were similar or lower with burning than in unburned controls. At Fisher Butte, *L. bradshawii* in the two burn treatment were similar to control plants, but three burns significantly increased foliar crown area, number of leaves, and schizocarps. Monitoring recovery for one or two years after a burn may only capture the initial stimulation provided by burning and may foster unrealistically high expectations concerning the viability of an endangered plant population.

Key words: burning, management of wetland prairies; endangered plant species; fire as management tool; growth; Lomatium bradshawii; *rare species; recruitment, endangered plant species; reproduction, rare plant species; wet prairie.*

Introduction

The understanding that fire is a natural process in many ecosystems has altered management practices away from fire suppression to the current use of fire as a management tool. However, fires are often reintroduced into systems only on evidence that fires occurred in the past and are not occurring now (Johnson and Miyanishi 1995). Fire affects individuals as well as populations, communities, and ecosystems, and the consequences of reintroducing burning must be considered at all ecosystem levels. A fire regime that is beneficial at one level of organization may be neutral or even detrimental at other scales, and managers need to be aware that potential benefits for one species or community may disadvantage others. The consequences of focusing a fire management program to benefit an individual species or community should be thoroughly explored before beginning such a program.

Fire is an important disturbance process in North American grasslands that had a natural fire frequency of 5–10 yr (Wright and Bailey 1982). Altering fire frequency can result in changes in species composition and diversity (Kucera and Koelling 1964, Kucera 1981). Burn season also affects species composition in prairies (Howe 1994). Fire effects differ by species, making an optimal overall fire frequency difficult to determine (Curtis and Partch 1948). Effects of a specific fire treatment should be evaluated against objectives for the site to be burned. If the objective is to increase the density of a rare plant species, its density should be measured prior to and following burning and compared with control/unburned densities. Following the fate of individuals for a number of years in burned areas may be required to understand the effects of fire treatments on target species. Increased vegetative

Manuscript received 22 December 1997; revised 3 September 1998; accepted 5 October 1998.
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growth, flowering, and seed production are commonly observed following fire (Daubenmire 1968, Vogl 1974, Kucera 1981, Wright and Bailey 1982), but the duration of these responses can vary. Only rarely are field studies of repeated treatments documented for extended periods of time (Tilman and Downing 1994). Long-term studies are needed to estimate the effects of repeated fires.

Before the arrival of Euro-Americans, burning by the Kalapuya Indians maintained western Oregon's Willamette Valley as an expansive prairie that was described by early settlers as populated by occasional solitary oaks, scattered tracts of open-grown oak woodlands, and dense riparian forest along stream and river channels (Habeck 1961, Thilenis 1968, Johannessen et al. 1971, Towle 1982, Boyd 1986). These native grasslands are home to many endemic plant species. However, <1% of the pre-Euro-American, Willamette Valley prairie ecosystem remains today (Christy and Alverson 1994). Since Euro-American settlement in the late 1800s, loss of prairie habitat to agricultural and pastoral practices, urbanization, and natural succession to forests has restricted many species to isolated pockets within the valley.

The historic and current prevalence of fire in grassland ecosystems of the world indicates the functional importance of fire in grassland community dynamics (Kucera 1981, Risser et al. 1981, Wright and Bailey 1982). Prairie plant species evolved adaptations to survive disturbance regimes characterized by frequent fall season fires. In the absence of natural and aboriginal fires, encroachment by woody species now threatens the integrity of remnant wetland prairies in the Willamette Valley (Sprague and Hansen 1946, Habeck 1962, Franklin and Dyrness 1973, Frenkel and Heinitz 1987).

Since development of commercial grass seed production in the Willamette Valley in the 1920s, fall burns were used to reduce pathogens and to invigorate perennial grass fields. In response to public pressure, reducing the acreage that can be burned recently restricted field burn. Due to public aversion to agricultural burning, public-land managers must have a sound scientific basis to justify the burning of natural areas. Prescribed burning is a management technique that may slow succession, sustain biological diversity, and favor fire-adapted species, but its effect on rare species is largely unknown. As managers begin to incorporate fire into management practices, data are needed on the response of rare species to repeated burns.

Willamette Valley bottom prairie, characterized by deep pluvial clays and a perched water table, is the most common habitat type of *Lomatium bradshawii* (Rose ex Math.) Math. and Const., a federally listed endangered plant species (Kagan 1980, Alverson 1989, Finley 1994). Commonly known as Bradshaw's desert parsley or Bradshaw's lomatium, *L. bradshawii* is a 20–50 cm tall perennial herb in the parsley family (Apiaceae). The plant has light yellow flowers, arranged in umbels, and corky-winged fruits. The flowers are subtended by bracts, which are singly or doubly divided into threes; this trait differentiates it from all other *Lomatium* species (Eastman 1990). *Lomatium bradshawii* does not reproduce vegetatively (Kaye 1992), and individual plants are easy to distinguish in the field.

Currently, *L. bradshawii* occurs in 16 isolated populations, all but one of which are located in remnant fragments of Willamette Valley prairie. One population was recently found in southwestern Washington. Documented populations range in sizes from <50 to ~25 000 individuals and occupied sites ranging in size from <1–40 ha (Parenti et al. 1993).

State and federal laws mandate that publicly owned lands containing threatened or endangered species be managed to perpetuate those species, but little is known about how to manage for *L. bradshawii*. To test the hypothesis that populations of *L. bradshawii* respond positively to fall season prescribed burns, and to consider the role of fire as a management tool, two public land areas in the Willamette Valley containing *L. bradshawii* were treated with two or three fall burns during a nine-year period.

METHODS

Two research sites, Rose Prairie and Fisher Butte, were used in this study. Both are within the Fern Ridge Research Natural Area administered by the U.S. Army Corps of Engineers (44° N, 123° W, 13 km west of Eugene, Oregon, USA). Both sites are in the southern Willamette Valley, which has moist, mild winters and moderately warm, dry summers. Mean annual precipitation at the Eugene, Oregon airport, 5–8 km from the research sites, is 114 cm; mean annual temperature is 12°C (National Oceanic and Atmospheric Administration 1982). The elevation at both Rose Prairie and Fisher Butte is 114 m (Finley 1994). Soils at the research sites are classified as Natroy–Bashaw silty clay and Dayton silt loam; they are alluvial, deep, poorly drained, and subject to frequent long periods of flooding during November–May. During the dry summer months, the soils become extremely hard and deeply cracked (U.S. Department of Agriculture Soil Conservation Service 1987).

During May and June 1988, three blocks, each with an area of ~2 ha, were laid out at Rose Prairie (A, B, and C). Treatments were randomly assigned to each block, an unburned control (C) and one example of each burn treatment (A and B). The two major communities at Rose Prairie, *Deschampsia cespitosa*/*Danthonia californica* and *Vaccinium caespitosum* (Pendergrass 1995), were present in each treatment. At Fisher Butte, five treatment blocks, each a ~4 ha rectangle, were laid out perpendicular to Oregon State Highway 126, which delineates the western boundary of the site. Treatments were randomly assigned to each block, an unburned control (C) and two replicates of each burn treatment (A, B, D, and E). The two major plant communities at Fisher Butte, *Deschampsia cespitosa*/*Danthonia californica* and *Rosa nutkana*/*Juncus nevadensis* (Pendergrass 1995), were present in each treatment.

Burn schedule

Prescribed burns were conducted at Rose Prairie and Fisher Butte on 11 October 1988 by the Eugene District, Bureau of Land Management, utilizing strip head burning techniques and wet lines for fire control. In 1988, blocks A and B were burned at Rose Prairie and blocks A, B, D, and E were burned at Fisher Butte. On 19 September 1989, block B at Rose Prairie and blocks D and E at Fisher Butte were reburned. The initial experimental design involved following the response of *L. bradshawii* after one fall burn in 1988 or two fall burns in 1988 and 1989; however, the Bureau of Land Management decided to reburn all burn treatments at both sites during the fall of 1991. Repeated burns allowed monitoring of the response of *L. bradshawii* to two or three burns within a four-year period, which may more closely mimic the fire regime present before Euro-American settlement of the Willamette Valley. Monitoring of the sites took place during 1988–1996. Fire parameters of flame length, height, depth, and angle; fire line and reaction intensities; and heat per unit area were documented and are presented elsewhere (Pendergrass et al. 1998).

Measurement procedure

Fifty *L. bradshawii* were randomly selected in each treatment block, a total of 150 at Rose Prairie and 250 at Fisher Butte. Each individual was mapped, tagged, and the height from the ground to the tip of the tallest leaf, widest diameter of foliar crown material (W1), and the diameter perpendicular to this (W2) were measured. Elliptical crown area was calculated using the following formula:

$$\text{Area} = (W1 \times W2 \times 3.142)/4.$$

The number of leaves, umbellets, and schizocarps (seed pods per umbellet) on each plant were also counted. Measurements of tagged individuals were repeated in the spring/early summer for the period 1989–1996. The number of individuals measured in each treatment varied throughout the measurement period, due to mortality and the aboveground absence and subsequent reappearance of some tagged individuals.

Eighteen of the tagged *L. bradshawii* at Rose Prairie and 30 at Fisher Butte (six per treatment block at each site) were randomly chosen as center points for density measurements. A circular 2-m radius plot was sampled around each tagged plant to estimate recruitment and density of *L. bradshawii.* With the exception of 1995, when data were not collected, recruitment/density plots were measured in late May 1988–1996.

Attrition during the eight-year sampling period reduced the sample size from the original 50 tagged *L. bradshawii* in each treatment block. The reduced sample size raised concerns that after nine years the original tagged plants might not be representative of the current populations of *L. bradshawii* at Rose Prairie and Fisher Butte. During May 1997, 150 randomly chosen *L. bradshawii* were measured at Rose Prairie and 150 at Fisher Butte, 50 from each treatment at each site.

Data are presented as means $\pm$ 1 SE. Comparisons between unburned controls in 1988 and 1996, between controls in 1996 and treatments in 1996, and between controls in 1988 and controls and treatments in 1997 were made using nonparametric Tukey-type multiple comparisons (Zar 1984). Conservative, nonparametric statistical analysis was used because of the following reasons: (1) the data are not normally distributed and do not consistently have similar variances, (2) during some measurement periods data are missing due to year-to-year variability in the aboveground presence of tagged *L. bradshawii,* and (3) replication of treatments was limited because of difficulties associated with using prescribed burns in management areas.

RESULTS

Preburn plant measurements

In 1988, before the prescribed burns, the 150 *L. bradshawii* measured at Rose Prairie were significantly smaller and produced fewer umbellets than the 250 individuals measured at Fisher Butte, but the mean schizocarp production per plant was similar at the two sites (Table 1). Foliage crown area frequency distributions were dominated by small individuals at both sites; only Fisher Butte had some plants with crown areas $>$250 cm^2 (Fig. 1a). Before the burns, most plants at both sites had three or four leaves; only Fisher Butte had plants with more than five leaves. Heights were normally distributed but peaked in the 20-cm height class at Rose Prairie and the 25-cm class at Fisher Butte (Fig. 1b).

The percentage of preburn plants that did not produce schizocarps was similar at Rose Prairie and Fisher Butte, 61% and 67%, respectively (Fig. 1c). At Rose Prairie 79% of the schizocarps were produced by plants in the smallest two crown area classes, while schizocarp production was more evenly distributed across plants of all sizes at Fisher Butte (Fig 1d).

Preburn foliar crown area, height, umbellets, and schizocarps per plant were similar for *L. bradshawii* in three communities: the *Deschampsia cespitosa*/*Danthonia californica* and *Vaccinium caespitosum* communities at Rose Prairie and the *Deschampsia cespitosa*/*Danthonia californica* community at Fisher Butte. However, plants growing in the *Rosa nutkana*/*Juncus nevadensis* communities at Fisher Butte were significantly larger and produced more umbellets and fruits ($P < 0.05$). The *Rosa nutkana*/*Juncus nevadensis* was the wettest of the four community types (Pendergrass, *personal observation*). The preburn communities were

TABLE 1. Preburn measurements of *Lomatium bradshawii* at Rose Prairie (RP-Pre) and Fisher Butte (FB-Pre) in 1988, and measurements in 1997 of 50 randomly chosen plants in each treatment: controls at both sites (RP-C and FB-C); Rose Prairie blocks burned two times (RP-2); Rose Prairie blocks burned three times (RP-3); Fisher Butte blocks burned two times (FB-2); and Fisher Butte blocks burned three times (FB-3).

Site	No. plants	Crown area (cm^2)	Height (cm)	No. leaves	No. umbellets	No. schizocarps
1988						
RP-Pre	150	41.2 ± 3.4*[,a]	17.7 ± 0.5*[,a]	3.1 ± 0.1*[,a]	7.6 ± 0.7*[,a]	5.3 ± 0.8[a]
FB-Pre	250	64.5 ± 5.3*[,c]	19.9 ± 0.4*[,c]	3.7 ± 0.1*[,c]	9.5 ± 0.9*[,c]	6.9 ± 1.0[c]
1997						
RP-C	50	36.8 ± 6.6[a]	17.5 ± 0.8[a]	2.7 ± 0.1[a]	5.7 ± 1.0[b]	5.4 ± 1.2[a]
RP-2	50	31.1 ± 6.9[a,b]	16.2 ± 1.0[a]	2.4 ± 0.1[b]	4.3 ± 0.9[b]	3.2 ± 0.9[a]
RP-3	50	28.6 ± 3.6[b]	18.5 ± 0.8[a]	2.7 ± 0.1[a]	5.1 ± 1.1[b]	3.7 ± 0.9[a]
FB-C	50	40.7 ± 7.1[d]	18.3 ± 0.8[c]	3.0 ± 0.1[d]	2.1 ± 0.7[d]	0.6 ± 0.3[d]
FB-2	50	58.5 ± 11.4[c,d]	19.2 ± 0.7[c]	3.1 ± 0.1[d]	4.1 ± 0.8[d]	2.6 ± 0.7[d]
FB-3	50	72.0 ± 10.3[c]	21.4 ± 0.8[c]	3.4 ± 0.3[c,d]	8.0 ± 1.3[d]	6.1 ± 1.5[c]

Note: Within a site, the same superscript letter (a or b for Rose Prairie, and c or d at Fisher Butte) indicates that a population parameter did not differ significantly between treatments ($P < 0.05$). Table entries are means ± 1 SE.
* Significant differences between Rose Prairie and Fisher Butte, $P < 0.05$.

distributed across control and burn treatments at both sites. Measured plant parameters were not significantly different in control and burn treatments in 1988, before the first fall burns.

Postburn crown area

In 1996, at the end of the eight-year measurement period, mean foliar crown areas of *L. bradshawii* in controls at Rose Prairie and at Fisher Butte were similar to those measured in 1988 (Table 2). By 1996, crown area was significantly larger in the two-burn treatment than the controls at both sites, but three burns only increased crown area at Fisher Butte. At both sites, crown area increased during the three years after one burn (1989–1991), was more variable during the seven years following two burns (1990–1996), and increased

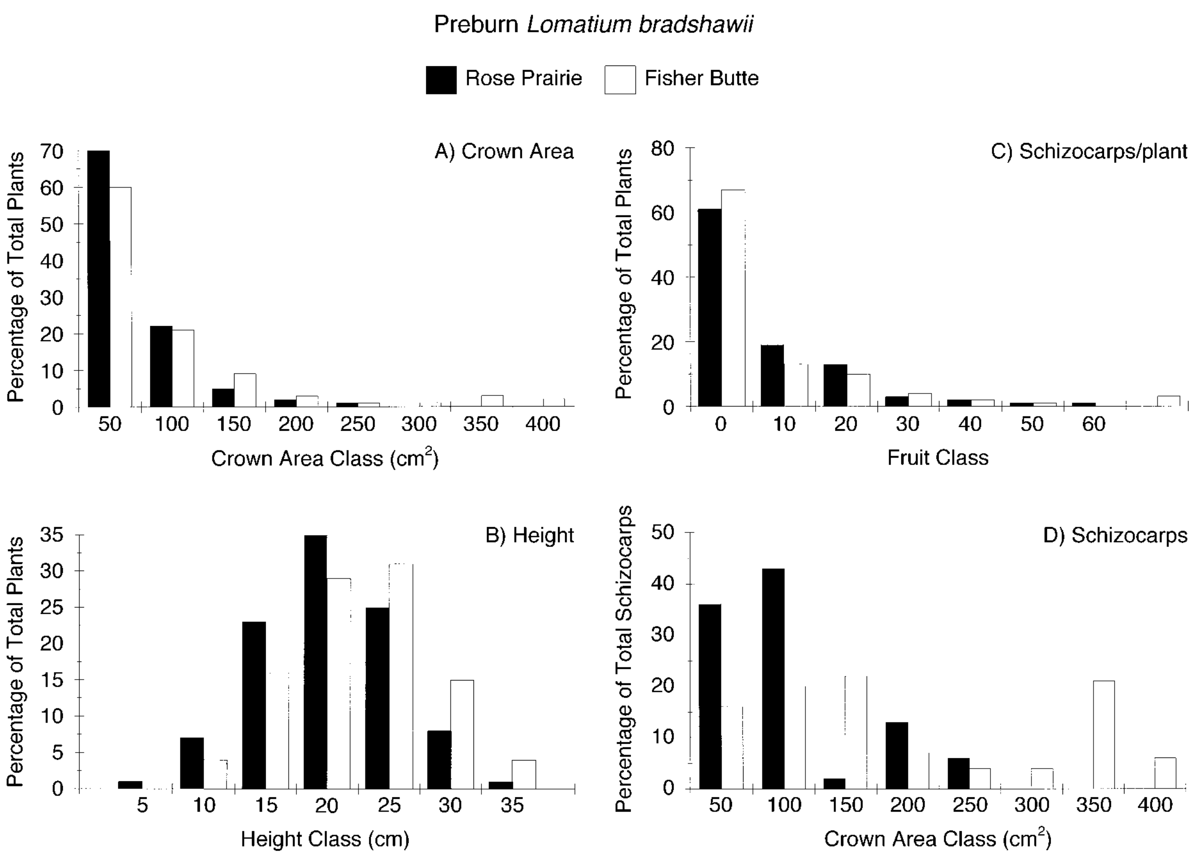

FIG. 1. Percentage of total plants by (A) crown area, (B) height, (C) schizocarp number class, and (D) percentage of total schizocarps per crown area class for 150 preburn *Lomatium bradshawii* at Rose Prairie and 250 at Fisher Butte in 1988.

TABLE 2. Foliar crown area (cm^2) of *Lomatium bradshawii* during 1988–1996 in unburned controls and after 1–3 burns at Rose Prairie and Fisher Butte (mean ± 1 SE).

	Rose Prairie				Fisher Butte			
Year	Control	One burn	Two burns	Three burns	Control	One burn	Two burns	Three burns
1988	41 ± 3[a]	···	···	···	64 ± 7[a]	···	···	···
1989	52 ± 4	52 ± 4	···	···	49 ± 5	90 ± 9	···	···
1990	40 ± 4	60 ± 5	53 ± 6	···	41 ± 4	96 ± 11	120 ± 14	···
1991	42 ± 4	71 ± 8	56 ± 5	···	43 ± 5	92 ± 10	115 ± 9	···
1992	62 ± 5	···	75 ± 6	63 ± 6	44 ± 5	···	121 ± 11	163 ± 13
1993	52 ± 4	···	49 ± 6	39 ± 4	44 ± 5	···	91 ± 10	108 ± 11
1994	34 ± 4	···	30 ± 4	40 ± 5	28 ± 3	···	72 ± 9	73 ± 9
1995	23 ± 3	···	32 ± 4	39 ± 4	47 ± 5	···	65 ± 7	75 ± 8
1996	48 ± 4[a]	···	62 ± 7[b]	41 ± 4[a]	52 ± 6[a]	···	111 ± 12[b]	115 ± 13[b]

Notes: The number of individuals measured at Rose Prairie varied from 150 in 1988 to 26 in 1996, and at Fisher Butte the number varied from 250 in 1988 to 49 in 1996. Crown areas within a site with the same superscript letter are not significantly different (Tukey test, $P > 0.05$).

then declined during the five years following three burns (1992–1996). Crown area responded more positively to burning at Fisher Butte than at Rose Prairie. The greatest response was measured in 1992 after three burns at Fisher Butte, when crown area was almost 400% larger than the 1992 controls.

Postburn height

During 1988–1996, plant height in controls increased significantly at Rose Prairie and decreased significantly at Fisher Butte (Table 3). In control plots, *L. bradshawii* were taller at Rose Prairie than at Fisher Butte. Height responded less positively with burning at Rose Prairie than Fisher Butte. In 1996, after two or three burns, *L. bradshawii* at Rose Prairie were not significantly taller than 1996 control plants, but plants at Fisher Butte in both burn treatments were significantly taller than controls.

Postburn umbellets

The mean number of umbellets produced by control *L. bradshawii* decreased significantly at both sites during the period 1988–1996 (Table 4). Umbellet production showed an initial strong positive response to burning at both sites; during 1988–1996, the number of umbellets per plant ranged 2–10 in control plants and 2–21 in the burn treatments. Umbellet production at Rose Prairie peaked in 1990 at 11 umbellets/plant in both burn treatments. By 1996, the number of umbellets per plant at Rose Prairie were similar in control, two-burn, and three-burn treatments, but all 1996 umbellet production was significantly lower than it was in 1988. At Fisher Butte, maximum umbellet production, 21 umbellets/plant, also occurred in 1990 after two burns; production was also high in 1990 after one burn and in 1992 after three burns. By 1996, the number at Fisher Butte were significantly higher in the two- and three-burn treatments compared with 1996 controls, but the number of umbellets in both 1996 burn treatments was similar to that measured in the in 1988 controls.

Postburn schizocarps

Schizocarps per plant in control plots also declined significantly, from five to seven to fewer than two, at both sites during 1988–1996 (Table 5). Schizocarp production was highest at both sites (9–18 schizocarps/plant) in 1990 after one or two burns. During most measurement periods, schizocarp production responded less favorably to burning at Rose Prairie than at Fisher Butte. However by 1996, the number of schizocarps per plant in the two- and three-burn treatments were similar to controls (<2 schizocarps/plant) at both

TABLE 3. Height (cm) of *Lomatium bradshawii* during 1988–1996 in unburned controls and after 1–3 burns at Rose Prairie and Fisher Butte (mean ± 1 SE).

	Rose Prairie				Fisher Butte			
Year	Control	One burn	Two burns	Three burns	Control	One burn	Two burns	Three burns
1988	18 ± 1[a]	···	···	···	20 ± 1[a]	···	···	···
1989	19 ± 1	17 ± 1	···	···	19 ± 2	20 ± 2	···	···
1990	20 ± 2	19 ± 2	17 ± 1	···	19 ± 2	22 ± 2	21 ± 1	···
1991	20 ± 2	20 ± 2	19 ± 2	···	17 ± 1	23 ± 2	23 ± 2	···
1992	19 ± 2	···	14 ± 1	14 ± 1	17 ± 1	···	19 ± 1	19 ± 2
1993	21 ± 2	···	18 ± 2	19 ± 2	19 ± 2	···	24 ± 2	24 ± 2
1994	22 ± 2	···	22 ± 2	22 ± 2	20 ± 2	···	24 ± 2	24 ± 2
1995	19 ± 2	···	21 ± 2	19 ± 2	18 ± 2	···	23 ± 2	23 ± 2
1996	20 ± 1[b]	···	21 ± 2[b]	20 ± 2[b]	18 ± 1[b]	···	23 ± 2[c]	23 ± 2[c]

Notes: The number of individuals measured at Rose Prairie varied from 150 in 1988 to 26 in 1996, and at Fisher Butte the number varied from 250 in 1988 to 49 in 1996. Heights within a site with the same superscript letter are not significantly different (Tukey test, $P > 0.05$).

TABLE 4. Umbellets per plant of *Lomatium bradshawii* during 1988–1996 in unburned controls and after 1–3 burns at Rose Prairie and Fisher Butte (mean ± 1 SE).

	Rose Prairie				Fisher Butte			
Year	Control	One burn	Two burns	Three burns	Control	One burn	Two burns	Three burns
1988	7.6 ± 0.8[a]	···	···	···	9.5 ± 1[a]	···	···	···
1989	4.6 ± 0.4	6.8 ± 0.7	···	···	3.2 ± 0.3	8.3 ± 0.7	···	···
1990	5.4 ± 0.6	11 ± 1	11 ± 1	···	5 ± 0.4	16.8 ± 1.5	21 ± 4	···
1991	3.1 ± 0.3	6.3 ± 0.6	6.2 ± 0.5	···	3.5 ± 0.4	11.4 ± 0.9	16.1 ± 7	···
1992	4.1 ± 0.3	···	8.7 ± 0.9	7.2 ± 1	2.3 ± 0.2	···	12 ± 4	16 ± 2
1993	6.8 ± 0.5	···	11.4 ± 1	9.9 ± 2	2.6 ± 0.3	···	12 ± 4	12 ± 3
1994	2.9 ± 0.2	···	2.1 ± 0.2	3.8 ± 2	1.5 ± 0.1	···	7.4 ± 3	7.4 ± 4
1995	3.2 ± 0.2	···	3 ± 0.2	3.4 ± 2	2.4 ± 0.2	···	8.2 ± 1	9.2 ± 2
1996	3.6 ± 0.3[b]	···	3.9 ± 0.3[b]	4 ± 2[b]	5 ± 0.4[b]	···	10 ± 3[b]	8.3 ± 2[b]

Notes: The number of individuals measured at Rose Prairie varied from 150 in 1988 to 26 in 1996, and at Fisher Butte the number varied from 250 in 1988 to 49 in 1996. Umbellets within a site with the same superscript letter are not significantly different (Tukey test, $P > 0.05$).

sites. During the eight-year measurement period, *L. bradshawii* consistently produced more schizocarps per umbellet at Rose Prairie (0.8 ± 0.09) than at Fisher Butte (0.57 ± 0.06).

Mortality and density

Year-to-year variability in the aboveground presence of *L. bradshawii* made estimations of individual mortality difficult. By 1996, eight years after the initial plant tagging at Rose Prairie, estimated mortality was similar in control, two-burn, and three-burn treatments. Forty-eight percent of plants in both the controls and two-burn treatment, and 46% in the three-burn treatment, were no longer present above ground and were assumed to be dead. At Fisher Butte significantly more individuals were not present above ground and assumed to be dead in the control treatment (51%) than in the two burn (39%) or three-burn treatments (40%). However, some tagged plants that were not encountered in one year were present the following year. Absence above ground for one year occurred in plants from control as well as burn treatments, but was most pronounced in the two-and three-burn treatments.

In 1988, seedling recruitment in control recruitment/density plots was almost three times higher at Rose Prairie than at Fisher Butte, 0.45 seedling/m^2 compared to 0.16 seedling/m^2 (Table 6). In 1996, no seedling recruitment was measured in controls at Rose Prairie and only 0.03 seedling/m^2 at Fisher Butte. With repeated burning, seedling recruitment responded more positively at Rose Prairie than at Fisher Butte. Recruitment was highest at Rose Prairie in 1993, where there were 2.9 seedlings/m^2 during the fourth year following two burns. By 1996, 0.12 seedling/m^2 was encountered in the two-burn treatment at Rose Prairie and 0.16 seedling/m^2 in the three-burn treatment; at Fisher Butte seedling recruitment was 0.01 seedling/m^2 in both burn treatments.

The total density of *L. bradshawii* at Rose Prairie and Fisher Butte in controls was similar in 1988 and 1996 (Table 7). The burn treatments increased *L. bradshawii* density at Rose Prairie, but not at Fisher Butte. The highest densities at Rose Prairie, 4.5 and 3.6 plants/m^2, were measured in 1993 and 1994, four and five years after two burns. By 1996, densities at Rose Prairie and Fisher Butte in the two- and three-burn treatments were similar to controls. The large difference in mean densities between controls and burn treatments at Rose Prairie in 1996 was not significant, because the data were highly variable.

Postburn seedlings

Seedlings were consistently a higher proportion of the total population at Rose Prairie than at Fisher Butte. During the eight-year period, seedlings constituted a mean of 23 ± 7% of plants in the controls at Rose Prairie and 15 ± 3% at Fisher Butte. Seedlings were the highest percentage of the total population at Rose Prairie during the five-year period following the two burns, when 49 ± 4% of the plants were seedlings; during the same period after two burns at Fisher Butte, seedlings composed 10 ± 2% of the individuals. Seedlings were the smallest percentage of the population at both sites in 1996 when they were 0, 6%, and 6% of controls, two-burn, and three-burn treatments at Rose Prairie, respectively; and 2%, 0.5%, and 0.5% of those treatments at Fisher Butte.

1997 measurements

The 1997 measurements of 50 randomly chosen *L. bradshawii* from each treatment at Rose Prairie indicated that foliar crown area in 1988 and 1997 controls and the 1997 two-burn treatment were similar, but that plants in the three-burn treatment were significantly smaller than the controls (Table 1). At Fisher Butte, *L. bradshawii* from 1988 controls and 1997 two- and three-burn treatments had similar crown areas, but 1997 controls were significantly smaller. Plant height was similar in all treatments at both sites. The number of umbellets was significantly higher in 1988 controls at both sites than in the 1997 controls or any of the 1997 burn treatments. The number of schizocarps was similar in 1988 and 1997 in all treatments at Rose Prairie; at Fisher Butte the 1988 controls and 1997 three-burn

TABLE 5. Schizocarps per plant of *Lomatium bradshawii* during 1988–1996 in unburned controls and after 1–3 burns at Rose Prairie and Fisher Butte (mean ± 1 SE).

	Rose Prairie				Fisher Butte			
Year	Control	One burn	Two burns	Three burns	Control	One burn	Two burns	Three burns
1988	5.3 ± 1.1[a]	⋯	⋯	⋯	6.9 ± 1[a]	⋯	⋯	⋯
1989	4 ± 1	9.2 ± 1.7	⋯	⋯	2.2 ± 1.3	7.4 ± 1.4	⋯	⋯
1990	3.3 ± 1.6	13 ± 1.8	9.4 ± 1.4	⋯	2.5 ± 0.9	17.9 ± 1.7	18 ± 2	⋯
1991	2.2 ± 0.8	5.6 ± 1.6	4.6 ± 0.9	⋯	2.2 ± 0.7	6.8 ± 1.2	10.5 ± 2.1	⋯
1992	4.6 ± 2	⋯	9.5 ± 1.1	4.9 ± 1.7	1.3 ± 0.4	⋯	7.1 ± 1.8	13.5 ± 2
1993	4.6 ± 1.1	⋯	8.8 ± 1.2	8.3 ± 1.2	1 ± 0.3	⋯	10 ± 1.8	10.7 ± 3
1994	2 ± 0.2	⋯	0.8 ± 0.7	2.5 ± 1	0.5 ± 0.1	⋯	5.1 ± 2	5.1 ± 2.8
1995	2.1 ± 1	⋯	2.5 ± 0.8	2.8 ± 1.7	0.6 ± 0.2	⋯	6.1 ± 2.1	6.7 ± 2
1996	1.8 ± 0.9[b]	⋯	1.9 ± 0.8[b]	2 ± 1.2[b]	0.6 ± 0.2[b]	⋯	0.7 ± 0.3[b]	0.3 ± 0.8[b]

Notes: The number of individuals measured at Rose Prairie varied from 150 in 1988 to 26 in 1996, and at Fisher Butte the number varied from 250 in 1988 to 49 in 1996. Schizocarps within a site with the same superscript letter are not significantly different (Tukey test, $P > 0.05$).

treatment had similar and significantly more schizocarps than the 1997 controls or 1997 two-burn treatment.

Climate, growth, and reproduction

Growth and reproduction of *L. bradshawii* was not consistently related to precipitation or air temperature at the nearest recording station (Eugene Federal Aviation Administration). The highly variable January–June precipitation during 1988–1996 did not correlate with the measured plant variables in either the control or burn treatments. For example, January–June precipitation in 1992 and 1994 was 11 cm lower than the 30-yr average, a 17% decrease (National Oceanic and Atmospheric Administration 1982). In 1992, crown areas of *L. bradshawii* in controls at Rose Prairie and in two-burn and three-burn treatments at both sites were the largest measured during this study. In 1994, with equally low precipitation for the January–June period, crown areas in controls and burn treatments at both sites were among the smallest measured.

During the three year period (1990–1992) when umbellet and schizocarp production were high and the three year period (1994–1996) when they were low in burn treatments at both sites, we could find no consistent pattern of precipitation or temperature as measured at the Eugene Federal Aviation Administration correlated with measured difference in reproduction.

Schizocarp production was not correlated with seedling establishment at either site. The year with the highest schizocarp production in burn treatments at both sites, 1990, was followed by low seedling recruitment in 1991. The highest seedling establishment at Rose Prairie, almost 3 individuals/m^2 in the two-burn treatment in 1993, was not preceded by unusually high schizocarp production in 1992, but may have been facilitated by the higher than normal precipitation. The 1993 January–June precipitation (Eugene Federal Aviation Administration) was 27 cm above the 30-yr mean. However, favorable conditions for recruitment at Rose Prairie did not enhance recruitment at Fisher Butte; in 1993 only 0.2 *L. bradshawii*/m^2 was added to the population at Fisher Butte. Seedling recruitment was not influenced by a reserve of *L. bradshawii* seed in the soil seed bank. Viable *L. bradshawii* seeds do not persist in the soil more than one year after they are shed; seeds either germinate or die (Kaye et al. 1994).

DISCUSSION

Research on the use of fire for restoration and management is in its infancy in many parts of the world where fire is often considered to be a difficult management tool (Bruns and Gilcher 1995). However, it is well understood that many plant species are adapted to disturbance (Pickett and White 1985), that wildfires tend to encourage more diverse plant communities

TABLE 6. *Lomatium bradshawii* recruitment (density of seedlings [no. seedlings/m^2]) during 1988–1996 in unburned controls and after 1–3 burns at Rose Prairie and Fisher Butte (mean ± 1 SE, $n = 6$).

	Rose Prairie				Fisher Butte			
Year	Control	One burn	Two burns	Three burns	Control	One burn	Two burns	Three burns
1988	0.4 ± 0.05	⋯	⋯	⋯	0.2 ± 0.04	⋯	⋯	⋯
1989	0.2 ± 0.04	0.2 ± 0.02	⋯	⋯	0.3 ± 0.05	0.3 ± 0.02	⋯	⋯
1990	0.2 ± 0.04	1.4 ± 0.3	1 ± 0.3	⋯	0.6 ± 0.04	0.3 ± 0.02	0.3 ± 0.02	⋯
1991	0.1 ± 0.01	0.8 ± 0.3	0.5 ± 0.2	⋯	0.3 ± 0.04	0.1 ± 0.02	0.1 ± 0.01	⋯
1992	0.2 ± 0.02	⋯	1.3 ± 0.2	0.6 ± 0.2	0.2 ± 0.03	⋯	0.06 ± 0.01	0.3 ± 0.01
1993	0.1 ± 0.01	⋯	2.9 ± 0.3	1.3 ± 0.1	0.5 ± 0.03	⋯	0.2 ± 1.8	0.2 ± 0.01
1994	1 ± 0.2	⋯	1.6 ± 0.3	0.8 ± 0.2	0.3 ± 0.03	⋯	0.2 ± 0.01	0.3 ± 0.1
1995	⋯	⋯	⋯	⋯	⋯	⋯	⋯	⋯
1996	0	⋯	0.4 ± 0.01	0.1 ± 0.01	0.03 ± 0.01	⋯	0.01 ± 0.01	0.01 ± 0.01

TABLE 7. Density of all *Lomatium bradshawii* (no. individuals/m^2) during 1988–1996 in unburned controls and after 1–3 burns at Rose Prairie and Fisher Butte (mean ± 1 SE, n = 6).

	Rose Prairie				Fisher Butte			
Year	Control	One burn	Two burns	Three burns	Control	One burn	Two burns	Three burns
1988	0.9 ± 0.1[a]	···	···	···	1.3 ± 0.1[a]	···	···	···
1989	1.0 ± 0.2	1.1 ± 0.2	···	···	1.8 ± 0.2	1.3 ± 0.3	···	···
1990	1.1 ± 0.1	2.4 ± 0.3	2.2 ± 0.3	···	2.4 ± 0.2	1.6 ± 0.3	1.6 ± 0.2	···
1991	0.5 ± 0.1	1.7 ± 0.1	1.2 ± 0.3	···	1.5 ± 0.2	1.1 ± 0.3	1.1 ± 0.2	···
1992	0.7 ± 0.2	···	2.8 ± 0.3	1.9 ± 0.3	1.4 ± 0.1	···	1.2 ± 0.2	1.5 ± 0.4
1993	1.0 ± 0.1	···	4.5 ± 0.4	3.1 ± 0.4	1.8 ± 0.2	···	1.7 ± 0.3	1.7 ± 0.3
1994	2.1 ± 0.2	···	3.6 ± 0.4	2.2 ± 0.3	2.2 ± 0.2	···	1.8 ± 0.3	1.4 ± 0.2
1995	···	···	···	···	···	···	···	···
1996	0.8 ± 0.2[a]	···	2.1 ± 0.4[a]	2.6 ± 0.7[a]	2.0 ± 0.2[a]	···	1.6 ± 0.3[a]	1.5 ± 0.5[a]

Note: Densities in treatments with the same superscript letter are not significantly different (Tukey test, $P > 0.05$).

(Weinstein and Shugart 1984), and that frequent prairie fires are necessary for the survival of short-lived (Loucks et al. 1985) or less common species (Kirkman and Sharitz 1994). As fire is more commonly used, the realization among managers is growing that regarding fire as either solely a positive or negative disturbance is too simplistic (Packard and Mutel 1997).

The need for fire management programs to protect and increase rare plant species is recognized around the world. The absence of fire since European settlement has reduced the presence of rare species in grassy balds in the Bunya Mountains of Queensland, Australia. Populations of *Bothriochloa bunyensis*, *Haloragis exaltata* subsp. *velutina*, and *Thesium australe* are threatened due to the transformation of grassland to forest or woodland in the absence of fire (Fensham and Fairfax 1996). In the southeastern United States, another rare species, *Helianthus eggertii*, is threatened due to the removal of fire from its limestone barrens habitat that has lead to increased competition and succession (Jones 1994).

The use of fire to promote rare species has shown positive, but often mixed, results. At Tiger Creek Preserve in Florida 13 rare plant species are being monitored at three levels of intensity after burning. Data for *Nolina brittoniana* are inconclusive as to the effects of fire on recruitment, but *Warea carteri* clearly shows that fire promotes population expansion (Menges and Gordon 1996). The requirement for low-competition habitat patches was also demonstrated for the endangered Californian species *Amsinckia grandiflora*. Burning significantly increased its survivorship, the number of reproductive individuals, and their size, but did not increase nutlet production (Pavlik et al. 1993).

However, managers need to exercise caution when prescribed fire is used to control invasive nonindigenous species, because the density and richness of native herbaceous species can also be negatively affected for as long as three years after a burn, as they were at sites in the prairie–forest border region of Illinois (Schwartz and Helm 1996). If rare species are present, the number of local extinctions may also increase after burning in prairies (Glenn and Collins 1992).

Repeated burning of wet prairies in the Willamette Valley was not detrimental to the endangered *L. bradshawii*. When both sites are considered together, *L. bradshawii* foliar crown area, height, umbellets, and number of schizocarps per plant initially responded positively to the burn treatments, but increases were not consistent across years following the treatments or consistently present at both sites.

The variable response of the same species to simular prescribed burns at different sites poses an additional problem for the manager who is charged with implementing a management plan to maintain and promote endangered species. Rose Prairie and Fisher Butte are only a few kilometers apart and are similar in topography and soils, but burning accentuated differences in size and reproductive capacity of *L. bradshawii* at the two research sites. The variable response of the same species to fire at different sites was reported for other prairies species (Hover and Bragg 1981, Glenn-Lewis et al. 1990, Svejcar 1990) and adds to the difficulty in evaluating the use of fire as a management tool.

The long history of fire in the Willamette Valley before Euro-American settlement is a strong indicator that native species are adapted to fire. Fall burns give a competitive advantage to early species, such as *L. bradshawii*, that have already produced seed and stored reserves for the next growing season, while disadvantaging late-flowering species that may not have completed their reproductive cycle (Howe 1994). Prescribed burns at Rose Prairie and Fisher Butte reduced the height of encroaching woody vegetation (Pendergrass et al. 1998), which benefits low-statured species, such as *L. bradshawii*, whose flowering rates decline rapidly with increasing shade (Wilson et al. 1993).

The scattered populations of *L. bradshawii* in the Willamette Valley occur in disjunct habitats that are now surrounded by agricultural lands. The probability of genetic exchange among these isolated populations is very low, and therefore they cannot be considered as metapopulations. Recovery strategies adapted for the recovery of endangered species such as *Cirsium pitcheri*, which has populations that interact spatially and temporally through pollen flow and seed dispersal

TABLE 8. Proposed experimental design to estimate optimal fire return interval for fall burning of areas containing *L. bradshawii* (P, preburn measurements; M, early summer measurements; Burn, fall burn).

Treatment interval	Year 1	2	3	4	5	6	7	8
1 yr	P, Burn	M, Burn	M, Burn	M, Burn	M, Burn	M, Burn	M, Burn	M
2 yr	P, Burn	M	M, Burn	M	M, Burn	M	M, Burn	M
3 yr	P, Burn	M	M	M, Burn	M	M	M, Burn	M
4 yr	P, Burn	M	M	M	M, Burn	M	M	M
6 yr	P, Burn	M	M	M	M	M	M	M
Control	P	M	M	M	M	M	M	M

(McEachern et al. 1994), are not applicable to *L. bradshawii*.

This research documented initial increases in crown area, umbellets, and schizocarps following fall burns, but the experimental design used did not allow evaluation of the optimal fire return interval for the long-term survival of *L. bradshawii*. Repeated burning also did not allow documentation of the long-term effects of just one or two burns. A more elaborate experimental design and monitoring the effects of a no-burn control and fire return intervals of from one to six years (Table 8) would provide a better data set to define an optimal fire cycle to maintain populations of this endangered species. Concordance between disturbance and the life history is essential for in situ restoration of endangered species (Pavlovic 1994). Disturbance size, intensity, and frequency, as well as the population structure of the target species, should be considered.

MANAGEMENT IMPLICATIONS

Our data set indicated that the growth and reproduction of *L. bradshawii* are strongly influenced by repeated burning, but the pattern and magnitude of the response varied between sites that were thought to be similar and were affected by variables not measured in this study. Research on the influence of microclimate, year-to-year variations in the duration of inundation, plant nutrient status, and the role of competition, herbivory, and pollinators might help explain year-to-year and site-to-site variations in the response of *L. bradshawii* to repeated burns.

Monitoring recovery for just one or two years after a burn may capture only the initial stimulation provided by burning and may foster unrealistically high expectations concerning the viability of an endangered plant population. The natural variability of plant populations at a site (Sharp et al. 1990) must also be considered in evaluating the effects of prescribed burns on a target species. Fire is only one of many interacting factors that influence plant populations and its use should be evaluated in terms of ecosystem processes and physiological requirements of target species.

When threatened or endangered species are present, managers are often overly cautious and hesitate to use a potentially damaging management tool such as fire. Gaining permission for and organization of prescribed burns can be difficult, and the outcome of a burn is not always predictable. Nevertheless, the absence of a recurring natural disturbance in systems where fire was present before the arrival of Euro-Americans is much more threatening to the continued presence of rare species than is the reintroduction of fire as a management tool.

ACKNOWLEDGMENTS

Support for this research was provided by the Oregon Field Office of The Nature Conservancy, U.S. Army Corps of Engineers, the Bureau of Land Management (BLM), Eugene District BLM fire crews, and the many technicians who helped with the field work. Thoughtful reviews by Lee Eddleman, Mark V. Wilson, and three anonymous reviewers were appreciated.

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