AN ABSTRACT OF THE THESIS OF

Aaron D. Drew for the degree of Master of Science in Wildlife Science presented on December 19, 2000. Title: Effects of Livestock Grazing and Small Mammal Populations on Endangered Bradshaw's Desert Parsley (*Lomatium bradshawii*) at Oak Creek, Willamette Valley, Oregon.

Abstract approved: Redacted for privacy
W. Daniel Edge

I evaluated the response of the federally listed endangered plant species Bradshaw's desert parsley (*Lomatium bradshawii*) to livestock grazing and small mammal depredation at Oak Creek, Linn County, Oregon, 1997-1998. I established six study blocks (three each in wooded and herbaceous pastures) with plots in each block randomly assigned to one of four intensities of livestock grazing based on biomass remaining after grazing (no grazing [1,746 kg/ha], high biomass [969 kg/ha], moderate biomass [670 kg/ha], and light biomass [318 kg/ha]). Small mammals were live-trapped in each of the study blocks pre and post application of the livestock grazing treatments. I mapped and measured 2,807 Bradshaw's desert parsley plants (n = 1,366 in the wooded and n = 1,441 in the herbaceous pastures) over the two year period to determine changes in schizocarp production, morphological structure (conical surface area and height), population composition (plant stage), survival, emergence of new plants, and effects of small mammal herbivory pre and post application of livestock grazing. Grazing reductions in standing crop biomass appeared to have a positive effect on emergence of new Bradshaw's desert parsley plants, while having no detectible effect on total plant density or survival. Differences in total plant density, survival, schizocarp production, morphological structure, and population composition were related to pasture type.

residual standing crop biomass may reduce small mammal use of an area, and thus may serve to reduce the impacts of small mammal herbivory. I found differences in small mammal depredation of Bradshaw's desert parsley between pastures and among livestock grazing treatments. Standing crop biomass and peak vole abundance were significant covariates in plant depredation rates. Livestock grazing initially appears to have increased Bradshaw's desert parsley plant emergence and density of several plant stages, but did not enhance survival at the Oak Creek site. I examined only the initial response of Bradshaw's desert parsley to livestock grazing; long-term impacts of this management practice are unknown. Direct comparisons between livestock grazing and other forms of vegetation management, such as mowing and prescribed burning, currently do not exist for Bradshaw's desert parsley and warrant further investigation.

Effects of Livestock Grazing and Small Mammal Populations on Endangered Bradshaw's Desert Parsley (*Lomatium bradshawii*) at Oak Creek, Willamette Valley, Oregon.

by
Aaron D. Drew

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

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Aaron D. Drew, Author

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I would especially like to thank my family and close friends for all their love, support, and words of encouragement throughout this entire process, which really seemed to come at all the right times when I needed to hear them the most.

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This thesis is dedicated in loving memory to

N B. Drew, E. "Pearl" Drew, Frank P. Drew, and Jean Mortensen.

Some very special people I miss very much and to whom I owe a lot of gratitude

for making me the person I am today.

Effects of Livestock Grazing and Small Mammal Populations on Endangered Bradshaw's Desert Parsley (*Lomatium bradshawii*) at Oak Creek, Willamette Valley, Oregon.

INTRODUCTION

Bradshaw's desert parsley (*Lomatium bradshawii*) is a member of the family Umbelliferae (or Apiaceae). Eastman (1990) describes the plant as 20 to 50 cm tall, glabrous, with basal leaves divided into fine, almost thread-like linear segments. Pale yellow flowers are arranged in a flat-topped umbel containing male (stamens only) and hermaphroditic (stamens and pistol) inflorescenses (Greenlee and Kaye 1995). Bradshaw's desert parsley is a taprooted herbaceous perennial that blooms from April through May (Eastman 1990, Kaye and Kirkland 1994, Greenlee and Kaye 1995). Schizocarps, or fruits, are present in late May to early July and are passively dispersed (Kagan 1980, Greenlee and Kaye 1995). Schizocarps (each containing two seeds at maturity) are oblong, 8 to 11 mm in length, thick-winged along the margin, and have thread-like ribs on the dorsal surface (Kagan 1980, Eastman 1990). The species is reliant on seed production for propagation and is not known to reproduce vegetatively (Kaye and Kirkland 1994).

Bradshaw's desert parsley is endemic to western Oregon and Washington, and historically was likely widespread in the wet, seasonally-flooded native prairies of the Willamette Valley. Bradshaw's desert parsley occurs now only at 17 known sites (Greenlee and Kaye 1995) in Marion, Lane, Linn, and Benton counties, Oregon, and two recently discovered populations in Clark County, Washington. All of these sites are apparently remnants of large, historic populations, which were fragmented by farming, flooding, and urban development (Eastman 1990, U. S. Fish and Wildlife Service

[USFWS] 1993). However, the actual historic distribution is unknown because the species was never widely collected (USFWS 1993). Greenlee and Kaye (1995) describe Bradshaw's desert parsley as occurring in two distinct habitat types, the least common being stream-covered basalt areas near the Santiam River. Most populations of Bradshaw's desert parsley occur on seasonally-saturated wet prairie remnants of the southern Willamette Valley (Greenlee and Kaye 1995).

Habitat loss is considered the major threat to the Bradshaw's desert parsley; approximately 0.1 % of the Willamette Valley prairie remains today (Ingersoll and Wilson 1991, USFWS 1993, Noss et al. 1995, Pendergrass et al. 1999). Isolated individual plants can also be found in remnant habitats along roadside ditches or bare-soil areas by dikes (USFWS 1993). Loss and fragmentation of habitat result in reduced population sizes, which increases the probability of extinction by demographic and environmental stochasticity (Fahrig 1997).

Bradshaw's desert parsley was federally listed as endangered in September 1988 (Code of Federal Regulations [CFR-50; 333-53 FR 38451] 1998). The status of individual populations throughout the Willamette Valley varies from site to site (Fig. 1, Table 1). Currently, the greatest threat to a majority of the remaining Bradshaw's desert parsley populations appears to be plant invasion, particularly woody species, which shade-out the Bradshaw's desert parsley and may compete for soil nutrients and moisture (Meinke 1980, Willoughby et al. 1992, USFWS 1993, Gisler 1994, Robinson 1995). Due to the cessation of disturbances such as fire, grazing, and major flood events, other plant species (native and introduced) are out competing Bradshaw's desert parsley in its remaining habitats (Kagan 1980, Meinke 1980, USFWS 1993).

Grazing may be one alternative for retaining the earlier seral components of seasonal wetland plant communities by retarding the progression of woody species and reducing competition from other plant species. Well-timed and carefully monitored livestock grazing may also serve as a management tool to reduce small mammal depredation on Bradshaw's desert parsley. By removing residual vegetation, small mammals' use of an area may decrease, thus promoting increased survival of Bradshaw's desert parsley. Greenly and Kaye (1995) documented a severe decline (from 22,795 [± 8,365] plants in 1993 to 3,020 [± 1,291] plants in 1994) in the Buford Park population of Bradshaw's desert parsley. Cattle were removed from Buford Park when Bradshaw's desert parsley was first discovered on the site in 1990, and Greenlee and Kaye (1995) observed substantial amounts of residual cover (thatch build up) once cattle were removed. Greenlee and Kaye (1995) hypothesized that the residual cover improved rodent habitat, increasing herbivory, which subsequently caused a decline in the plant population. Others have suggested that thick layers of thatch encourage depredation on Bradshaw's desert parsley by voles (USFWS 1993, Gisler 1994, Robinson 1995). Despite the negative impacts of livestock grazing noted for other *Lomatium* species (Willoughby 1987), populations of Bradshaw's desert parsley have been maintained in the Willamette Valley, Oregon and southern Washington by livestock grazing in the absence of fire (Kaye 1992). Greenlee and Kaye (1995) suggest that fire and carefully timed grazing may reduce small mammal herbivory on Bradshaw's desert parsley populations.

The life history and habitat ecology of Bradshaw's desert parsley has been the focus of previous studies (Kagan 1980, Kaye 1992, USFWS 1993). However, little is known regarding the effects of different land management practices on Bradshaw's desert parsley, specifically the impacts of livestock grazing. While livestock grazing has been viewed as largely detrimental to Bradshaw's desert parsley (as well as to other threatened or endangered plant populations), grazing may play a beneficial role in reducing competing vegetation and accumulation of thatch, and by providing a source of mechanical disturbance.

The first objective of this study was to determine the first-year response of Bradshaw's desert parsley (post-schizocarp dispersal) to various livestock grazing intensities resulting in different levels of residual standing crop biomass (control or no grazing [1,746 kg/ha], high biomass [969 kg/ha], moderate biomass [670 kg/ha], and light biomass [318 kg/ha]) at Oak Creek. I postulated the following hypotheses.

H_o: Bradshaw's desert parsley vigor (schizocarp yield, conical surface area, and plant height), density, survival, and emergence of new plants would not differ among levels of residual standing crop biomass (control, high, moderate, and light).

H_a: Bradshaw's desert parsley vigor, density, survival, and emergence of new plants differs among levels of residual standing crop biomass (control, high, moderate, and light).

I predicted that Bradshaw's desert parsley at the Oak Creek site would exhibit a favorable response to reduced levels of residual standing crop biomass compared to the controls by increases in plant vigor, density, survival, and emergence of new plants.

However, I predicted that heavy livestock grazing intensity may negatively affect plant vigor, density, survival, and emergence of new plants, at least for the first year following the treatment. I expected no significant changes in plant vigor, density, survival, and emergence of new plants in the control units between years.

The second objective of the study was to determine if small mammal abundance affect the response of Bradshaw's desert parsley to livestock grazing. For this second objective I formulated the following hypotheses.

H_o: Small mammal abundance among experimental blocks would not be a significant covariate in analysis of the effects of reduced levels of residual standing crop biomass on Bradshaw's desert parsley vigor, density, survival, and emergence of new plants.

H_a: Small mammal abundance would be a significant covariate in analysis the effects of reduced levels of residual standing crop biomass effects on plant vigor, density, survival, and emergence of new plants.

I predicted that small mammal abundance would not be a significant covariate in the analysis of livestock grazing effects on Bradshaw's desert parsley; having no additive effect on Bradshaw's desert parsley vigor, density, survival, and emergence of new plants. I predicted that small mammal abundance and areas used would be evenly distributed across the study site and would not be significantly affected by the removal of cover on a small scale, thus having no additive affect in the analysis.

Figure 1. Map of the known distribution of known Bradshaw's desert parsley populations (red circles) in the Willamette Valley, Oregon and southern Washington, 2000. Site numbers correspond to populations listed in Table 1.

Table 1. Population estimates of known Bradshaw's desert parsley locations for the Willamette Valley, Oregon and southern Washington (LaCamas). Plant numbers for each site represent conservative estimates of the actual populations for each location from USFWS 1993; the Oak Creek (OR) and LaCamas (WA) population estimates from 1994 and 1995, respectively). Site numbers correspond to numbered locations on Figure 1.

	Site Name	Ownership	Habitat Area (ha)	No. of Plants
1.	Kingston Meadows	Private	2.0 +	5,000
2.	Sublimity	Private	0.8	250
3.	Jackson-Frazier Wetlands	Benton County, Corvallis	6.1	350
4.	Muddy Creek	Private	2.0	50
5.	W. L. Finley National Wildlife Refuge	U. S. Fish and Wildlife Service	8.1 +	2,500
6.	Long Tom Area of Critical Environmental Concern	Bureau of Land Management	6.9	1,300
7.	Fern Ridge Lake	Army Corp of Engineers	40.5	10,000
8.	West Eugene Wetlands (including Willow Creek)	The Nature Conservancy, private, and Bureau of Land Management	16.2	25,000
9.	Veneta	City of Veneta	2.0	500
10.	Amazon Park	City of Eugene	2.8	750
11.	Coyote Creek (upstream) Spencer Creek	Private	2.0	200
12.	Springfield Drive Inn	Private	2.0	100
13.	Buford Park	Lane County	2.0	5,000
14.	Short Mountain-Camas Swale	Lane County and private	40.5	1,250
15.	Oak Creek	U. S. Fish and Wildlife Service	47.5	200,000
16.	LaCamas	Private	8.1	70,411
17.	Green Mountain Resort	Private, county easement pending	9.0	2,500

STUDY AREA

This study was conducted on Oak Creek approximately 1 km northwest of Sodaville, Linn County, Oregon. The site is a 48 ha ranch purchased by the USFWS, Willamette Valley National Wildlife Refuge Complex in December, 1996. The Oak Creek site is in the eastern most portion of the Willamette Valley at an elevation of 104 m. On 18 April 1994, Bradshaw's desert parsley was discovered on the property (Gisler 1994). A 1994 survey estimated 200,000 plants in this population, the largest known concentration of Bradshaw's desert parsley. The majority of these plants occur in two pastures (Units A and B) (Fig. 2). In contrast, 1993 estimates of 14 other Bradshaw's desert parsley populations in Lane, Benton, and Marion counties, totaled 52,250 plants on 134 ha (USFWS 1993). The high plant density and size of the Oak Creek site provided a unique opportunity to evaluate the impacts of livestock grazing on Bradshaw's desert parsley.

The property is characterized by seasonally flooded Bashaw silty clay, Courtney gravelly silt clay loam, Clackamas Variant silt loam, and Pengra silt loam soil types (U. S. Department of Agriculture [USDA] 1987). These soils are generally inundated with standing water from December through April, and are dry and cracked by July. While there is not a definite boundary between areas, the herbaceous pastures (Units B and C, Fig. 2) generally occur on the Bashaw silty clay soil type, and the wooded pastures (Units A and D, Fig. 2) occur on Courtney gravelly silt clay loam. The northern three pastures are comprised of Clackamas Variant and Pengra soil types. Soils in the herbaceous pasture (Bashaw silty clay) consist of deep poorly drained clay soils; characteristic of soils found in concave areas on flood planes, alluvial terraces, and alluvial fans (USDA 1987). Within the top 91 cm of the soil profile, Bashaw soils are predominantly silty clay to firm clay with pH ranging from 5.6 to 5.8 (USDA 1987). Fine roots and tuber pores are common within 91 cm of the soil surface (USDA 1987). As soil depth increases to 178 cm, clay layers become more firmly compact and pH becomes more neutral (pH 6.4 to 7.0); fine root and tuber pores become less common (USDA 1987). The upper 102 cm in the Bashaw Series is comprised of greater than 60% clay (USDA 1987). In contrast, the wooded pasture soils (Courtney Series) are predominantly poorly drained gravely silty clay loam soils. Courtney soils occur in slightly concave areas on low alluvial stream terraces (USDA 1987). The upper 122 cm of the Courtney Series consists of 20 to 30% gravel with pH ranging from 5.6 to 5.8 (USDA 1987). Fine root and tuber pores are common to a depth of 84 cm (USDA 1987). Gravely clay loam becomes more prominent as soil depth increases; consisting of 50 to 70% gravel (USDA 1987). Soil pH remains at 5.8 up to a depth of 152 cm within the Courtney Series (USDA 1987). Course tuber pores are common up to a depth of 121 cm (USDA 1987). Depth to bedrock in both the Bashaw and Courtney soils is more than 152 cm (USDA 1987). Ground water levels in the herbaceous pasture (Bashaw Series) tend to fluctuate less frequently throughout the year than in the wooded pasture (Courtney Series) (data collection in process).

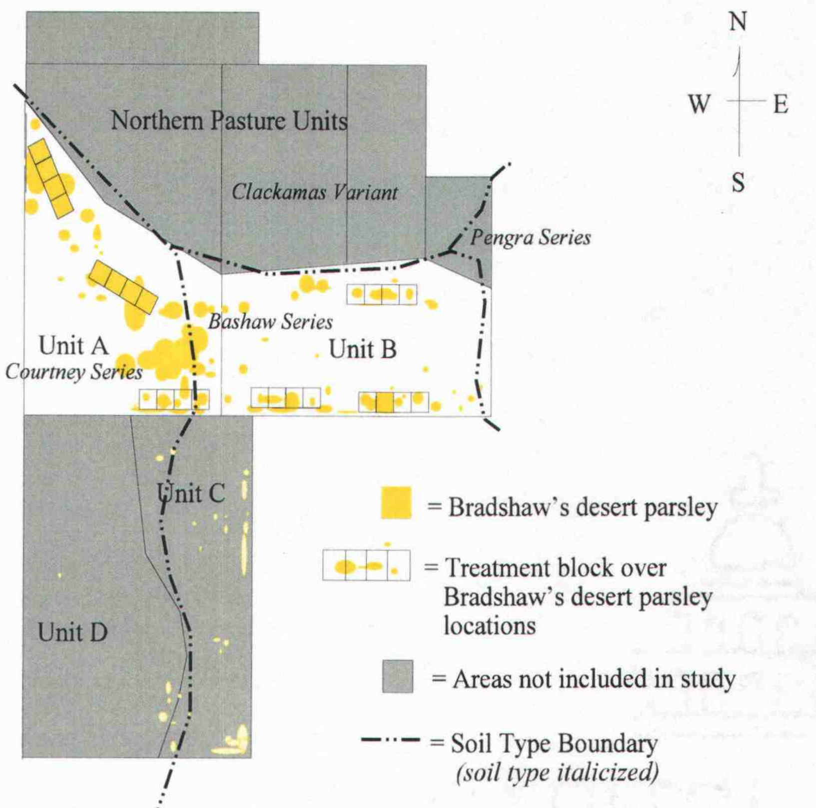

Figure 2. Map of Oak Creek study site with Bradshaw's desert parsley concentrations and study blocks, Linn County, Oregon, 1997-1998; the northern pasture units and units D and C were not included in the study. Map not to scale.

Riparian vegetation occurs along the western portion of the property (Units A and D, Fig. 2) and consists primarily of an overstory of domestic pear (*Pyrus communus*), Oregon ash (*Fraxinus latifolia*), and black hawthorn (*Crataegus douglasii*) (Gisler 1994, Merrifield 1994). Understory vegetation in the wooded areas is comprised of mixed grass and forb species, and a few shrubs including evergreen blackberry (*Rubus laciniatus*) and rose (*Rosa nutkana*) (Merrifield 1994).

The herbaceous wet prairie areas on the eastern portions of the Oak Creek property (Units B and C, Fig. 2) support diverse grass and forb species including sedge (*Carex densa*, *C. feta*, and *C. unilateralis*), juncus (*Juncus effusus* and *J. tenuis*), tufted-hairgrass (*Deschampsia cespitosa*), ryebrome (*Bromus secalinus*), reedgrass (*Calamagrostis canadensis*), peavine (*Lathyrus sphaericus*), buttercup (*Ranunculus orthorhynchos* and *R. uncinatus*), vetch (*Vicia tetrasperma*), and dutch clover (*Trifolium repens*) (Gisler 1994, Merrifield 1994). These vegetation associations are similar to those found on many other native prairie and Bradshaw's desert parsley sites throughout the Willamette Valley (Franklin and Dyrness 1973, Kagan 1980, Meinke 1980, Pendergrass et al. 1999).

The highest densities of Bradshaw's desert parsley occur in Units A and B with lower densities in Units C and D (Fig. 2). The remaining three northern units (20 ha) on the site were overgrazed, preventing collection of accurate species identification and composition data. Furthermore, these portions of the site were intensively managed as improved pasture units by the former owner and mostly contain introduced pasture grass and forb species. Units B and C were also once disced and furrowed by the previous land owner in an attempt to propagate improved pasture grass and forb cultivars. When the cultivated crops failed to become established in these two units, both fields were abandon and left to produce "natural" pasture crops.

Historically, the Oak Creek property was used for livestock grazing. The site was subjected to heavy livestock grazing since 1979. From 1979 to 1992, the entire property was subjected to year round, and at times intensive, livestock grazing. Sheep and cattle were the primary livestock grazed on the property, while draft horses and a donkey occasionally used the pastures. However, in the highest Bradshaw's desert parsley density areas (Units A and B, Fig. 2), livestock use was restricted to mid-summer through February. Prior to 1979 the property was also known to support livestock operations, however, the exact history and duration of use is not well documented.

METHODS

EXPERIMENTAL DESIGN

I established six 10 x 40 m blocks over preselected Bradshaw's desert parsley patches at the Oak Creek study site encompassing, as much as possible, a uniform plant distribution (Fig. 2). I established three blocks in Unit B (herbaceous pasture) and three in Unit A (wooded pasture). I subdivided each block into four 100-m^2 experimental units (Fig. 3), and established two semi-permanent plant mapping transects (0.5 x 10 m) in each of the experimental units (Fig. 4). Each experimental unit was randomly assigned one of four livestock grazing treatments based on residual standing crop biomass (control, high, moderate, or light) (Fig. 3). Prior to application of livestock grazing treatments, all detectible plants within the semi-permanent transects were mapped, measured, and categorized into one of seven plant stage classifications (Fig. 5). Plant mapping and measurements within the semi-permanent transects were repeated one year following treatment. Prior to (and the year following) the application of livestock grazing treatments, I collected data for schizocarp production, changes in plant morphology, density, survival, newly emerged plants, and Bradshaw's desert parsley depredation (including plant parts and total number of plant grazed or uprooted by small mammals). In addition to collecting plant data, I established 20 x 50 m small mammal trap grids over each experimental block.

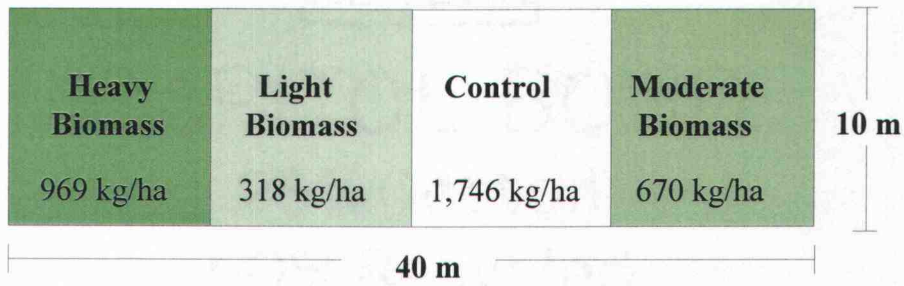

Figure 3. Block with grazing treatments based on residual biomass assigned to each of four 100-m^2 experimental units, Oak Creek study site, Linn County, Oregon, 1997-1998.

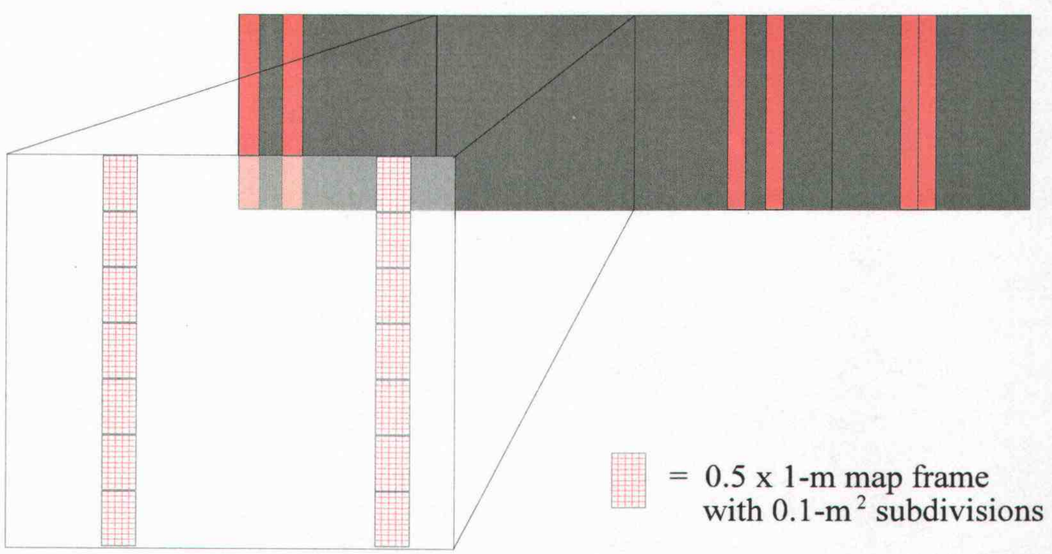

Figure 4. Mapping units were placed along two randomly distributed transects within each experimental unit at the Oak Creek study site, Linn County, Oregon, 1997-1998.

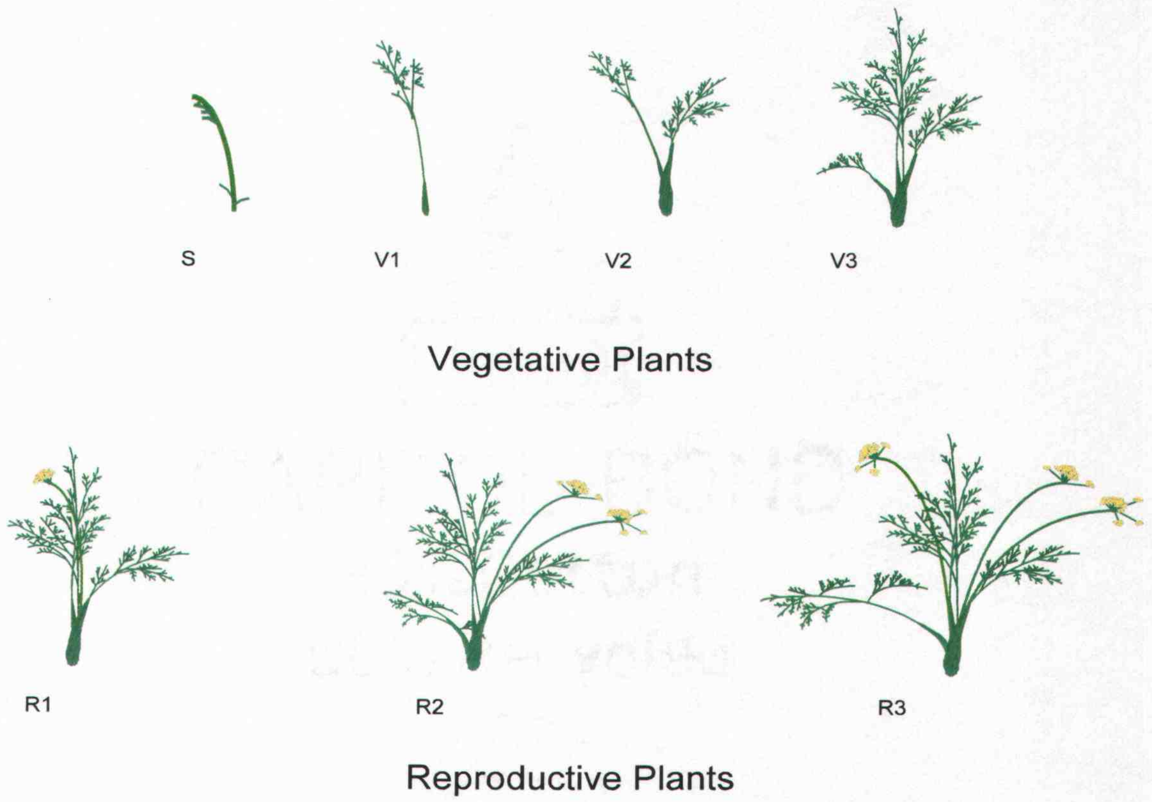

Figure 5. Bradshaw's desert parsley structure classification categories used for grazing study at Oak Creek, Linn County, Oregon, 1997-1998. S = seedling; V1 = non-reproductive plant with one leaf; V2 = non-reproductive plant with two leaves; V3 = non-reproductive plant with three or more leaves; R1 = reproductive plants with a single umbel; R2 = reproductive plants with two umbels; R3 = reproductive plants with three or more umbels (Classification categories from Kaye et al. 1994).

Livestock grazing treatments

I randomly assigned the four experimental units within each block to one of four treatments based on standing crop biomass to remain following livestock grazing: control (no grazing, $\bar{x} = 1,746 \pm 902$ kg/ha); high residual biomass (55% standing crop remaining, $\bar{x} = 969 \pm 302$ kg/ha); moderate residual biomass (38% standing crop remaining, $\bar{x} = 670 \pm 161$ kg/ha); and light residual biomass (18% standing crop remaining, $\bar{x} = 319 \pm 88$ kg/ha)(Fig. 3). Standing crop biomass estimates were based on oven dried clipping sample weights and represent vegetation remaining following livestock grazing. Treatment blocks were fenced with a double strand of electric wire (separating each 10 x 10 m treatment area) to control livestock within each of the experimental units. Grazing began 2 July 1997, when most of the Bradshaw's desert parsley had set seed. Nine Jersey cattle (one cow [approximate mass = 305 kg] and eight steers [approximate average mass = 373 kg]) were used for grazing the experimental units. Prior to grazing, cattle were held without feed overnight (12-14 hours) before being placed in the experimental units. Each day, following grazing, the cattle were returned to the holding corral where they were again held overnight without feed. Three cattle were placed in each of the experimental units and allowed to graze until the desired amount of vegetation was removed. Grazing prescriptions were based on ocular estimates of vegetation remaining following grazing. Because the standing crop production was much heavier in Unit A, these sites were grazed more intensively to obtain approximately the same residual biomass in both the Unit A and Unit B experimental units. Once the desired treatments were obtained, the cattle were then moved into the next treatment block, until all blocks had been grazed. All blocks within the study area were grazed within a two-week period. Livestock grazing treatments were applied only in 1997; no treatments were applied in 1998.

Following the grazing treatments, I clipped the residual vegetation to a 2.5-cm stubble height within five 1-m^2 plots randomly located in each of the experimental units (excluding the semi-permanent mapping transects). Clipped samples ($n = 120$) were oven-dried (37.8° C) and weighed to estimate the total standing biomass remaining following treatment (Milner and Hughes 1968, Cook and Stubbendiek 1986). I dried and re-weighed clipped samples daily until weights had stabilized.

Bradshaw's desert parsley mapping and measurements

Two semi-permanent plant mapping transects in each of the four experimental units within each block were established to map individuals from year to year and identify any new plants that appeared following the grazing treatment. Plant characteristics and locations were recorded during pre and post-treatment sampling. I used a 0.5 x 1 m map frame with 0.1-m^2 subdivisions to map all Bradshaw's desert parsley plants in each of the transects (modified techniques similar to those used by Kaye and Kirkland [1994]) (Fig. 4). I counted all Bradshaw's desert parsley plants within each transect and recorded vegetative height (not including the umbel), longest leaf length, number of schizocarps, and elliptical canopy area for each plant. I classified individual plants into one of seven plant-structure categories following Kaye et al. (1994) (Fig. 5), and mapped the location of each plant. I measured and mapped plants when most of the Bradshaw's desert parsley had well-developed schizocarps (14 May - 11 June 1997). Plants were again mapped and measured within the semi-permanent transects the year following treatment (5 May - 4 June 1998), with previously undetected plants added to the sample. In 1998, Bradshaw's desert parsley measurements were collected when plants had reached approximately the same developmental stage as in 1997. Only those schizocarps ≥5 mm in length were included in schizocarp production estimates. Mature schizocarps are generally 8 to 11 mm in length (Hitchcock and Cronquist 1981, Greenlee and Kaye 1995), however some of the plants at Oak Creek were still developing schizocarps at the time I collected data. I assumed schizocarps ≥5 mm would successfully mature to produce seeds. Schizocarps <5 mm were not included in production estimates, under the assumption that these fruits were not likely to reach maturity.

Small mammal trapping

I established a 20 x 50 m trap grid (Otis et al. 1978) over each of the blocks (Fig. 6). Each grid had a total of 55 trap stations, placed at 5-m intervals. One Sherman live trap was placed at each trap station. I trapped small mammals prior to (29 April - 10 May 1997), and immediately following (22 July - 2 August 1997) the grazing treatments in 1997. In 1998, the two trap periods were repeated (30 March - 10 April 1998 and 13 July - 24 July 1998) under conditions similar to the 1997 field season (plant development, weather conditions, and lunar phase [Bowers and Dooley 1993]), although no grazing treatments were applied during the second season. Traps were pre-baited with rolled oats and locked open four days before beginning trapping. On the fifth day, traps were re-baited, and run for five consecutive nights (trap periods). Traps were opened each evening and checked the following morning; I closed traps during the day. Captured small mammals were ear-tagged for individual identification and I recorded species, mass, sex, tag number, and station location for each capture. I released small mammals where they were captured.

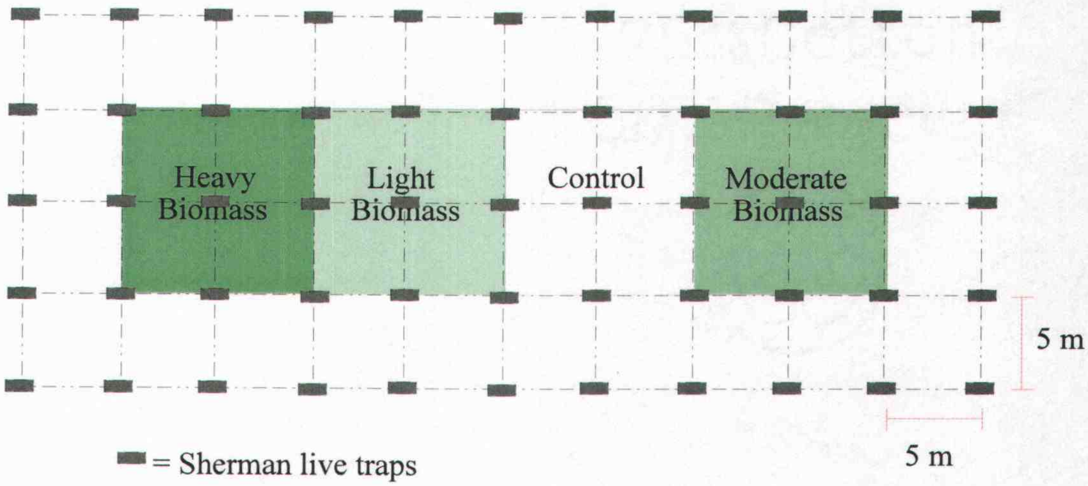

Figure 6. Small mammal trap grid used for each experimental block on Bradshaw's desert parsley grazing study at Oak Creek, Linn County, Oregon, 1997-1998.

DATA ANALYSIS

I used STATGRAPHICS (v. 2.1) to conduct statistical tests. I used a multifactorial Analaysis of Variance and the least significant difference model (LSD) to test the hypotheses that: 1) Bradshaw's desert parsley vigor, density, survival, or emergence of new plants does not differ among livestock grazing treatments, and 2) small mammal abundance is not a significant covariate in the analysis of the effects of livestock grazing on Bradshaw's desert parsley vigor, density, survival, or new plant emergence.

To evaluate the effects of livestock grazing on Bradshaw's desert parsley plant vigor, I excluded plants grazed or uprooted by small mammals from the analysis. I evaluated plant vigor based upon schizocarp production (total schizocarps produced per plant) and plant size (conical surface area [CSA]). Analyses were based on differences in these variables between 1997 and 1998. Expanding on elliptical crown area used by Pendergrass et al. (1999), I used CSA and plant height measurements for a more holistic view of the morphological response of Bradshaw's desert parsley to livestock grazing. I modified the general formula for the surface area of a cone ($S.A. = \pi r^2 + \pi r \times k$) to quantify CSA:

$$CSA = [(l \times w \times \pi) \div 4] + [\pi \times (l + w) \div 4] \times k$$

Where: l = longest length from outermost edges across the center of the canopy (not including inflorescence), w = width of canopy perpendicular to longest length measurement (not including inflorescence), and k = longest vegetative leaf measurement from base of plant to outer most tip of leaf (Fig. 7).

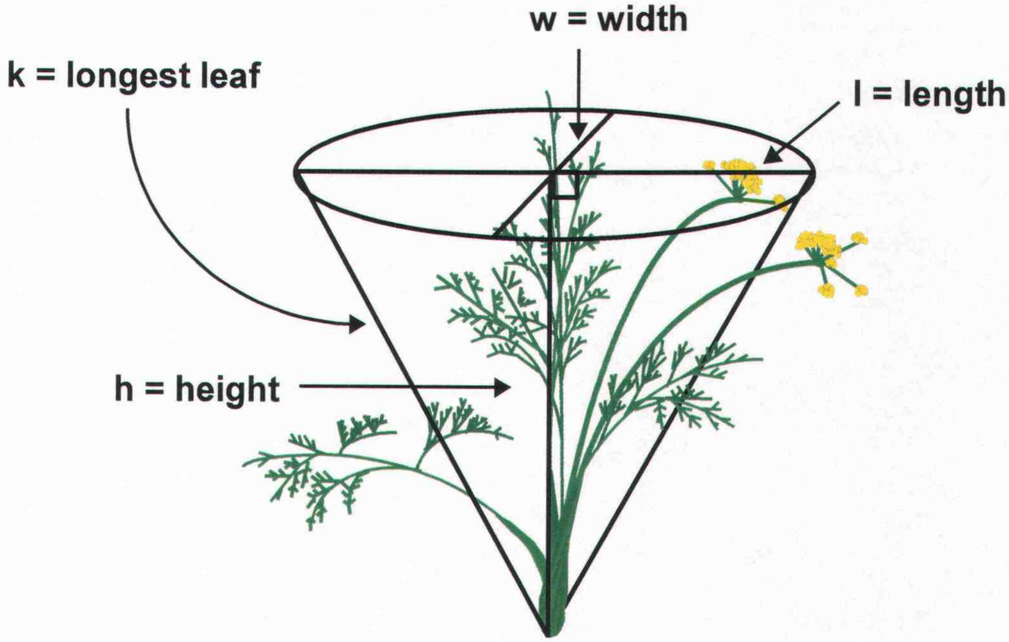

Figure 7. Measurements used in calculating conical surface area for determining response of Bradshaw's desert parsley to livestock grazing treatments at Oak Creek, Linn County, Oregon, 1997-1998.

I used total number of all plants mapped in 1997 and 1998 to evaluate plant density, survival, and new plant emergence. Mean plant density was obtained by accounting for total plants present (grazed or ungrazed) for each year. Total plants within each mapping transect were divided by the total area sampled and averaged for each experimental unit. Changes in plant densities between years were compared between pastures and among treatments.

Plant survival estimates were obtained from individual plants mapped in 1997 which re-emerged in 1998. Survival rates were estimated for each experimental unit as the percentage of plants that successfully re-emerged the following year. New plants mapped in 1998 were not included in the analysis for survival, but used in an analysis of new plants emerged for each treatment. New plants emerged were defined as plants that were not mapped in 1997.

In addition to comparing changes in plant vigor, density, survival and new plant emergence among livestock grazing treatments, data analysis included the effects of small mammal abundance on Bradshaw's desert parsley between pastures, and among experimental blocks and treatments. Small mammal data was compared with mean Bradshaw's desert parsley depredation rates among treatments and blocks, and plant parts grazed by small mammals. I also compared mean differences in species abundance related to year, pasture, experimental block and mean standing crop biomass. Small mammal abundance was based on total unique small mammal captures (ear-tagged individuals) by block for each species. Only a single capture was counted to obtain overall peak abundance estimates, whether the animal was captured only once or on numerous occasions. Depredation was expressed as the proportion of total plants within the mapping transects for each experimental unit, which were uprooted or grazed by small mammals. Proportion of plants depredated was then combined for each experimental unit to obtain a mean for each treatment and experimental block.

RESULTS

I mapped and measured 2,801 Bradshaw's desert parsley plants (n = 1,362 in the wooded and n = 1,439 in the herbaceous pastures) over the two-year period. A total of 2,314 plants (n = 1,100 in the wooded and n = 1,214 in the herbaceous pastures) were mapped during 1997, and 487 additional plants in 1998 (n = 262 in the wooded and n = 225 in the herbaceous pastures).

BRADSHAW'S DESERT PARSLEY RESPONSE TO LIVESTOCK GRAZING

Schizocarp production and reproductive potential

I used 1,124 reproductive Bradshaw's desert parsley plants (n = 487 in the wooded pasture, n = 637 in the herbaceous pasture) to determine average schizocarp production and morphological differences. Changes in schizocarp production between 1997 and 1998 did not vary among treatments ($F = 2.34$; d.f. = 3, 23; $P = 0.1058$), but did differ between pastures ($F = 8.01$; d.f. = 1, 23; $P = 0.0107$). Changes in the percent R1, R2, and R3 umbelled plants between 1997 and 1998 ($F \leq 2.40$; d.f. = 1, 23; $P \geq 0.1471$) were not significant covariates in the analysis. Plant CSA, height, stem length, and residual standing crop biomass remaining following treatment were also insignificant covariates ($F \leq 0.73$; d.f. = 1, 23; $P \geq 0.4109$). While schizocarp yield increased in both wooded and herbaceous pastures from 1997 to 1998, the herbaceous pasture produced significantly more schizocarps in the all livestock grazing treatments ($\bar{x} = 32 \pm 15$ schizocarps/m^2, high residual biomass; $\bar{x} = 30 \pm 15$ schizocarps/m^2, moderate residual biomass; and $\bar{x} = 34 \pm 15$ schizocarps/m^2, light residual biomass) when compared to the control ($\bar{x} = -33 \pm 15$ schizocarps/m^2). No significant difference in schizocarp production were detected in the wooded pasture among livestock grazing treatments and the controls (Fig. 8a). Although not a significant covariate when tested with other variables, average schizocarp production appeared to be negatively related to standing crop biomass ($r^2 = 0.32$; $n = 48$; $P = 0.074$) (Fig. 8b). I also observed changes in numbers of reproductive plants among treatments and between pastures. The greatest net loss of reproductive plants occurred in the controls, while net gains occurred among grazing treatments in both pastures (Table 2).

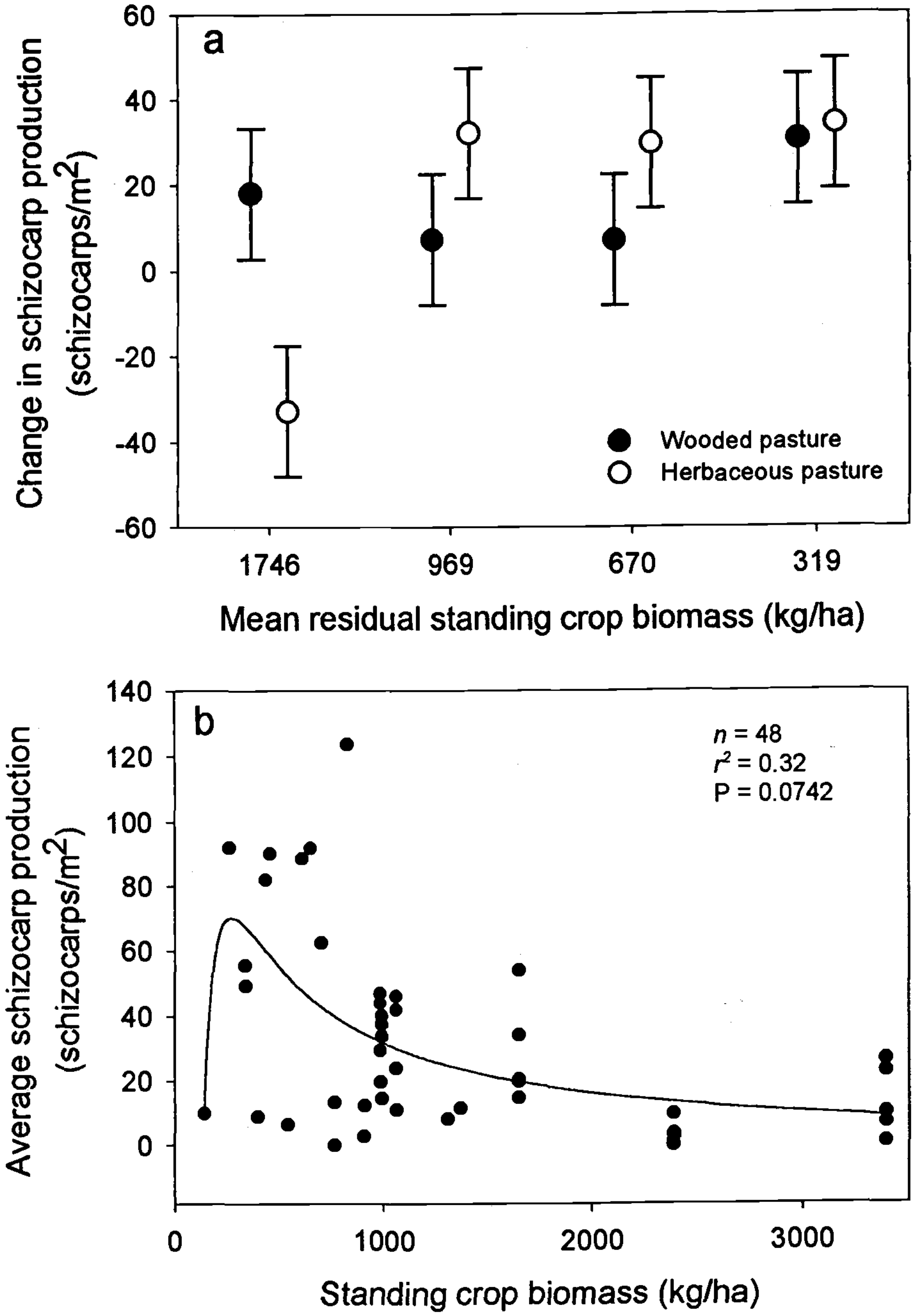

Figure 8. Changes in mean (± S.E.) Bradshaw's desert parsley schizocarp production following application of livestock grazing treatments in wooded and herbaceous pastures (a), and relationship between schizocarp production and standing crop biomass pre and post-treatment (b), Oak Creek, Linn County, Oregon, 1997 and 1998.

Table 2. Total reproductive Bradshaw's desert parsley plants and total schizocarp production pre and post livestock grazing at Oak Creek, Linn County, Oregon (1997 and 1998). R1 = reproductive plants with a single umbel; R2 = reproductive plants with two umbles; R3 = reproductive plants with three or more umbles; () indicate total number of reproductive plants in each category which did not produce shizocarps.

	Pretreatment		Post-treatment		Net gain/loss	
	Wooded Pasture	Herbaceous Pasture	Wooded Pasture	Herbaceous Pasture	Wooded Pasture	Herbaceous Pasture
Number of Plants						
R1	201 (142)	134 (68)	183 (130)	135 (86)	- 18	1
R2	143 (51)	172 (22)	134 (76)	179 (39)	- 9	7
R3	33 (7)	84 (6)	24 (10)	115 (14)	- 9	31
Total	377 (200)	390 (96)	341 (216)	429 (139)	- 36	39
Total Schizocarp Production						
R1	337	345	480	390	143	45
R2	884	1,894	947	3,234	63	1,340
R3	447	1,717	283	4,070	- 164	2,353
Total	1,668	3,956	1,710	7,694	42	3,738

	Net gain/loss of reproductive plants by livestock grazing treatment	
	Wooded Pasture	Herbaceous Pasture
Control	- 49	- 26
High residual biomass	- 17	25
Moderate residual biomass	10	11
Light residual biomass	20	29

Morphological response to livestock grazing

Change in reproductive Bradshaw's desert parsley CSA from 1997 to 1998 varied among treatments (F = 3.39; d.f. = 3, 23; P = 0.0461), but not between pastures (F = 0.44; d.f. = 1, 23; P = 0.5170). Differences in the percent of R1 (F = 11.36; d.f. = 1, 23; P = 0.0042), R2 (F = 20.35; d.f. = 1, 23; P = 0.0004), and R3 (F = 7.05; d.f. = 1, 23; P = 0.0180) plants were significant covariates in the analysis, but standing crop biomass was not (F = 0.64; d.f. = 1, 23; P = 0.4352). Differences in reproductive plant CSA were greater in the wooded pasture controls than in other treatments, but did not vary among either the wooded or herbaceous pasture in the heavy, moderate, or light residual biomass treatments (Fig. 9a).

Differences in vegetative Bradshaw's desert parsley CSA were not detected among treatments (F = 0.63; d.f. = 3, 23; P = 0.6082), but did vary between pastures (F = 5.44; d.f. = 1, 23; P = 0.0340). Differences in percent of V1 (F = 0.25; d.f. = 1, 23; P = 0.6262), percent of V2 (F = 0.25; d.f. = 1, 23; P = 0.6237), percent of V3 (F = 0.26; d.f. = 1, 23; P = 0.6207), and standing crop biomass (F = 1.12; d.f. = 1, 23; P = 0.2894) were insignificant covariates in the analysis (Fig. 9b). Vegetative CSA differences were greater in the wooded pasture ($\bar{x}$ = -147 $\pm$ 47 cm^2) and than in the herbaceous pasture ($\bar{x}$ = -27 $\pm$ 47 cm^2).

Differences in reproductive plant height varied between pastures (F = 14.59; d.f. = 1, 23; P = 0.0017) and among livestock grazing treatments (F = 4.39; d.f. = 3, 23; P = 0.0209). Differences in percent of R1 (F = 17.6; d.f. = 1, 23; P = 0.0008), percent of R2 (F = 19.43; d.f. = 1, 23; P = 0.0005), and standing crop biomass (F = 4.16; d.f. = 1, 23; $P = 0.0594$) were significant covariates, but percent of R3 plants was not ($F = 2.49$; d.f. = 1, 23; $P = 0.1364$). Differences in height of reproductive plants in the wooded pasture ($\bar{x} = 4 \pm 1$ cm) were greater than in the herbaceous pasture ($\bar{x} = 1 \pm 1$ cm). Differences in height of reproductive plants in the wooded pasture controls ($\bar{x} = 5 \pm 3$ cm) were greater than other treatments (heavy residual biomass, $\bar{x} = -4 \pm 2$ cm; moderate residual biomass, $\bar{x} = -4 \pm 2$ cm; and light residual biomass, $\bar{x} = -2 \pm 2$ cm), but did not vary among treatments in the herbaceous pasture (no grazing, $\bar{x} = -1 \pm 2$ cm; heavy residual biomass, $\bar{x} = -3 \pm 2$ cm; moderate residual biomass, $\bar{x} = -2 \pm 2$ cm; and light residual biomass, $\bar{x} = -1 \pm 2$ cm, respectively).

Differences in vegetative Bradshaw's desert parsley plant height varied between pastures ($F = 5.97$; d.f. = 1, 23; $P = 0.0274$), but not among grazing treatments ($F = 0.10$; d.f. = 3, 23; $P = 0.9607$). Differences in standing crop biomass ($F = 0.40$; d.f. = 1, 23; $P = 0.5375$), percent of V1 ($F = 0.00$; d.f. = 1, 23; $P = 0.9753$), percent of V2 ($F = 0.00$; d.f. = 1, 23; $P = 0.9863$), and percent of V3 ($F = 0.00$; d.f. = 1, 23; $P = 0.9763$) plants were insignificant covariates in the analysis. Differences in vegetative plant height were greater in the wooded ($\bar{x} = -6 \pm 1$ cm) than in the herbaceous ($\bar{x} = -1 \pm 1$ cm) pasture.

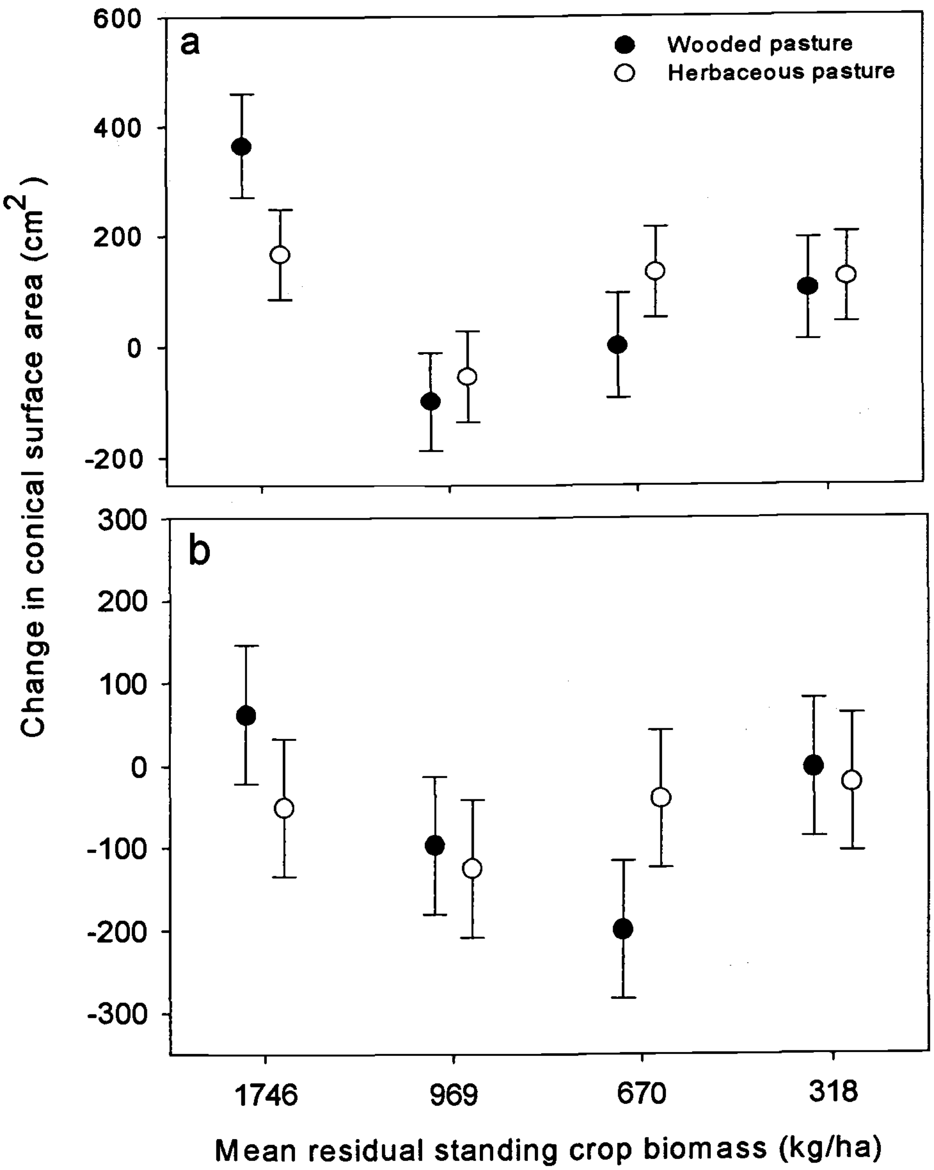

Figure 9. Change in mean (± S.E.) conical surface area for reproductive (a) and vegetative (b) Bradshaw's desert parsley in wooded and herbaceous pastures from before and after application of livestock grazing treatments at Oak Creek, Linn County, Oregon, 1997-1998.

Density, survival, and emergence of new plants

No significant changes in total plant density were documented in either pasture (F = 0.56; d.f. = 1, 23; P = 0.6486) or among treatments (F = 0.55; d.f. = 1, 23; P = 0.4688). Standing crop biomass was an insignificant covariate in the analysis (F = 0.26; d.f. = 1, 23; P = 0.6150) for determining differences in plant densities (Fig. 10). I also detected no differences in plant survival between pastures (F = 0.30; d.f. = 1, 23; P = 0.5906) or among treatments (F = 0.40; d.f. = 3, 23; P = 0.7514), nor was small mammal abundance a significant covariate in the analysis (F = 0.01; d.f. = 1, 23; P = 0.9202) (Fig. 11). However, the number of new plants emerged differed between pastures (F = 8.06; d.f. = 1, 23; P = 0.0109), but not among treatments (F = 2.64; d.f. = 3, 23; P = 0.0811), and peak vole abundance (F = 8.56; d.f. = 1, 23; P = 0.0090) was a significant covariate in the analysis (Fig. 12). The number of new plants emerged was higher in the wooded pasture ($\bar{x} = 3 \pm 1$ new plants/m^2) than in the herbaceous pasture ($\bar{x} = 1 \pm 1$ new plants/m^2), and increased in all treatments compared to the controls (Fig. 12). New plant emergence was negatively associated with peak vole abundance.

Overall plant population structure in both the wooded and herbaceous pasture remained relatively stable (Table 3). The most significant differences documented between pastures were in seedling (F = 4.15; d.f. = 1, 23; P = 0.0559) and R3 (F = 7.22; d.f. = 1, 23; P = 0.0146) plant densities. In both the wooded and herbaceous pastures, seedling densities decreased ($\bar{x} = -0.9 \pm 0.3$ and $\bar{x} = -1.7 \pm 0.3$ seedlings/m^2, respectively) during the second year of the study. R3 plant densities increased in the herbaceous pasture ($\bar{x}$ = 0.2 $\pm$ 0.1 plants/m^2) but decreased in the wooded pasture ($\bar{x}$ = - 0.1 $\pm$ 0.1 plants/m^2).

Changes in densities were also documented in several plant stages as a result of livestock grazing. Among treatments, differences in plant densities were detected for R2 (F = 4.50; d.f. = 1, 23; P = 0.0152), R3 (F = 5.23; d.f. = 1, 23; P = 0.0084), and V2 (F = 2.91; d.f. = 1, 23; P = 0.0611) plant stages following livestock grazing. Overall, multiple umbelled plant densities increased in all livestock grazing treatments when compared to the controls. The greatest increase in R2 densities was in the lightest residual standing crop biomass treatments, with the largest decrease occurring in the controls. R3 plant densities increased in all livestock grazing treatments when compared to the decrease documented in the controls. However, V2 plant densities declined in the light residual biomass treatments but increased in the controls (Table 3).

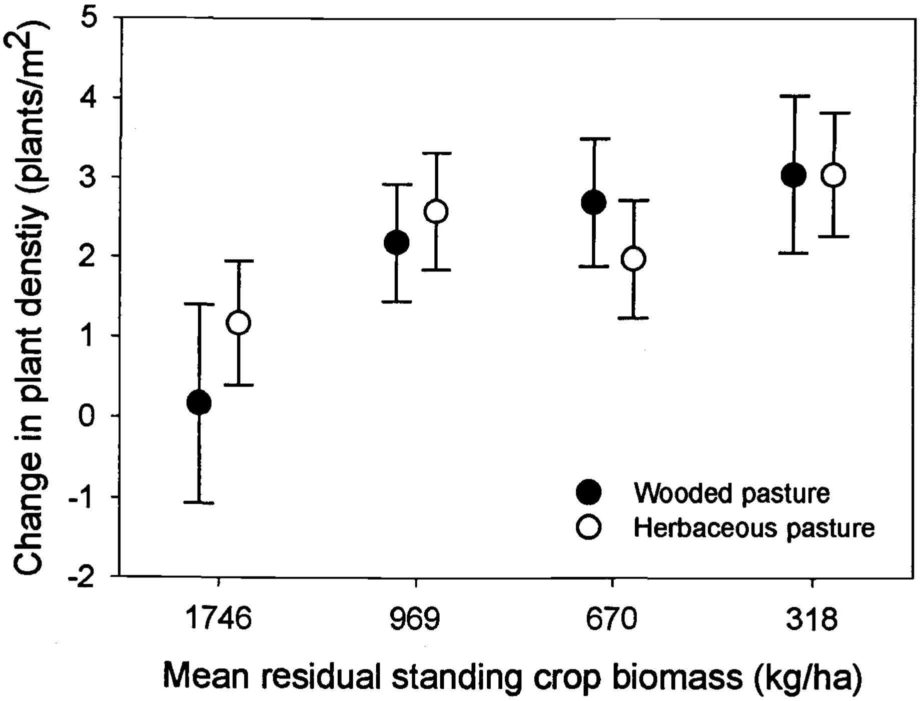

Figure 10. Change in mean (± S.E.) Bradshaw's desert parsley density in wooded and herbaceous pastures from before and after application of livestock grazing treatments at Oak Creek, Linn County, Oregon, 1997 and 1998.

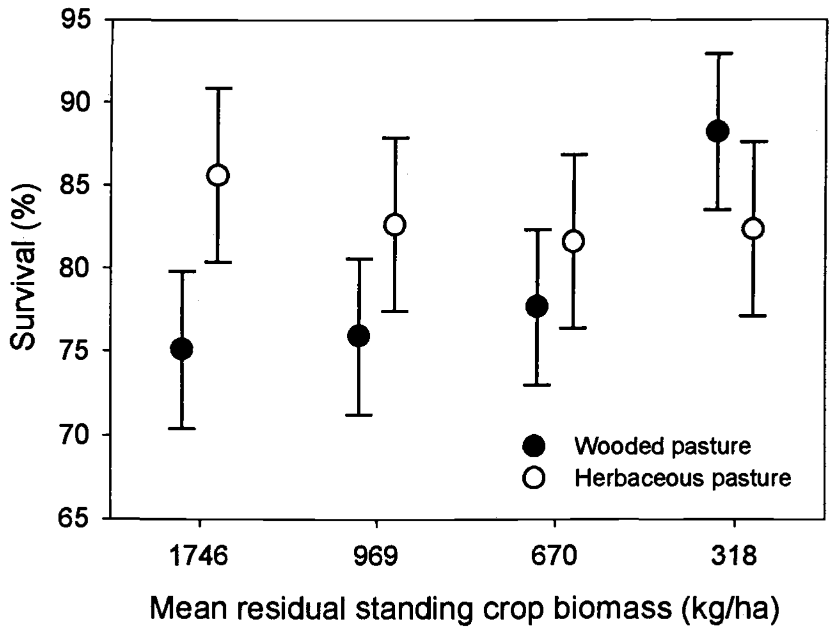

Figure 11. Mean (± S.E.) survival of Bradshaw's desert parsley one year following application of livestock grazing treatments in wooded and herbaceous pastures at Oak Creek, Linn County, Oregon, 1998.

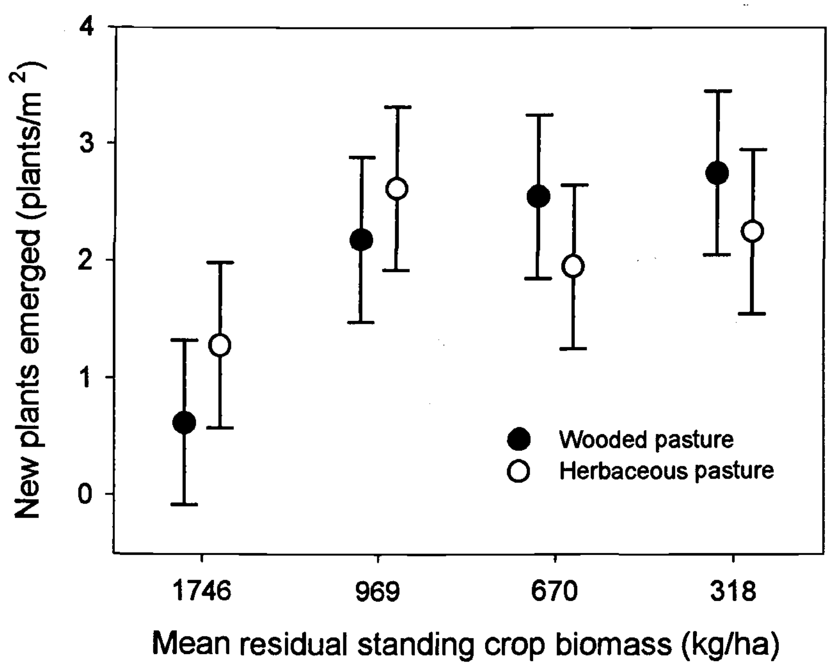

Figure 12. Mean (± S.E.) new Bradshaw's desert parsley plants emerged in wooded and herbaceous pastures following application of livestock grazing treatments at Oak Creek, Linn County, Oregon, 1998.

Table 3. Mean (± S.E.) changes in Bradshaw's desert parsley densities (plants/m^2) by plant stage, pasture, and residual standing crop biomass following livestock grazing at Oak Creek, Linn County, Oregon (1997 and 1998). R1 = single umbelled reproductive plants, R2 = reproductive plants with two umbels, R3 = reproductive plants with three or more umbels, S = seedlings, V1 = vegetative plants with one leaf, V2 = vegetative plants with two leaves, V3 = vegetative plants with three or more leaves.

Pasture and plant stage	Standing crop biomass (kg/ha) 1,746	969	670	319	F	P-value
Wooded pasture					Between pastures	
R1	- 0.68 ± 0.34	- 0.31 ± 0.34	0.62 ± 0.34	0.12 ± 0.34	0.37	0.5505
R2	- 0.47 ± 0.33	- 0.01 ± 0.33	- 0.07 ± 0.33	0.63 ± 0.33	0.32	0.5765
R3	- 0.16 ± 0.18	0.07 ± 0.18	0.24 ± 0.18	0.24 ± 0.18	7.22	0.0146
S	- 1.03 ± 0.64[a]	- 1.80 ± 0.64[a]	- 1.43 ± 0.64[a]	- 0.99 ± 0.64[a]	4.15	0.0559
V1	0.15 ± 0.15	0.01 ± 0.15	- 0.19 ± 0.15	- 0.42 ± 0.15	2.32	0.1444
V2	0.70 ± 0.36	0.07 ± 0.36	- 0.13 ± 0.36	- 0.06 ± 0.36	0.00	0.9789
V3	0.08 ± 0.52	0.71 ± 0.52	1.28 ± 0.52	1.52 ± 0.52	0.36	0.5575
Herbaceous pasture					Among treatments	
R1	- 0.05 ± 0.34	- 0.17 ± 0.34	- 0.22 ± 0.34	0.01 ± 0.34	0.84	0.4901
R2	- 0.63 ± 0.33	- 0.01 ± 0.33	- 0.06 ± 0.33	0.67 ± 0.33	4.50	0.0152
R3	- 0.47 ± 0.18	0.56 ± 0.18	0.33 ± 0.18	- 0.03 ± 0.18	5.23	0.0084
S	- 1.37 ± 0.64[a]	- 2.33 ± 0.64[a]	- 0.96 ± 0.64[a]	- 0.59 ± 0.64[a]	1.58	0.2279
V1	- 0.01 ± 0.15	- 0.11 ± 0.15	- 0.15 ± 0.15	- 0.17 ± 0.15	2.29	0.1109
V2	0.22 ± 0.36	1.33 ± 0.36	- 0.14 ± 0.36	- 0.83 ± 0.36	2.91	0.0611
V3	0.85 ± 0.52	1.01 ± 0.52	0.52 ± 0.52	1.22 ± 0.52	0.89	0.4654

[a] Seedling yield may not be a reliable estimate of actual production due to timing of data collection and possible effects of small mammal depredation. Depredated seedlings may be undetectable.

SMALL MAMMAL IMPACTS ON BRADSHAW'S DESERT PARSLEY

Small mammal depredation of Bradshaw's desert parsley

During the pretreatment year, percent plant depredation differed between pastures ($F = 4.25$; d.f. = 1, 23; $P = 0.0559$), but not among treatments ($F = 0.81$; d.f. = 3, 23; $P = 0.5077$) (Fig. 13). Standing crop biomass ($F = 3.62$; d.f. = 1, 23; $P = 0.0754$) and peak deer mouse abundance ($F = 4.88$; d.f. = 1, 23; $P = 0.0420$) were significant covariates in the analysis. During the pretreatment year, percent depredation was highest in the herbaceous pasture ($\bar{x} = 22 \pm 5\%$) and lowest in the wooded pasture ($\bar{x} = 4 \pm 5\%$).

Following the application of livestock grazing, percent Bradshaw's desert parsley depredation differed between pastures ($F = 9.62$; d.f. = 1, 23; $P = 0.0069$) but not among treatments ($F = 1.99$; d.f. = 3, 23; $P = 0.1563$) (Fig. 14). However, peak vole abundance ($F = 9.58$; d.f. = 1, 23; $P = 0.0069$) was a significant covariate in the analysis (Fig. 13). In 1998, depredation was greater in the wooded pasture ($\bar{x} = 51 \pm 9\%$) than in the herbaceous pasture ($\bar{x} = 7 \pm 9\%$). Standing crop biomass explained greater than 50% of Bradshaw's desert parsley depredated during both years of the study (Fig. 13 and Table 4).

In both 1997 and 1998, total number of leaves grazed differed between pastures ($F = 3.27$; d.f. = 1, 23; $P = 0.0892$) and among livestock grazing treatments ($F = 2.81$; d.f. = 3, 23; $P = 0.0728$); peak vole abundance ($F = 12.06$; d.f. = 1, 23; $P = 0.0031$), peak deer mouse abundance ($F = 3.41$; d.f. = 1, 23; $P = 0.0834$), and standing crop biomass ($F = 7.52$; d.f. = 1, 23; $P = 0.0145$) were significant covariates in the analysis. Total number of leaves grazed by small mammals was greater in the wooded ($\bar{x} = 124 \pm 30$

leaves per block) than in the herbaceous ($\bar{x}$ = 20 $\pm$ 30 leaves per block) pasture. The greatest amount of leaf herbivory occurred in the controls ($\bar{x}$ = 112 $\pm$ 29 leaves), followed by the moderate and heavy residual biomass treatments ($\bar{x}$ = 81 $\pm$ 19 leaves and $\bar{x}$ = 87 $\pm$ 21 leaves; respectively); the least amount of small mammal herbivory occurred in the lightest residual biomass treatments ($\bar{x}$ = 8 $\pm$ 25 leaves).

Small mammals at the Oak Creek site appeared to prefer the leafy parts of Bradshaw's desert parsley plants more than reproductive stems. Total number of inflorescence stems grazed by small mammals did not differ between pastures (F = 0.21; d.f. = 1, 23; P = 0.6539) or among treatments (F = 0.56; d.f. = 3, 23; P = 0.6510), nor were peak vole abundance (F = 1.02; d.f. = 1, 23; P = 0.3281), peak deer mouse abundance (F = 0.49; d.f. = 1, 23; P = 0.4926), or standing crop biomass (F = 1.82; d.f. = 1, 23; P = 0.1965) significant covariates.

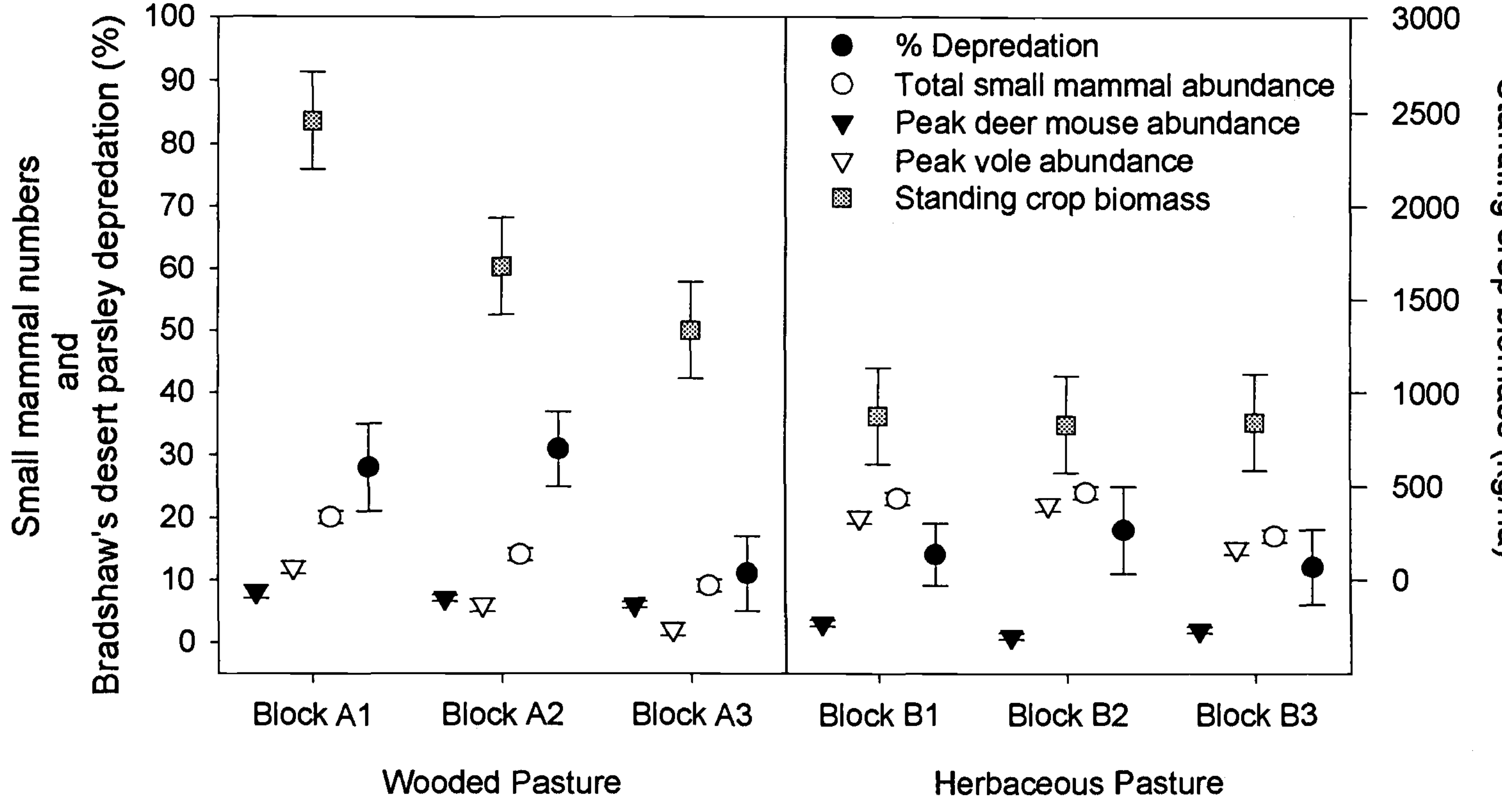

Figure 13. Mean (± S.E.) Bradshaw's desert parsley depredation, standing crop biomass, gray-tailed/Townsend's vole peak abundance, deer mouse peak abundance, and total small mammal peak abundance by treatment block at Oak Creek, Linn County, Oregon, 1997 and 1998 combined.

Small mammal abundance and habitat associations

Peak vole abundance differed between years ($F = 120.06$; d.f. = 1, 47; $P < 0.0001$) and pastures ($F = 75.09$; d.f. = 1, 47; $P < 0.0001$). Peak vole abundance increased from $\bar{x} = 5$ ($\pm$ 1 unique captures) in 1997 to $\bar{x} = 22$ ($\pm$ 1 unique captures) in 1998, and was greater in the herbaceous ($\bar{x} = 20 \pm 1$ unique captures) than in the wooded pasture ($\bar{x} = 6 \pm 1$ unique captures) over the two year period (Table 4 and Fig. 15). Standing crop biomass ($F = 11.29$; d.f. = 1, 47; $P < 0.0001$) was a significant covariate in the analysis of peak vole abundance, accounting for 97% of the variation in vole abundance at the Oak Creek site over the two year period. Similarly, deer mouse abundance differed between years ($F = 85.55$; d.f. = 1, 47; $P < 0.0001$) and pastures ($F = 104.12$; d.f. = 1, 47; $P < 0.0001$), but standing crop biomass ($F = 0.00$; d.f. = 1, 47; $P = 0.9630$) was not a significant covariate. Deer mouse abundance increased from $\bar{x} = 3$ ($\pm$ 0 unique captures) in 1997 to $\bar{x} = 7$ ($\pm$ 0 unique captures) in 1998. Deer mice were more commonly associated with the wooded ($\bar{x} = 7 \pm 0$ unique captures) than the herbaceous ($\bar{x} = 2 \pm 0$ unique captures) pasture (Table 4 and Fig. 15).

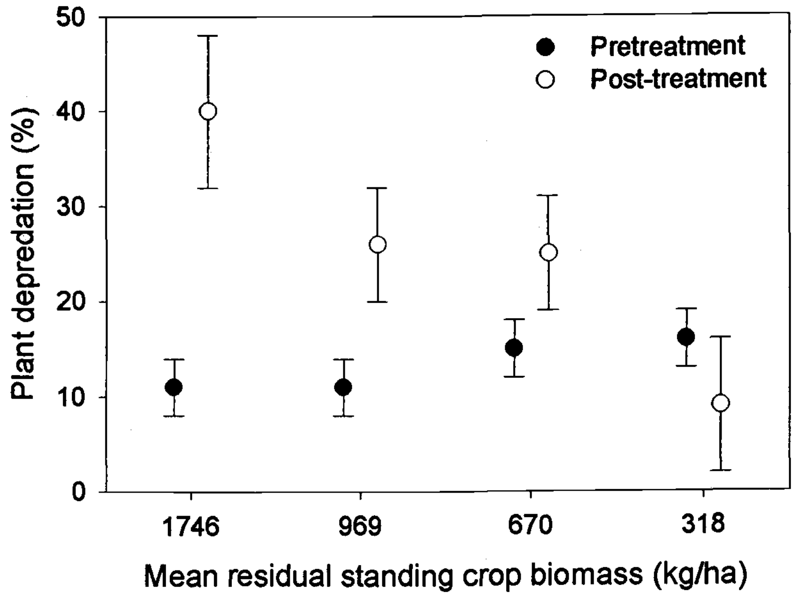

Figure 14. Mean (± SE) percent Bradshaw's desert parsley depredation by small mammals in both wooded and herbaceous pastures pre and post application of livestock grazing treatments at Oak Creek, Linn County, Oregon, 1997 and 1998.

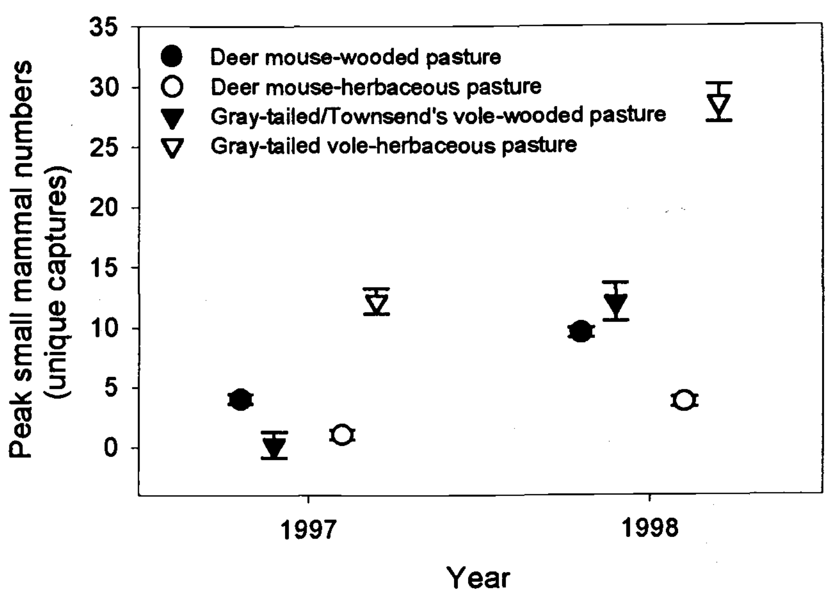

Figure 15. Mean (± SE) peak small mammal estimates based on unique captures for wooded and herbaceous pastures at Oak Creek Linn County Oregon, 1997 and 1998.

Table 4. Total number of unique small mammal captures, Bradshaw's desert parsley depredation rates, and standing crop biomass among wooded and herbaceous pasture units pre and post livestock grazing at Oak Creek, Linn County, Oregon (1997 and 1998).

Pasture and Block No.	Avg. standing crop biomass (kg/ha)		Bradshaw's desert parsley depredation (%)		Unique vole captures		Unique deer mouse captures	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Wooded pasture								
A1	3,392	1,517	21	42	8[a]	19[a]	4	11
A2	2,392	965	22	45	0	14[a]	6	8
A3	1,652	1,018	6	19	1[b]	4[b]	3	10
Herbaceous pasture								
B1	993	759	8	20	10[c]	29[c]	1	5
B2	1,061	597	12	19	12[c]	32[c]	1	2
B3	985	700	9	11	5[c]	24[c]	0	4

[a] Vole captures consisted of both gray-tailed and Townsend's voles.
[b] Vole captures consisted of Townsend's voles only.
[c] Vole captures consisted of gray-tailed voles only.

DISCUSSION

BRADSHAW'S DESERT PARSLEY RESPONSE TO LIVESTOCK GRAZING

My hypothesis that Bradshaw's desert parsley vigor, density, survival, and new plants emerged would differ among livestock grazing intensities was only partially supported by data collected at the Oak Creek site. CSA, reproductive plant height, new plants emerged, and density of several plant stages changed as a result of livestock grazing, but schizocarp production, total plant density, and survival did not.

Emergence of new plants into the population at Oak Creek increased following the application of livestock grazing (Fig. 12). In both the wooded and herbaceous pasture, new plant emergence increased when compared to the controls, but did not differ among grazing intensities. Survival and total plant densities did not vary among livestock grazing treatments, but plant density of R2 and R3 plants was found to be effected by livestock grazing. While no differences where found among most plant stage categories, densities of R2 and R3 of reproductive plants increased following the application of livestock grazing. Willoughby (1987) found reproductive plants to be almost nonexistent within areas annually grazed by livestock in both years of his study. In contrast, mid-summer (post-schizocarp production) livestock grazing at the Oak Creek site did not appear to impact Bradshaw's desert parsley plant population composition (vegetative versus reproductive) in either the wooded or herbaceous pastures (Table 3).

Although no repeated livestock grazing treatments were applied at the Oak Creek study site, my results suggest schizocarp production, density of several plant stages, and number of newly emerged plants increased as a result of a reduction in standing crop biomass. Pendergrass et al. (1999) also suggests a reduction in standing crop biomass with the use of fall prescribed burning accentuates differences in size and reproductive capacity of Bradshaw's desert parsley at two sites near Eugene, Oregon, and documented higher schizocarp production in the prescribed burn treatments than for plants located in controls. Pendergrass et al. (1999) observed an increase of reproductive plant potential with increased frequency of burning. At one of Pendergrass et al.'s (1999) study sites, three burns over an eight year period significantly increased foliar crown area, number of leaves, and schizocarps, while Bradshaw's desert parsley in two-burn treatments were similar to controls.

Livestock grazing appears to have initially benefitted new Bradshaw's desert parsley emergence, while having no effect on population structure, survival, total plant density, plant vigor, and schizocarp production. In 1998, Bradshaw's desert parsley populations throughout the plants range were suffering declines (with the exception of the Oak Creek and LaCamas populations). At least five of the other populations were managed with the use of prescribed fire, which had been deferred because of burning restrictions. While much of the current research and management has involved the use of prescribed fire, this study is the first to evaluate the use of livestock as a possible management alternative. In the Willamette Valley, prescribed burning is becoming increasingly restrictive because of smoke management. Livestock grazing may be one relatively inexpensive and effective alternative for managing Bradshaw's desert parsley habitat. Furthermore, the mechanical disturbance created from livestock use of an area may serve to mediate the release of established plants, which may be suppressed by physical barriers at the soil surface (i.e., heavy leaf litter from overstory vegetation, or heavy root masses from adjacent perennial grasses) as well as creating favorable microhabitat site conditions for newly establishing seedlings (Harper et al. 1965, Coffin and Lauthenroth 1992, Yang 1996). However, Kagan (1980) suggests that annual disturbance whether from fire or grazing may be detrimental to establishing seedlings.

In most of the analyses, differences observed were between pastures. Although no differences were documented among treatments, the most pronounced increase in plant densities occurred in the wooded pasture during the second year of the study while remaining unchanged in the herbaceous pasture (Fig. 10). A net loss of reproductive plants also occurred in the wooded pasture during the second year of the study, while a net gain was observed in the herbaceous pasture (Table 2). Kagan (1980) reported that Bradshaw's desert parsley appears to do best in open situations, and documented the highest abundance of Bradshaw's desert parsley in quadrats with the lower-statured tufted hairgrass (*Deschampsia cespitosa*) cover.

The effects of livestock grazing on plant vigor were also variable and related to pasture type. Schizocarp production increased in all livestock grazing treatments when compared to controls, but only in the herbaceous pasture. Plant CSA and height decreased in the livestock grazing treatments compared to the controls; however decreases in plant height and CSA were not consistent across treatments. Although livestock grazing did not appear to effect plant vigor or population structure, I found differences in plant morphology, population structure, and schizocarp production between pastures and years. At the Oak Creek study site, both reproductive and vegetative Bradshaw's desert parsley plants growing in the wooded pasture were consistently larger than those plants in the herbaceous pasture. Reproductive potential also varied between pastures; based on density of multiple umbelled reproductive plants (R2 and R3). The differences I observed in plant characteristics (CSA, plant height, population structure and schizocarp production) between the wooded and herbaceous pastures at the Oak Creek site may be attributed to a number of factors including standing crop biomass, shading, plant competition (above- and below-ground), soil characteristics, timing (seasonality) and amount of precipitation, and ambient temperatures during the growing season (Silvertown and Doust 1993).

Although I did not collect data on solar radiation, I suggest shading is a major factor responsible for differences in both vegetative and reproductive plant morphology, population structure, and schizocarp yield between the wooded and herbaceous pastures. The wooded pasture was dominated by a heavy understory of meadow foxtail as well as being shaded by the overstory of pear and hawthorn. Standing crop biomass of herbaceous material was 2.5 times greater on average in the wooded pasture than that produced in the herbaceous pasture (1,466 kg/ha difference between the two pastures) and biomass was a significant covariate in determining plant height, CSA, and schizocarp yield at the Oak Creek study site. In the Red Hills of southern California, Willoughby (1987) found significant differences in plant height and canopy cover of *Lomatium congdonii* related to repeated heavy livestock grazing. *Lomatium congdonii* plants in grazed areas were shorter and total canopy cover <25% of ungrazed sites. Willoughby (1987) also documented significant variability in plant measurements between years in both grazed and ungrazed areas, which were attributed to higher precipitation received proceeding the second year. In contrast, Pendergrass et al. (1999) documented initial increases in crown area, plant height, and umbellets per plant following prescribed burning. Reductions in standing crop biomass, whether from livestock grazing or prescribed burning, appears to initially benefit Bradshaw's desert parsley. However, further research is needed to directly compare these two management strategies.

Bradshaw's desert parsley in the wooded pasture at the Oak Creek site may be putting more energy into production of photosynthetic material (vegetative growth) to compensate for light-limited conditions, with less energy expended on reproduction. Kagan (1980) found that peduncle height was positively correlated to fruit production. If a plant is putting more energy into vegetative growth to compensate for competition for light resources production may be suppressed under heavier standing crop biomass or shaded conditions. This response may be a compensatory response for asymmetric competition when light is a limiting factor (Silverton and Doust 1993). The ability for Bradshaw's desert parsley to obtain enough energy to regenerate root reserves would become an important factor in the long-term persistence of the plant. Benjamin (1984) documented cultivated carrots (Apiaceae) with leaves pinned to lower canopy height produced roots that where 60% smaller than unpinned carrots. Furthermore, Huber et al. (1996) found that shading of parent *Bunium bulpocatanum* (Apiaceae) plants had negative impacts on offspring performance, which ultimately influenced final tuber weight via seedling characteristics. Under environmentally stressed conditions, or in some cases under natural circumstances, following reproduction a plant may also show evidence of reduced inflorescence (Ashman 1992). Reproductive Bradshaw's desert parsley commonly express dormancy (T. N. Kaye, Oregon State University, Department of Botany and Plant Pathology, Pers. commun.). Whether this is in response to energy expended during growth and reproduction, or in response to environmental stresses is unknown. Dormancy in vegetative and reproductive Bradshaw's desert parsley plants has been reported to occur for one to four growing seasons (T. N. Kaye, Oregon State University, Department of Botany and Plant Pathology, Pers. commun.).

The most notable factors in schizocarp production at the Oak Creek site were pasture and the amount of standing crop biomass present (Table 2 and Fig. 8b). Schizocarp production in the wooded pasture declined by a total of 214 schizocarps, while in the herbaceous pasture schizocarp production almost doubled (3,213 total schizocarp increase) during the second year of the study. Decreased schizocarp production in the wooded pasture may have been attributed to the amount of standing crop biomass (Fig. 8b), shaded habitat conditions, and decreased numbers of multiple umbelled plants (having a population weighted toward single-umbelled plants) during the second year of the study. In the herbaceous pasture, multiple umbelled plants increased during the second year of the study, especially those having three or more umbels, and were more common than in the wooded pasture during both years of the study (Table 2). During the pretreatment year in the wooded pasture, a total of 53% of all reproductive Bradshaw's desert parsley plants did not produce schizocarps, while only 25% of plants were nonreproductive in the herbaceous pasture. Single-umbelled plants (R1) were also more common in the wooded pasture (53% of reproductive plants) than the herbaceous pasture (34% of reproductive plants). The number of R1 plants is an important factor, because Bradshaw's desert parsley has an unusual breeding system with over 90% of the flowers produced being exclusively male; and hermaphroditic flowers occur mainly on the second umbel of a plant (Kagan 1980, Kaye 1992).

I documented differences in schizocarp production between years and pastures, but not among livestock grazing treatments at the Oak Creek site. In 1998, schizocarp yield was 1.5 times greater than schizocarp production recorded during the pretreatment year. While general habitat conditions (pasture type and standing crop biomass) may have been a factor in reproduction, other variables probably favored Bradshaw's desert parsley reproduction during the second year of the study. Differences in precipitation between the two growing seasons were probably an important factor. Mean annual precipitation was normal in 1997 (113.4 cm) when compared to the 20-year average (110.5 cm), but 1998 was substantially wetter (152.4 cm)(Oregon Climate Service data, Hyslop Farm, Station Number 351862, Corvallis). Although, Pendergrass et al. (1999) found no consistent correlations of Bradshaw's desert parsley population growth and reproduction with January through June precipitation or air temperatures, a positive relationship has been documented with fall and winter (September through February) precipitation at other sites in the Willamette Valley, Oregon (T. N. Kaye, Oregon State University, Department of Botany and Plant Pathology, Pers. commun. and unpubl. data).

Soils and hydrology may also help to explain the differences observed between the wooded and herbaceous pastures at the Oak Creek site. Soils in the two pastures differs in composition and texture (USDA 1987), and hydrology (data collection in progress), as well as the plant communities they support. At other Bradshaw's desert parsley sites in the Willamette Valley, soil redox potentials, soil nutrients, soil texture, and duration of flooding were all variables that were suggested to affect wetland-associated plant communities (Finley 1995) and Bradshaw's desert parsley morphological characteristics (Pendergrass et al.1999). Pendergrass et al. (1999) documented differences in plant size and reproductive potentials across four vegetative community types, with larger plants (producing more umbellets and schizocarps) occurring on the wettest of the four sites. In contrast, the largest plants at the Oak Creek study site occurred under shaded conditions, but schizocarp production was significantly reduced on those sites compared to the herbaceous pasture (Table 2). Experiments need to be conducted to separate factors such as light, standing crop biomass, plant competition, soil potentials and hydrology.

Species response to disturbance are governed primarily by their life history and physiological traits and by the characteristics of the disturbance (Chambers 1995). Species reproductive traits are especially important in determining the potential of a species to establish and persist following disturbance (Chambers 1995). Disturbance characteristics determine the success of different reproductive strategies and significantly influence community structure (Chambers 1995). When considering the possible effects of disturbances on plant communities, or individual species, it is not only important to understand the direct impact of the disturbance, but how that disturbance may alter other characteristics of a system as well.

Disturbance may be beneficial to Bradshaw's desert parsley by giving it a competitive advantage over neighboring vegetation. Most species of *Lomatium* in the Pacific Northwest are commonly associated with relatively open environmental conditions. Although species in this genus vary largely in elevation gradients and conditions in which they occur (elevation, soil types, etc.), the one similar characteristic appears to be all occur in relatively open or partially wooded areas (Kagan 1980, Hitchcock and Cronquist 1981, Willoughby 1987, Kaye 1992), and in areas where disturbance may reduce competition from other species. All species of this genus also flower relatively early in the season (February though May) (Thompson and Pellmyr 1989, Eastman 1990, Kaye 1992, Thompson 1998), which may reduce competition with later-flowering species. Future monitoring at the Oak Creek site and expansion of studies to investigate and compare other management alternatives is warranted.

SMALL MAMMAL IMPACTS ON BRADSHAW'S DESERT PARSLEY

My hypothesis that small mammal populations would be a significant factor in determining Bradshaw's desert parsley vigor, density, survival, or emergence of new plants response to livestock grazing was only partially supported by my data. While not an important factor in any of the plant vigor analysis, small mammal populations were important in explaining differences in plant densities, survival and new plant emergence between pastures and among treatments.

Small mammal populations may be one limiting factor affecting populations of Bradshaw's desert parsley at the Oak Creek site. Small mammal depredation of Bradshaw's desert parsley may be facilitated by the amount of standing crop biomass (or residual cover) and species-specific preferences for Bradshaw's desert parsley. Amount of standing crop biomass affected Bradshaw's desert parsley depredation at the Oak Creek site. Small mammal depredation was heaviest in the controls (no livestock grazing), followed by the livestock grazing treatments with heavy and moderate residual biomass. The least amount of Bradshaw's desert parsley depredation occurred in the most intensive livestock grazing treatments where cover was greatly reduced (Fig. 14). Changes in plant density, survival, and number of new plant emerged were also related to pasture type (Table 4 and Fig. 13). Structural complexity may determine small mammal presence (Van Apeldoorn et al. 1992, Andren 1994, Verts and Carraway 1998), abundance and occurrence within a particular area (Black 1968, Reynolds 1980). Small mammals may spend less time foraging on Bradshaw's desert parsley when cover is reduced and the habitat (herbaceous versus wooded pasture) is structurally simplified. In general, small mammal-habitat associations may be related to predator avoidance, relative food abundance and dietary preferences (Bowers 1990, Lima and Dill 1990, Newman 1991, Bowers and Dooley 1993). The presence of cover facilitates small mammal movements (Wegner and Merriam 1990, La Polla and Barrett 1993), and cover removal or fragmented habitat conditions may reduce populations and alter movement patterns (Reynolds 1980, Gains et al. 1992, Bowers and Dooley 1993, Ims et al. 1993, Diffendorf et al. 1995, Edge et al. 1995, Wolff et al. 1997). In western Oregon, Edge et al. (1995) reported that mowing or haying caused a decline in numbers and disrupted social organization of gray-tailed voles. However, small mammal response to cover removal may vary depending on species, age, and reproductive condition (Diffendorf et al. 1995, Edge et al. 1995, Wolff et al. 1997).

At Oak Creek study site, livestock grazing may have disrupted habitat use patterns of gray-tailed voles by removing cover and destroying well-traveled and established runways. Much of the depredation activity at Oak Creek appeared to occur within close proximity to established small mammal runways. Mack and Pyke (1984) documented much of the herbivory of cheatgrass (*Bromus tectorum*) occurred near vole runways.

Nutrient quality of vegetation may also be a major contributor in dietary selection by small mammals (Ostfeld and Klosterman 1986). Cockburn and Lidicker (1983) reported that California voles (*Microtus californicus*) fed mostly on legumes and broad-leaved forbs because of their nutritional value. Voles show a strong selection for green vegetation, especially forbs (Moen et al. 1993). At Oak Creek, much of the small mammal herbivory of Bradshaw's desert parsley occurred primarily on the vegetative portions of the plants, with very little depredation occurring on reproductive stems. Furthermore, small mammal herbivory most often occurred when the plant's schizocarps were green and developing; no herbivory was observed on browning or "cured" mature stems or fruits during either year of the study.

While voles may be responsible for much of the above-ground herbivory of Bradshaw's desert parsley at the Oak Creek study site, impacts from other small mammal species probably occurred. Deer mice comprised a majority of all small mammal captures at Oak Creek. Seeds can make up a majority of the deer mouse diet, however deer mice also feed on green vegetation (Hooven and Black 1976, Verts and Carraway 1998). Pocket gophers (*Thomomys* sp.) were also present at the Oak Creek site although none were captured during the study. In a ten-year study to evaluate biotic factors effecting *Lomatium dissectum*, Thompson (1998) attributed 43% of plant mortality directly to feeding on roots by pocket gophers. I suspect that much of the small mammal impacts to Bradshaw's desert parsley at Oak Creek can be attributed above-ground herbivory by voles, but the potential exists for impacts caused from below-ground herbivory by pocket gophers.

The long-term effects of repeated above-ground herbivory and timing of grazing events are not well known for this plant genera. However, because Bradshaw's desert parsley is a taprooted perennial, and the crown of the plant exists below the ground surface, the plant may be able to withstand repeated grazing over time as long as the crown of the plant is not affected and root reserves are sufficient to support the plant through harsh environmental periods. Moen et al. (1993) attributed the greatest damage to herbs to the position of meristematic tissue on the plant. If Bradshaw's desert parsley is able to sufficiently regenerate root reserves, via photosynthesis from above-ground biomass production, the effects of small mammal herbivory may remain negligible over time. Kaye (Oregon State University, Department of Botany and Plant Pathology, Pers. commun.) also suggests that vegetative and reproductive plants may lay dormant for one to four growing seasons and then re-emerge. Whether this is in response to the costs associated with reproduction from a previous year, or in response to herbivory, is not understood.

Although many studies have focused on evaluating effects of livestock grazing on specific plants and/or plant communities, few have evaluated the importance of small mammal herbivory in shaping these systems and effecting plant community dynamics. Understanding these relationships may be an important consideration because small mammals populations may play an important role in effecting plant community assemblages (Piemeisel 1938, 1945; Cockburn and Lidicker 1983; Mack and Pyke 1984; Pyke 1986, 1987; Moen et al. 1993; Diffendorfer et al. 1995). According to Pyke (1987: 825) the "ecological and evolutionary consequences of grazing are functions of six principle components: the severity of grazing, the frequency of grazing, the patchiness of grazing within the community, the selectivity of the grazer, the compensatory growth response of the plant to grazing, and the age of the plant or the plant part when grazing occurs."

To adequately assess the applicability of a particular land management practice for the protection and enhancement of a limited plant resource (particularly threatened or endangered species) it is increasingly important to assess the role of often overlooked ecological processes, which may have additive effects. On a microhabitat scale, reducing vegetative cover may provide secure sites for Bradshaw's desert parsley (increasing plant density, survival, and new plant emergence) by reducing the probability of depredation by small mammals, while at the same time reducing intraspecific competition from neighboring plants.

MANAGEMENT RECOMMENDATIONS

Late-season (post-schizocarp production) livestock grazing appears to have neutral or initially beneficial effects on Bradshaw's desert parsley at the Oak Creek study site. Number of newly emerged plants and multiple umbelled reproductive plant densities all increased among livestock grazing treatments. Small mammal herbivory on Bradshaw's desert parsley was also reduced in the livestock grazing treatments. However, because these results only represent one year post-treatment, the long-term effects of livestock grazing on Bradshaw's desert parsley cannot be adequately assessed. I recommend that the study plots established for this research be fenced with semi-permanent livestock exclosures and plots continue to be monitored over the next five years. Continued monitoring of plots will allow the refuge to set up a more complete and precise management prescription if livestock grazing is used as a management tool for the Oak Creek site. Continued monitoring of these plots will give baseline information as to intensity and periodicity of the various livestock grazing treatments necessary to maximize the benefit to Bradshaw's desert parsley (i.e., light grazing every other year, moderate grazing every third year, or heavy grazing every fifth year). The monitoring should include mapping individual plants (adding new plants to the pre-existing map records), collecting plant stage, plant fate, schizocarp production, and depredation data. I also suggest small mammal trapping efforts be continued periodically to supplement future plant data. Small mammal trapping could be conducted in mid-summer, immediately following mapping and plant data collection. This time of year corresponded with peak small mammal populations at the Oak Creek site during both years of my study. Application of livestock grazing treatments should also be considered for other times of the year (i.e., winter/early spring prior to plant emergence). However, using livestock during the critical growth and reproductive periods for Bradshaw's desert parsley is not recommended. Future evaluation of livestock grazing should also be expanded to assess application of various levels of herbivory on a rest-rotation on alternate years. In addition to further livestock grazing research and monitoring, future studies at the Oak Creek site could be expanded to include and evaluate other possible management practices such as tree and brush removal, application of prescribed fire and mowing compared to livestock grazing, incorporation of climatological data, and hydrological data (monitoring of ground water conditions at the site), which may also benefit Bradshaw's desert parsley. Prescribed burning and mowing has been used to manage other Bradshaw's desert parsley populations in the Willamette Valley, but has not been integrated into the management program at the Oak Creek site. The Oak Creek site would provide a unique opportunity to directly evaluate and compare the three management strategies. Because there were habitat type differences in many of the aspects of this study, clearing brush and trees from the wooded pasture and combining those areas with future research may provide for better management assessment of a particular strategy. In conjunction, I recommend a different study design or increased sample size, in order to form a more sensitive analysis for detecting differences. Future research should also assess the effects of the various management practices on a plant community level in addition to their effects on a single species. In the interim period, I recommend that livestock grazing continue at light to moderate intensity (remaining standing crop biomass between 670 to 969 kg/ha) outside of the exclosure areas to reduce the accumulation of residual vegetation until more precise management prescriptions can be formulated.

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