POPULATION TRENDS OF *LOMATIUM BRADSHAWII* BEFORE AND AFTER PRAIRIE FIRES: 1988-1997

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INTRODUCTION

Lomatium bradshawii (Bradshaw's lomatium) is listed by the U.S. Fish and Wildlife Service (USFWS), the Oregon Department of Agriculture (ODA), and the Oregon Natural Heritage Program (ONHP) as an endangered species (ONHP 1998). The conservation of the species is therefore of mutual concern to federal, state, and other agencies. Tools for management of the species and its habitat are needed to ensure long-term population sustainability in a fragmented landscape. A USFWS recovery plan for *L. bradshawii* (Parenti *et al.* 1993) targets population monitoring and enhancement as two actions needed to meet recovery objectives for the species. Population monitoring alone will not contribute to the species' recovery unless it is combined with rigorous analysis to identify populations at risk and evaluate enhancement techniques. The goal of this report is to evaluate the effects of fire on the population dynamics and trends of *L. bradshawii* at three federally-managed sites, from 1988 through 1997. Analyses of the effect of fire using transition matrix models (over the period of 1988-1993) have been reported previously and are update here.

Research into the pollination biology of the species, including interactions with insect floral-visitors that could be influenced by applications of pesticides in adjacent habitat, has been reported elsewhere (Kaye and Kirkland 1994).

Study species: Biology, range, and habitat

Lomatium bradshawii is an herbaceous plant from a perennial taproot. It reproduces by seed only, without vegetative spread. The species is pollinated by a diverse assemblage of insects, especially solitary bees and flies (Kaye 1992, Kaye and Kirkland 1994). Most known populations of *L. bradshawii* occur in habitat fragments in the Willamette Valley of western Oregon, except for one recently discovered in southwestern Washington. Approximately sixteen populations are known rangewide, varying in size from less than fifty to 25,000 individuals, and less than one to about 100 acres (Parenti *et al.*, 1993; recent reports). The largest concentration of reported sites is in the southwest Willamette Valley, west of Eugene, Oregon.

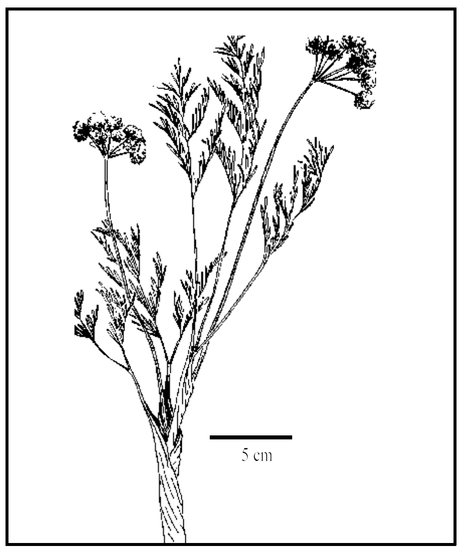

Figure 1. *Lomatium bradshawii* is an endangered species of Willamette Valley prairies. Drawing from Meinke (1981).

Lomatium bradshawii occurs in grasslands and prairies now represented as small parcels and fragments of formerly widespread habitat types. Two habitat types have been described for *L. bradshawii*. The first, and least common, is shallow, stream covered basalt found in Marion County and Linn County near the Santiam River. This habitat is characterized by thin soil that is seasonally saturated, and *L. bradshawii* occurs in vernal wetlands and along stream channels (Alverson, 1990). The second, more common, habitat type is valley bottom prairie that is often dominated by *Deschampsia cespitosa* (tufted hairgrass) and characterized by deep pluvial clays and a perched water table. The latter habitat type has been described repeatedly (e.g., Moir and Mika 1976, Kagan 1980, Alverson 1989, Connelly 1991, and Finley 1994), and typifies the sites included in our study. Both habitat types are part of the prairie-oak savannah ecosystem of western Oregon interior valleys that was widespread before fire suppression and settlement in the late 1800s (Habeck 1961, Johanesson *et al.* 1977).

Objectives

The objective of this report is to evaluate the trends in population growth and plant density at three sites as they relate to managed fire frequency. In particular, we aim to assess the effects of fire during fire management and several years post fire.

METHODS

The following field study-design for burning treatments was conceived of and implemented by Dr. Boone Kauffman, Kathy Pendergrass, and Karen Finley of Oregon State University, Department of Rangeland Resources (Connelly and Kauffman 1991a, 1991b, Finley and Kauffman 1992).

Study sites

Information from populations at three locations was used in our evaluation of the effects of fire on plant density and population viability. All sites were within the southwest part of the species' range, in an area west and north of Eugene, Oregon (Figure 2). Two sites, Fisher Butte and Rose Prairie, are on Army Corps of Engineers property and are included in the Fern Ridge Research Natural Area. The third site is managed by the Bureau of Land Management at the Long Tom Area of Critical Environmental Concern (ACEC). Throughout this report, these sites are referred to as Fisher Butte, Rose Prairie, and Long Tom, respectively.

Population trends

The effect of fire on population trends for *Lomatium bradshawii* was evaluated at Fisher Butte and Rose Prairie by sampling permanent monitoring plots annually in areas exposed to three burning treatments. Six life-history stages were identified and spread sheets were used to determine the total number of plants in each plot, and the number in each stage.

Burning treatments--Three burning treatments were conducted from 1988 through 1991 to determine the effects of fire on *Lomatium bradshawii* population viability. At Fisher Butte and Rose Prairie, these treatments were control (no burning--treatment 0), burned twice (1988 and 1991--treatment 1), and burned three times (1988, 1989, and 1991--treatment 2). At Long Tom, only one burning treatment was conducted over the whole population area due to the small size of the population and the urgent need to control invading woody vegetation. This site was burned three times in six years (1988-partial burn, 1990, and 1992). The population areas on ACOE land were divided into three more or less equal strips, roughly four hectares each at Fisher Butte and two hectares each at Rose prairie, and randomly assigned one of the three treatments prior to burning.

Sampling monitoring plots--Established *Lomatium bradshawii* plants were selected throughout the population areas and tagged with metal wires. The individuals were numbered, and a subset were randomly selected to serve as center points for circular plots in which all *L. bradshawii* individuals were monitored at least once per year, beginning in 1988 at Fisher Butte and Rose Prairie, and 1990 at Long Tom. Monitoring was continued through 1997 at all sites. No data were gathered at Rose Prairie and Fisher Butte in 1996, however. These plots were 2-m radius at Fisher Butte and Rose Prairie, and 1-m radius at Long Tom. The plot numbers are listed here for reference to data sheets and other reports. Therefore, the population of inference for this study included all *L. bradshawii* plants within 1 or 2 meters (depending on the site) of all tagged plants.

Fisher Butte

Treatment 0: plots 367, 374, 376, 380, 386, 753, 763, 775, 784, 800
Treatment 1: plots 171, 184, 187, 190, 196, 305, 306, 311, 325, 330
Treatment 2: plots 215, 218, 227, 238, 245, 259, 264, 269, 278, 292

Rose Prairie

Treatment 0: plots 5, 12, 22, 134
Treatment 1: plots 36, 39, 46, 144, 145, 149, 236, 707
Treatment 2: plots 56, 77, 84, 95, 213

Long Tom

Treatment 3: plots 802, 813, 816, 834, 844, 873, 879, 883, 895, 899

When monitored, the status of each plant rooted within the circular plot was recorded directly onto a scale map of the plot. Symbols were used to show the location of each plant and denote its status as follows: vegetative with one leaf, vegetative with two leaves, vegetative with 3 or more leaves, reproductive with one umbel (flower cluster), reproductive with two umbels, and reproductive with three or more umbels. Reproductive plants were segregated by umbel number because one-umbel plants rarely produce seed, while two-umbel plants produce seed on the second umbel, and three umbel plants may produce many seeds (see Kaye and Kirkland, 1994 for a description of the breeding system). We combined vegetative plants with one or two leaves into a single stage because field observations indicated that plants with one leaf often produced a second leaf later in the year, and therefore leaf number of small plants may be a function of sampling date, not plant vigor. All first-year vegetative plants with one or two leaves were considered seedlings; larger plants that appeared without observation in a previous year were not considered seedlings because they were too large. All vegetative plants with one leaf were considered seedlings in 1988. Seed production and umbel number were recorded annually for all tagged plants, including those at the center of each plot and elsewhere in the population area. Occasionally, plants near the edge of the plot were mapped just outside or inside the perimeter, to track plants that shifted position somewhat each year.

Calculation of density--Data from the plot maps were transcribed into a spreadsheet for summary and analysis. We used spread-sheet and data-base computer software to calculate the density of each stage within each treatment each year, and to display trends of vegetative plants, reproductive plants, and all plants graphically.

Statistical analysis: Fisher Butte and Rose Prairie--We used SAS General Linear Model to test for a burning treatment effect on reproductive plant and total plant density between 1988 and 1993, and between 1988 and 1997. The last burn at this site was in 1991, so 1993 represents two-years post-fire (and is the last year of data considered in previous matrix modeling analyses), and 1997 represents the most recent data available. In this analysis, we used site (Rose Prairie and Fisher Butte) as a blocking factor to control for site to site variability. Prior to analysis, we selected a type I error rate (α) of 0.1. Also, to compare treatments, we used Fisher's Protected LSD. Data from all plots for each treatment combinations were averaged prior to analysis to avoid pseudo-replication. No transformations of the data were necessary to meet the assumptions of normality and equal variances required by ANOVA.

Statistical analysis: Long Tom ACEC--To determine if the population at Long Tom ACEC had increased in density from 1990 to 1996, we performed a paired t-test (one-tailed, α=0.1). Data on plant density at Long Tom were not available prior to the 1990 sample. We performed this test for reproductive plant and total plant density.

Updated population viability analyses

Population viability analyses have been conducted for *Lomatium bradshawii* and results for the period 1988 through 1993 have been presented in previous reports (Kaye et al. 1994, Caswell and Kaye 1996). Data since 1993 have accumulated since that time, and these observations were used to document the growth rate and viability of *Lomatium* populations in the treatment areas in post-fire years. We used data from 1992-93, 1993-94, and 1996-97 to construct mean matrices for each treatment at each site. Note: no data were recorded from these plots in 1995, so no transition matrices can be derived for 1994-95 or 1995-96. We used RAMAS/stage to calculate lambda (λ, the population growth rate), extinction probability, and mean extinction time for each treatment at both sites. The methods of this approach have been described in previous reports (e.g., Kaye et al. 1994).

RESULTS

Population trends

Fisher Butte and Rose Prairie--Trends in population density at Fisher Butte and Rose Prairie are displayed in Figures 2-7. In general, it appears that within two years of a fire populations showed an increase in density of vegetative, reproductive, and total plants. For example, at Rose Prairie, two years after the 1988 burn, densities of reproductive, vegetative and total plants increased dramatically, while density in the unburned plots decline (Figures 5-7). Two years after the 1991 burn, the same pattern was repeated, except densities in the unburned plots also increased, but less substantially. At Fisher Butte, this pattern is more difficult to discern, and it is not clear from the graphs (Figures 2-4) that fire improved population density. Densities in the two burned treatments (burned in 1988 and 1991, and burned in 1988, 1989, and 1991) show trends more similar to each other than to the unburned controls. At Rose Prairie, for instance, average density in the burned plots generally followed the same highs and lows, while in the unburned plots average density seemed to follow an independent trajectory. Note, however, that 1991 appeared to be a universally poor year, with plants in all categories at both sites dropping in density in that year. Also, increases in density in the burned treatments appeared to last only a few years, so that by 1996 the gains were either less substantial or no longer present.

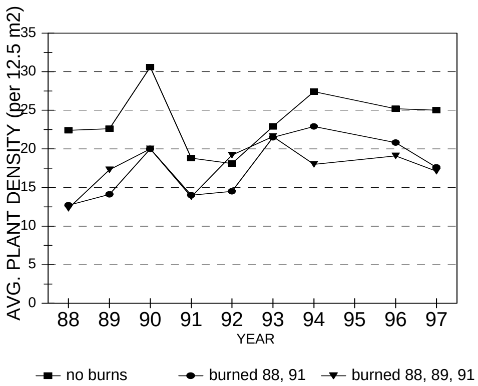

Figure 2. Fisher Butte: changes in density of all plants over time, 1988-1997.

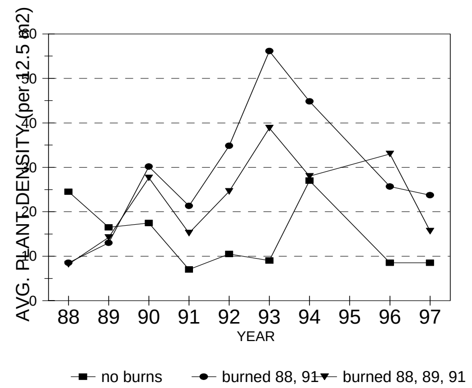

Figure 5. Rose Prairie: changes in density of all plants over time, 1988-1997.

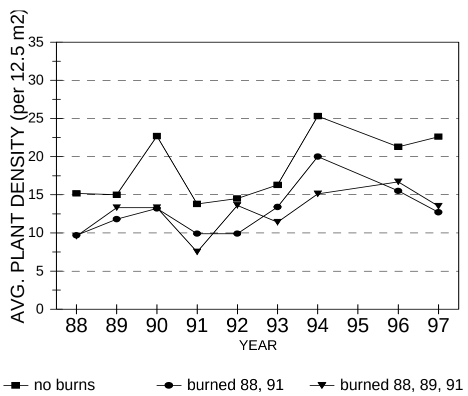

Figure 3. Fisher Butte: changes in density of vegetative plants over time, 1988-1997.

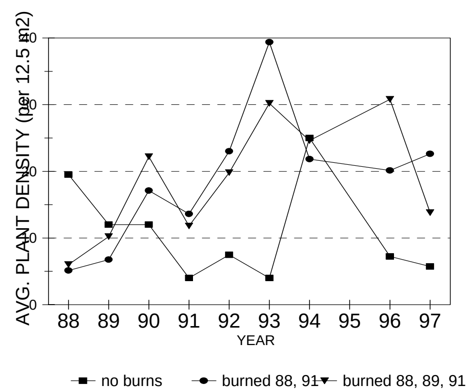

Figure 6. Rose Prairie: changes in density of vegetative plants over time, 1988-1997.

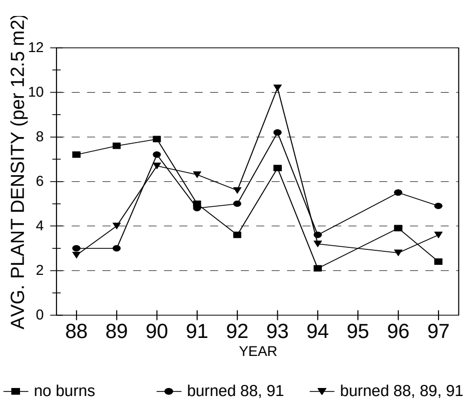

Figure 4. Fisher Butte: changes in density of reproductive plants over time, 1988-1997.

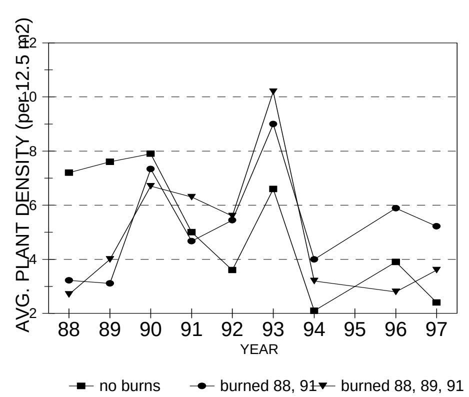

Figure 7. Rose Prairie: changes in density of reproductive plants over time, 1988-1997.

Statistical analyses--Fire had a significant effect on changes in reproductive plant density between 1988 and 1993 (*P*=0.012, Table 1), but this effect did not persist through 1997 (*P*=0.27). No significant effect from burning was detected for total plant density between 1988-93 (*P*=0.43) or 1988-97 (*P*=0.51, Table 1), but the effect of burning appeared to show a positive trend.

Average density of all plants and reproductive plants in unburned plots declined or remained unchanged between 1988 and 1993, but increased in both burned treatments (Figure 8). This difference was statistically significant for reproductive plants only (see above & Table 1). Burning twice or three times significantly increased reproductive plant density (Figure 8), but there was no significant difference between the two burning treatments.

Between 1988 and 1997 the same general pattern persisted, with plant densities declining in the unburned treatments and increasing in the burned treatments (Figure 9). However, this pattern was not statistically significant (Table 1).

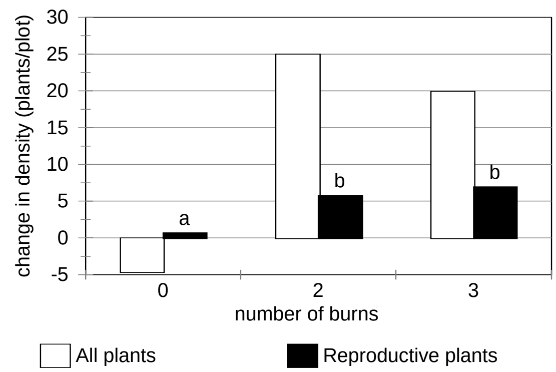

Figure 8. Change in average plant density (plants per 12 m^2) between 1988-93 in unburned plots (0), plots burned in 1988 and 1991 (2), and plots burned in 1988, 1989, and 1991 (3). Fire had a significant effect on reproductive plant density (P=0.012). Bars with the same letter were not significantly different (Fisher's protected LSD).

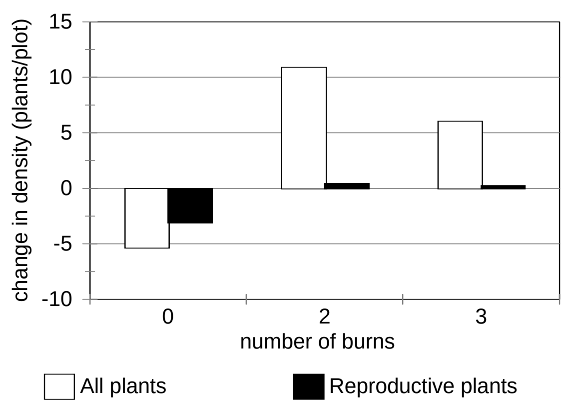

Figure 9. Change in average plant density (plants per 12 m^2) between 1988-97 in unburned plots (0), plots burned in 1988 and 1991 (2), and plots burned in 1988, 1989, and 1991 (3). Effects of fire treatements were not significant (P>0.27).

Table 1. ANOVA of fire treatment effects on *Lomatium bradshawii* total and reproductive plant density at Fisher Butte and Rose Prairie (blocks), 1988 vs. 1993 and 1988 vs. 1997.

1988 vs. 1993, density of total plants

Source	DF	Sum of Squares	F Value	Pr > F
Model	3	1152.55000000	1.00	0.5345
Error	2	766.26333333		
Corrected Total	5	1918.81333333		
	R-Square	C.V.		TOT8893 Mean
	0.600658	145.7103		13.4333333
Source	DF	Type I SS	F Value	Pr > F
BLOCK	1	146.02666667	0.38	0.5999
TRTMNT	**2**	**1006.52333333**	**1.31**	**0.4322**

1988 vs. 1993, density of reproductive plants

Source	DF	Sum of Squares	F Value	Pr > F
Model	3	45.14745000	58.03	0.0170
Error	2	0.51863333		
Corrected Total	5	45.66608333		
	R-Square	C.V.		REP8893 Mean
	0.988643	11.38796		4.47166667
Source	DF	Type I SS	F Value	Pr > F
BLOCK	1	1.06681667	4.11	0.1797
TRTMNT	**2**	**44.08063333**	**84.99**	**0.0116****

1988 vs. 1997, density of total plants

Source	DF	Sum of Squares	F Value	Pr > F
Model	3	286.84040000	0.68	0.6423
Error	2	282.43053333		
Corrected Total	5	569.27093333		
	R-Square	C.V.		TOT8897 Mean
	0.503873	305.7479		3.88666667
Source	DF	Type I SS	F Value	Pr > F
BLOCK	1	10.03626667	0.07	0.8148
TRTMNT	**2**	**276.80413333**	**0.98**	**0.5050**

1988 vs. 1997, density of reproductive plants

Source	DF	Sum of Squares	F Value	Pr > F
Model	3	16.53670000	1.98	0.3527
Error	2	5.56230000		
Corrected Total	5	22.09900000		
	R-Square	C.V.		REP8897 Mean
	0.748301	-213.8049		-0.78000000
Source	DF	Type I SS	F Value	Pr > F
BLOCK	1	1.38240000	0.50	0.5538
TRTMNT	**2**	**15.15430000**	**2.72**	**0.2685**

** significant at the α=0.05 level.

Long Tom ACEC--The average density of plants at Long Tom ACEC started in 1990 at about 17 per plot (plot area at Long Tom was 3.1 m^2), dropped to 10 in 1991, then climbed steadily to 31 in 1994, only to drop each year after to 13 in 1997 (Figure 8). The pattern of vegetative plants followed the same general trend over these years. Reproductive plants behaved similarly through 1993 (the year after the last burn), then declined steadily through 1996. These trends are not easily correlated with fire effects: in 1991, the year after a fire, population density declined, but in 1993, also a year following a fire, the population increased (with the exception of reproductive plants). This may be because 1991 was a poor year due to climatic conditions that swamped the positive effects of prairie burning. For both total plants and vegetative plants, two years post-fire resulted in either a recovery (1990 to 1992) or increase (1992 to 1994) of density.

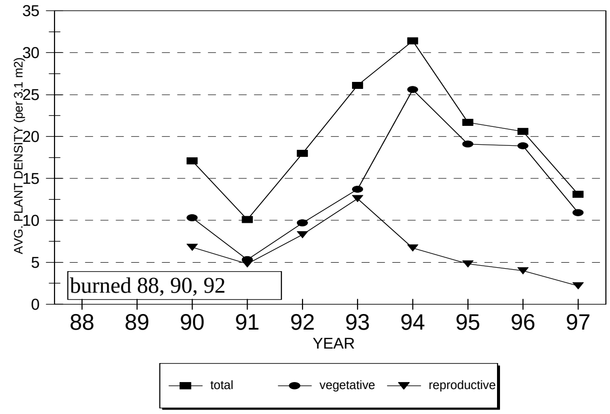

Figure 8. Long Tom ACEC: changes in density of vegetative, reproductive, and total plants over time, 1988-1997.

Statistical comparisons of plant density in 1990 and 1997 indicate that there has been no overall increase in total plant or reproductive plant density (Table 2) at the end of this study, despite repeated burning. Average total plant density decreased from 17 to13, but this change was not significant (P=0.166). In contrast, average reproductive plant density actually declined over this period (P=0.005) from nearly 7 individuals per plot in 1990 to about 2 in 1997 (Table 2).

Table 2. Paired t-tests of 1990 and 1997 plant density for total plants and reproductive plants at Long Tom ACEC. Total density did not change significantly over the course of the study, but density of reproductive plants declined.

	Total 90	*Total 97*
Mean density	17.1	13.1
Variance	94.1	90.989
Observations	10	10
Pearson Correlation	0.619	
Pooled Variance	92.54	
Hypothesized Mean Difference	0	
df	9	
t	1.507	
P(T<=t) one-tail	0.083	
t Critical one-tail	1.833	
P(T<=t) two-tail	**0.166**	
t Critical two-tail	2.262	

t-Test: Paired Two-Sample for Means

	Repro 90	*Repro 97*
Mean density	6.8	2.2
Variance	16.622	5.067
Observations	10	10
Pearson Correlation	0.332	
Pooled Variance	10.844	
Hypothesized Mean Difference	0	
df	9	
t	3.68	
P(T<=t) one-tail	0.0025	
t Critical one-tail	1.833	
P(T<=t) two-tail	**0.005**	
t Critical two-tail	2.262	

Updated Population Viability Analyses

Rose Prairie and Fisher Butte--In the post-fire environment, the positive effects of fire on population growth rate and extinction dynamics found earlier (Kaye et al 1994, Caswell and Kaye 1996) were no longer detectable in the study populations. All of the populations had low growth rates ($\lambda<1.0$), and all had high probabilities of extinction within 100 years (Table 3). Growth rates ranged from a high of 0.964 in unburned plots to a low of 0.803 in plots burned three times at Rose Prairie. At Fisher Butte, the highest growth rate, 0.918, was observed in the twice-burned treatment, while the lowest, 0.828, occurred in the three-burn area (Table 3). No pattern associated with past number of burns was evident. These low growth rates and high extinction probabilities (all>0.8) were associated with average extinction times ranging from 22 years to 65 years, suggesting that extinction is not imminent and that management efforts, such as resumed burning, could reverse the current downward trends.

Long Tom ACEC--At Long Tom, the population growth rate from 1990 through 1997 was only

0.890, and mean extinction time was 42 years. Extinction is virtually certain within 100 years at current declines (extinction probability equaled 1.0 (95% CI=0.97-1.0), despite management actions at the site to date.

Table 3. Post fire population dynamics in burning treatment plots at Rose Prairie and Fisher Butte, 1992-97. All of these populations have λ<1.0, indicating that they are projected to decline.

Site/ prior treatment	λ	Extinction probability (95% confidence interval)	time to extinction
Rose Prairie			
no burns	0.964	0.9 (0.87-0.93)	65 yrs
2 burns	0.898	0.97 (0.94-1.0)	56 yrs
3 burns	0.803	1.0 (0.96-1.0)	22 yrs
Fisher Butte			
no burns	0.904	1.0 (0.97-1.0)	39 yrs
2 burns	0.918	1.0 (0.97-1.0)	34 yrs
3 burns	0.828	1.0 (0.97-1.0)	23 yrs

DISCUSSION

Density of reproductive *Lomatium bradshawii* individuals in western Oregon prairies increased in the presence of fire. The abundance of reproductive plants responded positively to burning (either twice or three times) between 1988 and 1997. Although total density (reproductive and vegetative plants combined) followed the same pattern as reproductive plants alone (i.e., density declined without burning and increased in the presence of fire), this response was not statistically significant. These results apply to Fisher Butte and Rose Prairie.

At the Long Tom ACEC, only one fire treatment was applied between 1988 and 1997. Therefore, no direct comparisons regarding the effect of fire are possible at that location. Also, the site is partially wooded with *Fraxinus latifolia* (Oregon ash), making it a different type of habitat than the open wet-prairies typical for *Lomatium bradshawii*. From 1990 to 1997, this population varied substantially in density of reproductive, vegetative and total plants. Total plant density, for example, declined from 1990 to 1991, then increased through 1994, and fell again through 1997. This pattern appears to be the same as seen at Fisher Butte and Rose Prairie in the control plots, suggesting that the population dynamics of *L. bradshawii* in the *presence* of fire at Long Tom are similar to dynamics at these other sites in the *absence* of fire. Burning may not be having a substantial impact on *L. bradshawii* at the Long Tom ACEC population, or its effect is short-lived and difficult to detect.

The results from Rose Prairie and Fisher Butte presented here are in general agreement with prior transition matrix model analyses which indicate that fire improves population growth rate and chance of survival for *Lomatium bradshawii* (Kaye et al. 1994; Caswell and Kaye 1996). They also coincide with the results of previous studies that indicate fire increases crown size, umbel production, and seed output of this species (Connelly and Kauffman 1991b, Finley and Kauffman 1992, and Wilson et al. 1993, Pendergrass et al. 1999). The congruence of these very different approaches to evaluating the impact of fire on *L. bradshawii* strengthens the conclusion that prairie burning is an effective tool for maintaining populations of this endangered species.

The positive effects of fire, however, appear to be temporary. Within a few years of a burn, the populations respond positively. But our analyses of plant density and population growth rate several years after burning suggest that fire improves these populations for only one to three years, then the effect dissipates. For example, density increased in burned plots between 1988 and 1993, but there was no benefit from these burns by 1997, six years after the last burn. Likewise, population growth rate responded well during the period averaged from 1988 through 1993. When data from 1992 through 1997 were examined, however, past burning had no positive residual effects. In fact, all populations were projected to decline given observed dynamics from 1992 through 1997. Burning must be frequently applied to populations of *Lomatium bradshawii* in order to benefit the species.

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