AN ABSTRACT OF THE THESIS OF

Margaret S. Laws for the degree of Master of Science in Rangeland Resources presented on November 23, 1999. Title: Control of *Lepidium latifolium* and Restoration of Native Grasses.

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Abstract approved: __________

David A. Pyke

Lepidium latifolium L. (perennial pepperweed, LEPLA) is an exotic invader throughout western North America. At Malheur National Wildlife Refuge (MNWR) in southeast Oregon, it has invaded about 10% of meadow habitats that are important for wildlife. This study's objective was to determine the most effective and least environmentally harmful treatment to control this weed and restore native vegetation using integrated pest management techniques. During summer 1995, nine 0.24-ha plots in three meadows infested with *L. latifolium* at MNWR were randomly assigned to a treatment with metsulfuron methyl herbicide, chlorsulfuron herbicide, disking, burning, herbicide (metsulfuron methyl or chlorsulfuron) then disking, herbicide (metsulfuron methyl or chlorsulfuron) then burning, or untreated. Changes in *L. latifolium* ramet densities and basal cover of vegetation, litter, and bare soil were evaluated in 1996 and 1997. Sheep grazing was evaluated as a treatment for reduction in flower production along roadsides and levees during summer 1997. Revegetation treatments of seeding, transplanting or natural (untreated) revegetation were attempted at plots treated with chlorsulfuron, disking, chlorsulfuron then disking, and at untreated plots from October 1996 through September 1997. Chlorsulfuron was the most effective control treatment with greater than 97% reduction in *L. latifolium* ramet densities two years after treatment. Metsulfuron methyl was an effective control (greater than 93% reduction) for one year. Disking was ineffective. Burning was ineffective at the one site where sufficient fine fuels existed to carry fire. Herbicide treatments were associated with increased grass and reduced forb cover. Disking was associated with reduced grass and litter cover. Disking combined with either herbicide treatment was associated with reductions in all plant cover (49 to 100%), increased bare ground, and invasion by other weedy species such as *Cirsium arvense* (L.) Scop. (Canada thistle, CIRAR) and *Bromus tectorum* L. (cheatgrass, BROTE). Ungrazed *L. latifolium* averaged 4513 flowers per ramet. Sheep grazing reduced *L. latifolium* flower production by at least 98%. Revegetation treatments were unnecessary in sites treated with chlorsulfuron and were ineffective at all treatment sites.

Control of *Lepidium latifolium* and Restoration of Native Grasses

by

Margaret S. Laws

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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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Margaret S. Laws, Author

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CONTRIBUTION OF AUTHORS

Dr. David A. Pyke, Kevin Kilbride, and Fred Paveglio were involved in the design, analysis, and writing of each manuscript. Joel David assisted with site selection, treatment application, data collection, and coordinated efforts between agencies.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF APPENDIX FIGURES

DEDICATION

This thesis is dedicated to all the hard-working people at

Malheur National Wildlife Refuge.

Control of *Lepidium latifolium* and Restoration of Native Grasses

INTRODUCTION

Natural resources are economically and esthetically important. Agriculture, recreation, and tourism associated with wildlife enjoyment and harvest are major industries. The escalating encroachment by invasive weeds and their effects on wildlife, livestock, native vegetation, and crops is an area of growing concern to a wide segment of the population. Ecologically sound, cost-effective techniques to reduce weed infestations and restore native plant diversity are needed. One invasive weed which public interests desire to control is *Lepidium latifolium* L. (perennial pepperweed, LEPLA) (Svejcar 1997).

L. latifolium is designated a noxious weed in several western states, including Oregon, and forms a rapidly spreading pernicious infestation. It is native to temperate parts of Europe, the Mediterranean basin, central and southwestern Asia (Lye 1989) and is thought to have been accidentally introduced into the United States as a contaminant of *Beta vulgare* L. (sugar beet) seed shipments (Blank and Young 1997; Weber 1989). It has now invaded all the western states, coastal New England, Canada, Mexico, northern Europe, and Australia (Blank and Young 1997; Whitson 1996; Young et al. 1995). *L. latifolium* occurs in a variety of habitats, including coastal marshes, high altitude meadows, and alkaline sinks in desert valleys (Weber 1989). It typically invades riparian habitats, then spreads to meadows and pastures where it infests disturbed sites, forming dense monotypic colonies which exclude many other herbaceous species (Blank and Young 1997; Tosso et al. 1986; Young et al. 1995). On the Malheur National Wildlife Refuge (MNWR) in eastern Oregon, *L. latifolium* is estimated to have displaced 5% (about 500 ha) of meadow and 10% (about 2500 ha) of upland vegetation (U.S. Fish and Wildl. Serv. unpubl. data). Its presence is deemed to significantly reduce native hay quality, resulting in economic losses (Young, Palmquist, and Wotring 1997). Young et al. (1995) have speculated that it may be harmful to livestock.

L. latifolium is a cool-season, broadleaf perennial of the Brassicaceae that reproduces through root stocks and seeds (Blank and Young 1997; Hitchcock and Cronquist 1973; Young et al. 1995). Seed production and viability are high. Blank and Young (1997) mentioned that production from stands of 200 ramets m^{-2} extrapolated to 16 billion seeds ha^{-1}. Miller et al. (1986) reported germination rates from 96 to 100% over a wide range of alternating or constant temperatures and no significant differences in germination for seeds from the same site collected in different growing seasons, or from different sites in the same season. Seeds are not dormant and disperse at irregular intervals throughout the winter (Young et al. 1995). *L. latifolium* sprouts earlier than many native plants in the Great Basin; I observed it to be the only green plant of note in some locations at MNWR during March 1995. When above ground portions are killed or damaged, root and crown buds sprout rapidly (Blank and Young 1997; Young et al. 1995). Wotring et al. (1997) reported that root stock sections less than 2.5 cm long and 0.5 to 4.0 cm diameter can sprout new plants.

These traits make mechanical control difficult. No biological control has been identified; import of exotic insects or plant pathogens as control agents requires careful scrutiny since such pests might attack related native endangered or valuable crop species (Birdsall et al. 1997). Some herbicide treatments, such as sulfonylurea compounds, may be effective, but application is complicated by proximity of *L. latifolium* infestations to open water (Young et al. 1995). Small plot experiments using chlorsulfuron to reduce *L. latifolium* cover have shown promising results (Reid et al. 1997; Young et al. 1998) but none have conducted experiments using large field application techniques and equipment, nor have they evaluated the impacts on co-occurring plants in native communities.

The National Wildlife Refuge System Improvement Act of 1997 mandates maintenance of biological integrity, diversity, and environmental health of refuge lands; invasive exotic species are identified as one of the threats to biological integrity of refuges (Hood 1998). Management goals for MNWR include preservation and reintroduction of natural diversity and abundance of flora and fauna on refuge lands with emphasis on native or indigenous species (U.S. Fish and Wildl. Serv. 1985). Restoration of rangeland ecosystems depends on biotic and abiotic interactions that affect plant establishment (Pyke and Archer 1991). Native plants that volunteer from naturally distributed seed or root stocks may not establish and fully occupy the void left by a removed weed. If the site is not fully occupied, other undesirable species may invade and occupy it. Since grasses often dominate undisturbed meadows and adjoining upland ecosystems, seeding or transplanting native grasses might facilitate their establishment while reducing the potential for *L. latifolium* or other noxious weeds to occupy vacated sites. A short-lived "nurse crop" may provide a further option to protect sites from reinvasions after weed control. Seeding or transplanting a fast growing, but locally short-lived species to occupy vacated sites may provide ameliorated microsite conditions conducive to growth of native species as the nurse crop population declines. Nurse crops have been used successfully to reduce weed competition and protect seedlings from wind and severe temperatures in irrigated pastures (Vallentine 1989).

In 1995, we initiated tests of several chemical and mechanical controls of *L. latifolium* at MNWR (Kilbride et al. 1997). The current study examined the changes in *L. latifolium* density and in plant community cover and composition following an integrated series of control treatments (herbicide, disking, burning, and selected combinations thereof). We anticipated that effective *L. latifolium* control treatments would affect native plant populations as well, necessitating efforts to restore native vegetation. Revegetation of native grasses was attempted by seeding and transplanting *Leymus triticoides* (Buckley) Pilger (creeping wildrye), *Leymus cinereus* (Scribner & Merr.) A. Löve (basin wildrye), and *Elymus elymoides* (Raf.) Swezey (bottlebrush squirreltail). The possibility of using *Agropyron intermedium* (Host) Beauv. (intermediate wheatgrass) as a nurse crop was also investigated.

Eradicating new, isolated weed populations greatly enhances the overall effectiveness of control measures (Moody and Mack 1988). *L. latifolium* seeds are an important source of new invasions, given the significant amount of seed produced coupled with its high rate of germination (Blank and Young 1997; Miller et al. 1986). Reducing sexual reproduction should reduce the spread of *L. latifolium*. Therefore, we investigated the use of sheep grazing to control flower production of *L. latifolium*.

MATERIALS AND METHODS

Study Site Descriptions

Study sites consisted of three wet meadow areas and a canal levee at MNWR. The MNWR is located in the Malheur-Harney Lakes Basin (Oregon Closed Basin), about 50 to 115 km south of Burns in Harney County, Oregon (Figure 1). It includes more than 1.2 million ha of drainage with no outlet to the sea. The Refuge covers over 75,000 ha comprised of 34% uplands, 33% marshes, 17% dry alkali lake beds, 14% meadows, 1% crop lands, and less than 1% riparian areas (U.S. Fish and Wildl. Serv. 1985). It is located in the Humboldt Major Land Resource Area (Soil Conserv. Serv. 1958). Elevation at the MNWR headquarters is 1250 m above sea level (U.S. Fish & Wildl. Serv. 1985).

The regional climate is characterized by cold, moist winters and hot, dry summers. Annual precipitation ranges from 228-304 mm. The precipitation occurs primarily as snow from November through March. Mean monthly precipitation ranges from 11 mm in July and September to almost 30 mm in May (Figure 2). Localized convection storms occur during summer months. The area has a frost-free period of 110 to 140 days. The mean annual temperature is 11°C; mean monthly temperatures range from -10°C in January to 30°C in August (Figure 3).

The West East Big Sagebrush (BS) field (T27S, R31E, Section 33, Coyote Buttes quadrangle), Oliver Springs (OS) field (T28S, R31E, Section 25, Diamond

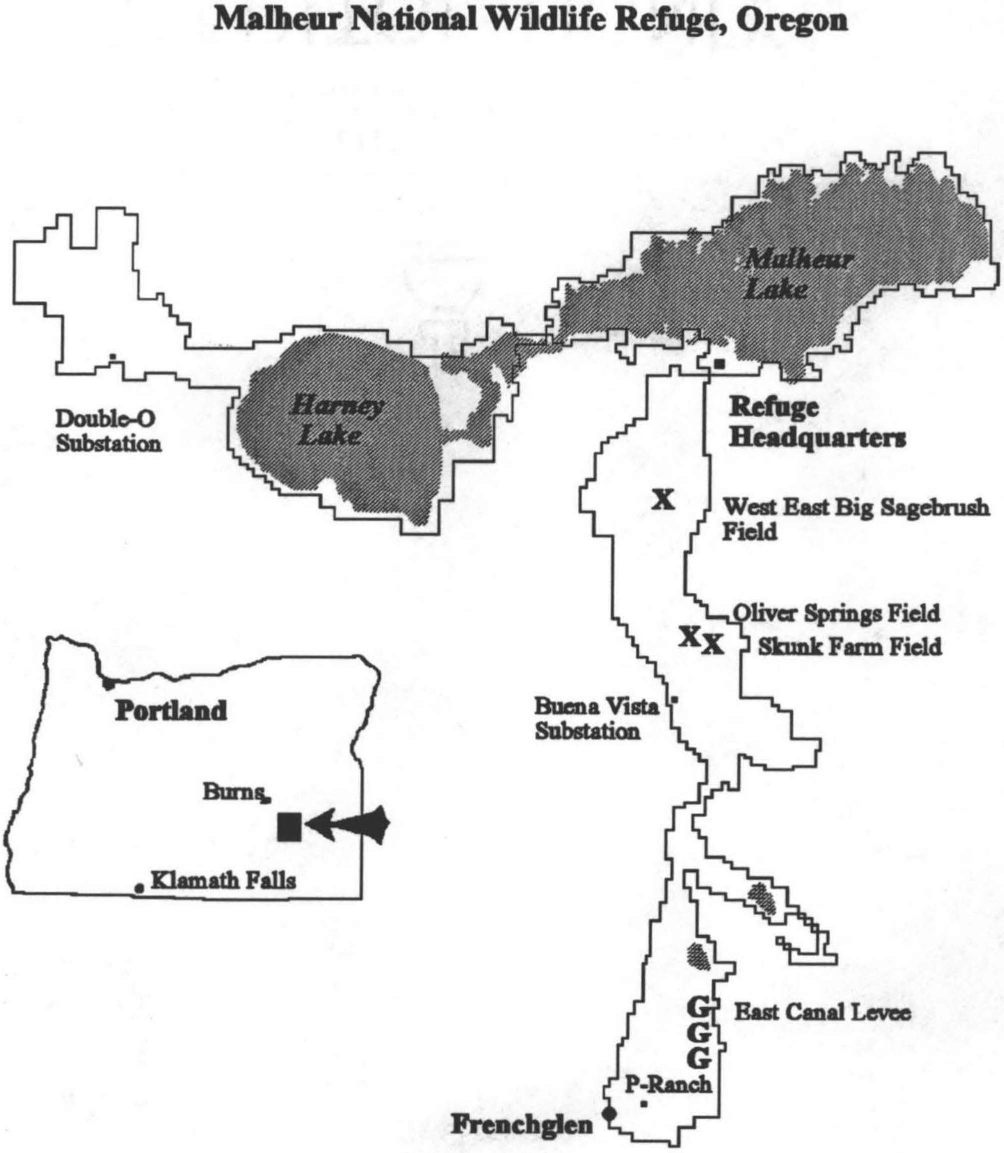

Figure 1. Location of wet meadow (X) and grazing (G) study sites where *Lepidium latifolium* control treatments and native grass restoration treatments were conducted at Malheur National Wildlife Refuge, Oregon.

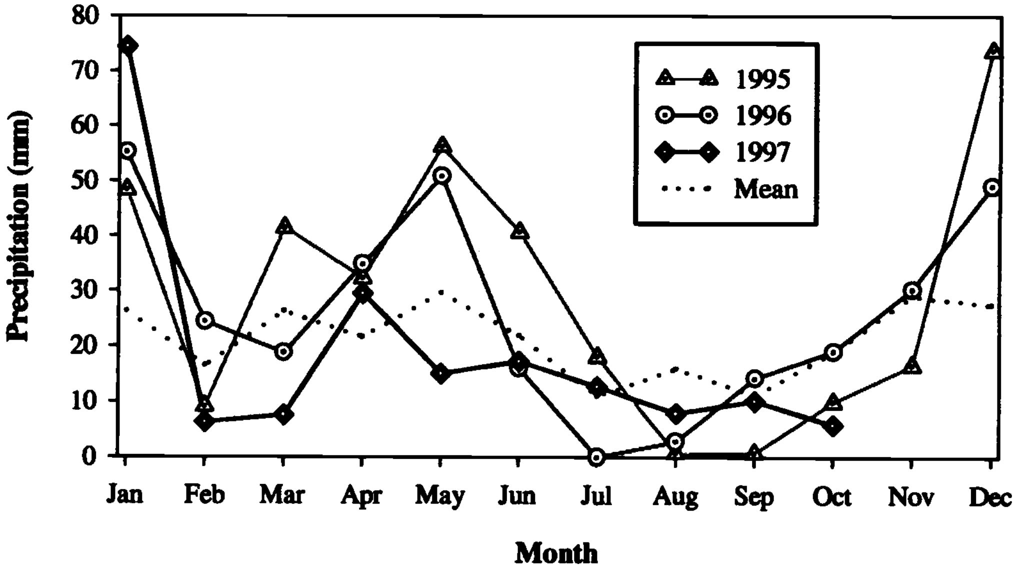

Figure 2. 1995 to 1997 and 30-year mean monthly precipitation at Malheur National Wildlife Refuge, Oregon (Oregon Climate Service, Oregon State University).

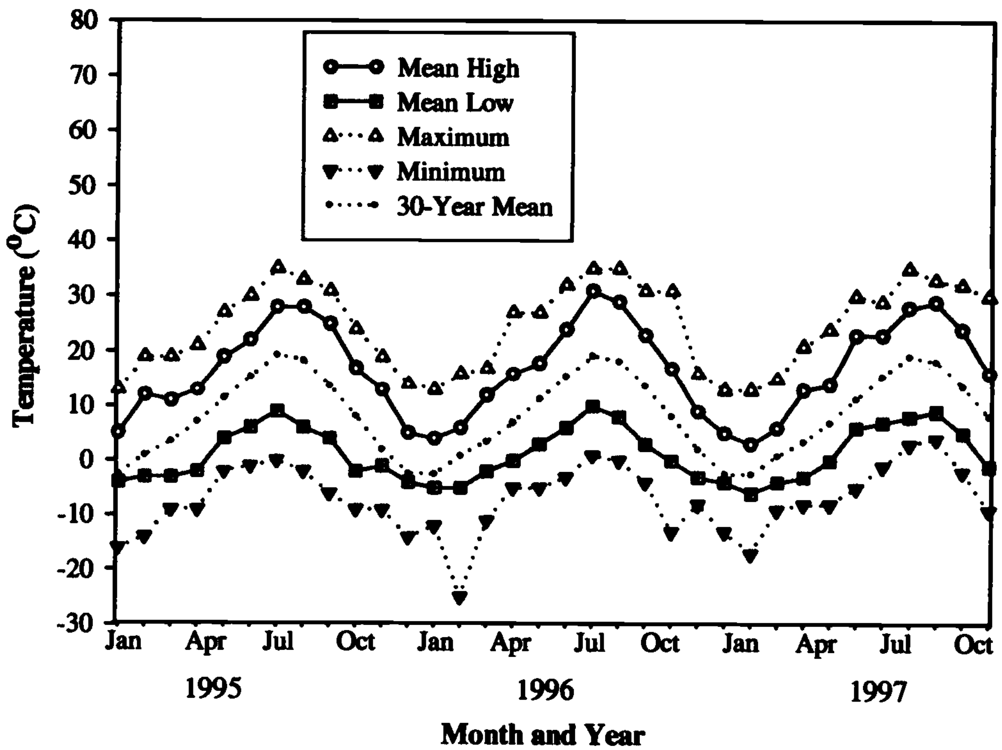

Figure 3. 1995 to 1997 maximum, minimum, and 30-year mean monthly air temperatures at Malheur National Wildlife Refuge, Oregon (Oregon Climate Service, Oregon State University).

Swamp quadrangle), and Skunk Farm (SF) field (T28S, R31E, Sections 25-26, Diamond Swamp quadrangle) were selected as 1995 treatment replicates because of their large dense stands of *L. latifolium*. Soils at the three field sites were dominated by the Skunkfarm series (Skunkfarm-Simmons-Doubleo complex) which was characterized as very deep, somewhat poorly drained soils formed in alluvium from mixed igneous rock sources, possessing a dark grayish brown silt loam surface layer about 5 cm thick over very dark grayish brown, brown and pale brown clay loam upper subsoil about 40 cm thick and lower subsoil of pale brown loam about 30 cm thick with a substratum of brown fine sandy loam to a depth of 150 cm (Natural Resources Conserv. Serv. unpubl. data). Both OS and SF fields had neutral to slightly acid soils (pH of 6.5 to 6.8). The BS field was wetter, with large areas exhibiting anaerobic soil conditions. It had moderately to strongly alkaline soils (pH of 8.3 to 8.8) and contained considerably more residual native grasses than the OS and SF fields.

Herbaceous wet meadow species characterized the three field sites before encroachment by *L. latifolium*. Perennial grasses such as *L. cinereus*, *L. triticoides*, *Poa secunda* J. Presl (Sandberg bluegrass), and *Distichlis spicata* (L.) Greene (inland saltgrass) dominated drier areas, while *Juncus* sp. L. (rushes), *Carex* sp. L. (sedges) and *Typha latifolia* L. (common cattail) dominated wetter locations; adjacent uplands were dominated by *Artemisia tridentata* Nutt. ssp. *wyomingensis* Beetle and Young (Wyoming big sagebrush) or *Sarcobatus vermiculatus* (Hook.) Torr. (black greasewood) and associated species (U.S. Fish & Wildl. Serv. 1985).

The East Canal levee (T31S, R32-1/2E, Drewsey Quadrangle) was selected for the 1997 grazing treatment because of its dense stands of *L. latifolium* in close proximity to water, where herbicides could not be applied. The area had water and fencing boundaries conducive to herding. The levee soils consisted of dredged spoil from the canal compacted by heavy equipment and graveled to serve as a road.

The East Canal levee was a disturbed site, characterized primarily by herbaceous riparian vegetation including *Juncus* sp., *L. cinereus*, *Chenopodium album* L. (common lambsquarters, CHEAL), *Cirsium arvense* (L.) Scop. (Canada thistle, CIRAR) and some residual woody species including *Salix* sp. L. (willow) and *Ribes aureum* Pursh (golden currant) (U.S. Fish & Wildl. Serv. 1985).

Chemical and Mechanical Treatments

Three replicate fields (OS, SF and BS) had nine 0.24-ha (36 by 66 m) plots established within dense stands of *L. latifolium*. Each plot was randomly assigned to one of nine treatments in 1995. Treatments in each replicate field included herbicide applications of chlorsulfuron (Telar®), applied at 63 g ai ha^{-1} (3 oz per acre), or metsulfuron methyl (Escort®), applied at 16.8 g ai ha^{-1} (1 oz per acre); disking; prescribed burning; chlorsulfuron followed by disking; metsulfuron methyl followed by disking; chlorsulfuron followed by burning; metsulfuron methyl followed by burning; and an untreated plot.

Chlorsulfuron and metsulfuron methyl herbicides were selected for their mode of action, which includes low toxicity to animals and many non-target plant species, as well as for their relatively short environmental persistence. Both herbicides are systemics which are absorbed by both roots and foliage, rapidly inhibiting plant growth. As sulfonylurea compounds, they inhibit branched-chain amino acid biosynthesis. They target the enzyme acetolactate synthase (ALS), leading to depletion of the amino acids valine, leucine, and isoleucine, and accumulation of 2-oxobutyrate and its transamination product, alpha-amino-*n*-butyrate (Retzinger and Mallory-Smith 1997; Rhodes et al. 1987). Their dissipation in the soil is primarily by hydrolytic degradation of the sulfonylurea linkage. This linkage is relatively stable in neutral and alkaline solutions but the hydrolysis increases with acidity (Brown et al. 1999). Since the hydrolytic cleavage is affected by pH, soil pH impacts the residual persistence of these herbicides. Thus, this class of herbicides has residual persistence on neutral to alkaline soils but degrades readily on acidic soils (Beyer et al. 1987). Mineralization of chlorsulfuron or metsulfuron methyl and their degradation products is mediated by soil microorganisms to yield carbon dioxide and unextractable soil-bound residues; metabolism in animals is minimal due to rapid elimination (Roberts 1998).

Herbicides were applied at their maximum recommended rates for the target species to identify maximum effectiveness. The range of application rates recommended by the manufacturer for chlorsulfuron was 21 to 63 g ai ha^{-1} (1 to 3 oz per acre). Metsulfuron methyl had only one application rate listed for *L.*

latifolium: 16.8 g ai ha^{-1} (1 oz per acre). Herbicides were mixed with a silicon-based nonionic surfactant (Sylgard® 309) at 0.06 ml L^{-1} of spray solution to increase adherence to the plants' surface area and thereby enhance plant uptake of the herbicide. The herbicide mixtures were applied by tractor-mounted broadcast sprayer on mornings with less than 8 km h^{-1} wind speed and no precipitation within 24 h before treatment. Herbicides were applied during *L. latifolium* bud development on June 13 and 15, 1995 at OS and SF and at the start of flowering on July 5, 1995 at BS. The delayed applications of herbicide at BS occurred because of standing water followed by muddy conditions on the field through the end of June that precluded tractor operation.

Mechanical treatments of disking or prescribed burning were selected for evaluation since refuges throughout the national wildlife refuge system commonly have the equipment and qualified operators, familiarity with the techniques, and additional specialized training requirements are not necessary. Such factors can be important in determining the cost-effectiveness of control efforts.

Disk treatments used a 4.3 m-wide disk (91.4 cm blades) to unearth, cut and dry root stocks and produce a smooth seedbed for germination of the soil seed bank. Each disk treatment consisted of three to six passes of the equipment in different directions to ensure breakdown of the sod. Disk-alone treatments were applied twice, on July 11 and August 23, 1995. Herbicide-disk treatments received herbicide on June 13-July 5, 1995 and were not disked until August 23, 1995, to allow the herbicide to have its full impact.

Burn treatments were mowed to a stubble height of 10 cm on October 17, 1995 using a tractor-propelled brush mower. Cut vegetation was left to dry for one week to increase fire heat at the soil surface. Fires were ignited by drip torches using back-fire techniques to slow the spread and increase the heat at the soil surface. Herbicide-burn treatments received herbicide on June 13-July 5, 1995 and were mowed on October 17, 1995 then were burned one week later.

Fuel biomass was measured before and after burning to determine the amount of fuel consumed by the fire. All live and dead vegetation was collected from ten randomly located 1-m^2 plots within the 0.18-ha (30 by 60 m) core area (Figure 4) of each burn treatment. *L. latifolium* was sorted into separate samples from other vegetation, then all samples were oven-dried for 48 h at 21°C and weighed. The amount of fuel consumed was calculated as the difference between the average of the sum of live and dead vegetation from before the fire and the average of the unburned vegetation remaining after the fire.

Fire behavior was measured independently by three observers and averaged for each behavior measurement. Each observer measured flame length, height, and depth. One observer measured rate of spread (m s^{-1}) between eight fenceposts that were equally spaced across the planned direction of the burn. Another observer measured a minimum of eight residence times (s) of the flame front at each fencepost. Using these measurements, three fire intensity calculations were made. Fireline intensity (I_{FL}, kW m^{-1}), the rate of energy released along one meter width of flame front was calculated from flame length (Byram 1959). Reaction intensity

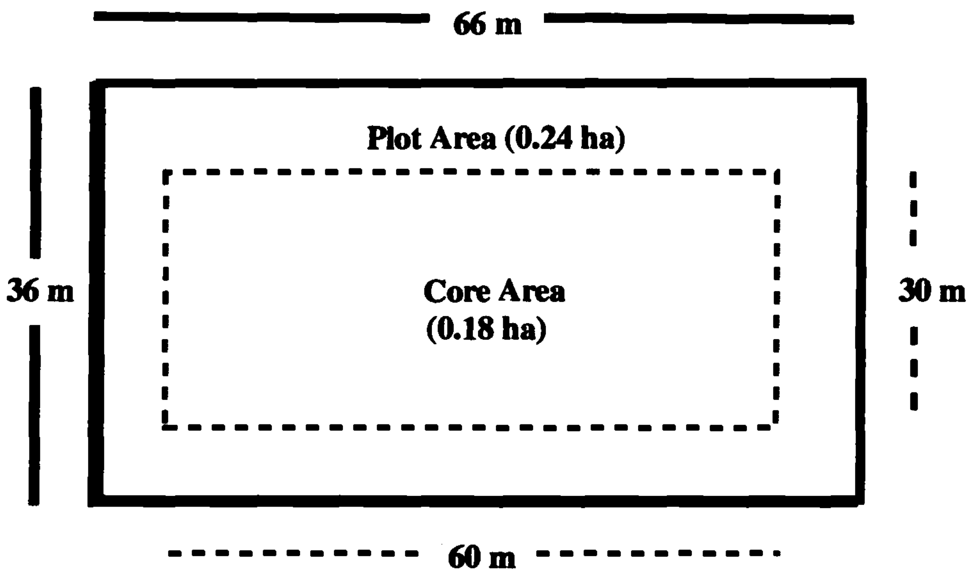

Figure 4. Plot and core area dimensions for wet meadow treatments to control *Lepidium latifolium* at Malheur National Wildlife Refuge, Oregon.

(I_R, kW m^{-2}), the rate of energy release per square meter of flame zone was calculated using flame depth and I_{FL} (Alexander 1982). Heat per unit area (H_A, kJ $^{-2}$), was estimated by using 18,700 kJ kg^{-1} for the heat of combustion of consumed forbs adjusted by subtracting 24 kJ per percent moisture in the fuel (Van Wagner 1972) and the rate of spread (Rothermel and Deeming 1980).

Vegetative responses to treatments were assessed in the core area in each plot (Figure 4) to minimize edge effects. The core area was sampled during late May to early June in 1995 (pre-treatment), 1996, and 1997 (1 and 2 yr post-treatment). Each plot's core area was divided in half lengthwise and four 30-m transects were randomly located in each half. Density and cover data were collected at five regular intervals (6 m apart) along each transect. *L. latifolium* density (ramets m^{-2}) at each transect location was counted in a rectangular (1.0 by 0.35 m) sampling frame. Basal cover (%) of live plant species (V), bare soil (B), and litter (R) was determined using a 50-point (4 cm between points) frame at each transect location (Bonham 1989). Density plots and cover frames were subsamples along each transect and were averaged to provide transect values; transects were subsamples of a core area and were averaged to provide core area values (a single replication) for analysis. *L. latifolium* densities in the first and second years after treatment were transformed to relative proportions of the pre-treatment densities in each core area for analysis. A one-way ANOVA, using a split-plot in time design, compared the relative *L. latifolium* ramet density as the dependent variable against treatment, year, and their interactions as independent variables (SAS 1996). Least-squares means were compared to determine significant differences among factors. Basal cover values were calculated by transect and analyzed for changes by treatment over time using principal components analysis (PCA) with percent bare ground, residue (litter), *L. latifolium*, forbs, grasses, sedges and rushes, *Bromus tectorum* L. (cheatgrass, BROTE), *C. arvense*, shrubs and aquatic plants as the principal components (PC-ORD 1996).

Grazing Treatment

Sheep grazing as a treatment to control *L. latifolium* reproduction was tested at MNWR during summer 1997. Sheep grazed on both edges of a gravel road atop the East Canal levee from the intersection with Five-Mile Road south 9.2 km (8.53 vegetated ha). From June 9 to July 31, 1997, 440 ewe-lamb combinations were herded through the area twice for a total of 23,055 sheep-use days or 15 AU ha^{-1} during the 53-day study period. The levee on the opposite side of a flooded ditch, which paralleled the East Canal levee, was the ungrazed comparison.

Six 100-m transects were randomly located within *L. latifolium* infestations on each of the grazed and ungrazed sides of the East Canal. *L. latifolium* ramets were collected on August 4 by randomly alternating between grazed and ungrazed sites. From a randomly selected starting point within the first 10 m of each transect, the closest *L. latifolium* ramet was collected every 10 steps (about 1 m per step) along the transect. Ramets were cut at ground level, stored individually in paper bags, and the numbers of flowers per ramet were counted and recorded. Because sheep were present before *L. latifolium* began to flower, no pre-treatment data were collected. The numbers of flowers per ramet were averaged per transect by grazed or ungrazed treatment and analyzed for differences between treatments using a two-sample t-test, PROC TTEST (SAS 1996).

Revegetation Treatments

In 1995, it was envisioned that treatments to control *L. latifolium* might adversely effect native vegetation, necessitating restoration of native plant populations. Since the broad spectrum herbicides being tested were known to harm many broadleaf species and some grasses, revegetation using grass species was deemed more likely to succeed. Revegetation treatments were to be attempted on sites where *L. latifolium* control treatments were the most effective. In 1996, it became apparent that the most effective treatments against *L. latifolium* had the least need for revegetation efforts; native grasses grew abundantly after herbicide treatments removed the *L. latifolium*. Sites that had the greatest need for native revegetation were those treated with disking, chlorsulfuron followed by disking, and untreated plots. Revegetation treatments were applied in the core areas of these and of sites treated with chlorsulfuron alone.

In a split-split plot design, each core area was divided into fifteen 2-m by 6-m plots that were randomly assigned to one of the following revegetation treatments: seeding, transplanting, or no treatment. Revegetation of three native grass species (*L. cinereus, L. triticoides,* and *E. elymoides*) was attempted. Seeds for these species were collected at MNWR during 1995 and 1996, from plants located within 1 km of treatment plots to provide local genotypes. A secondary supply was acquired from the Natural Resources Conservation Service (NRCS) Plant Materials Center in Bridger, Montana (*L. cinereus* "Trailhead," *L. triticoides*

"Shoshone,", and *E. elymoides* accession 9019219). One introduced species, *A. intermedium*, which is short-lived when grown locally, was attempted as a nurse crop. Seeds for this species were also obtained from the NRCS Plant Materials Center in Bridger, Montana (*A. intermedium* "Rush"). Seeds were cleaned and tested for germinability and viability using AOSA (1993) techniques. Germination for native grass species was 88% (NRCS seed) and 39% (local seed) for *L. cinereus*, 97% (NRCS) and 14% (local) for *L. triticoides*, and 1% (NRCS) and 4% (local) for *E. elymoides*. Germination for *A. intermedium* was 92% (NRCS seed only).

Seeding treatments were seeded in October 1996 using an experimental size rangeland drill (a "no till" drill). Each of the four species (2,000 seeds per species) was sown as separate monocultures at each selected core area. A mixture of the four species (500 seeds each) was also sown at each selected core area. The four monocultures and one mixture were sown in five 6-m rows, spaced 30 cm apart, at a depth of 1 to 2 cm. Row ends were marked with different colored survey flags for each species and untreated rows. A master layout map was maintained for reference. Once each month from June through September 1997, any live seedlings were identified and recorded by species, row, and distance from the row-end flags. Survival was averaged for revegetated and untreated subplots within each *L. latifolium* treatment. Plants still alive in September were considered established.

Transplants were grown at the MNWR headquarters during April and early May 1997. Seeds were planted in 15 cm deep by 2 cm diameter tubes filled with a mix of 25% sand, 25% vermiculite, and 50% soil from the recipient site. Subsequent seedlings of each species were transplanted in five rows, 20 per row, 30 cm apart, in their treatment plots during June and early July 1997. Row ends were marked with colored survey flags using the same color assignments as the seeded plots. At transplant, each seedling was provided 1 L of water, applied 0.5 L before transplantation to moisten the site and 0.5 L after transfer. Survival of each transplant was monitored using methods described for seed survival, above.

Establishment was analyzed as an ANOVA using PROC GLM (SAS 1996). Establishment data were log-transformed, with fate (established or dead) assigned as the dependent variable and *L. latifolium* control treatment, revegetation treatment, and grass species as independent variables.

RESULTS

Chemical and Mechanical Treatments

There were significant differences in *L. latifolium* density (F=9.61, p=0.0014) among control treatments (Figure 5). Chlorsulfuron was the most effective control treatment with more than 97% reduction in *L. latifolium* ramet

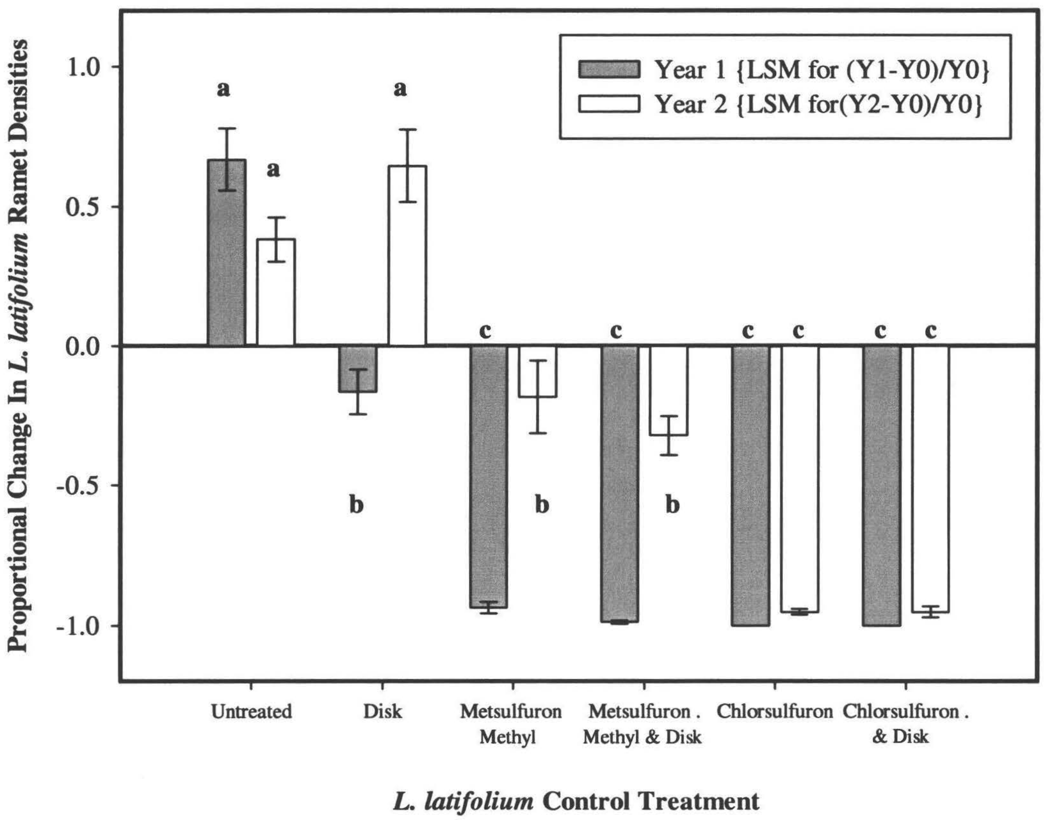

Figure 5. Least-squares means (+/- 1 SE) proportional changes in *Lepidium latifolium* densities by control treatment from pre-treatment (Y0) to one- (Y1) and two-years (Y2) post-treatment for three fields at Malheur National Wildlife Refuge, Oregon.

densities two years after treatment (Table 1). Metsulfuron methyl reduced ramet densities more than 93% for one year with reduced effectiveness the second year. Disking reduced ramet densities about 29% in the first year after treatment, but resulted in a 43% increase over pre-treatment levels after two years. Chlorsulfuron followed by disking reduced ramet densities more than 94% for two years. Metsulfuron methyl followed by disking reduced ramet densities more than 99% in year one with loss of effectiveness thereafter.

Table 1. Mean stem densities per m^2 (± 1 SE) of *Lepidium latifolium* by treatment from pre-treatment (Year 0) to one- (Year 1) and two-years (Year 2) post-treatment for three fields at Malheur National Wildlife Refuge, Oregon.

Lepidium latifolium **Control Treatment**	**Year 0 (1995)**	**Year 1 (1996)**	**Year 2 (1997)**
Untreated	31 (2.2)	44 (3.5)	36 (2.5)
Chlorsulfuron	41 (4.8)	0 (0)	1 (0.3)
Metsulfuron methyl	27 (2.1)	2 (0.5)	21 (3.7)
Disk	28 (2.8)	20 (2.2)	40 (3.7)
Chlorsulfuron/Disk	21 (1.5)	0 (0)	1 (0.3)
Metsulfuron methyl/Disk	33 (3.2)	0 (0.2)	16 (2.5)
Burn	25 (1.6)	30 (3.8)	33 (4.1)
Chlorsulfuron/Burn	53 (8.4)	0 (0)	1 (0.5)
Metsulfuron methyl/Burn	42 (7.4)	1 (0.5)	14 (3.3)

Burn treatments were unsuccessful at OS and SF. Results of the single successful fire replicate (BS) were therefore excluded from the overall analyses. The BS replicate demonstrated a 21 to 34% increase in *L. latifolium* ramet densities over time with the burn treatment alone. Combinations of herbicides followed by burning paralleled the reductions noted with herbicides alone: two years of greater than 99% reduction in *L. latifolium* ramet densities with chlorsulfuron/burn and a first-year reduction of *L. latifolium* ramet densities with metsulfuron methyl/burn of more than 97%, followed by an increase in densities the second year, giving a two-year decrease of about 67% (Figure 6). There was generally more available fuel for fire at BS ($\bar{x} \pm 95\%$ C.I., 68.7 ± 54.7 g m^{-2}) but amounts were more variable than at the other sites (OS 48.4 ± 6.7 g m^{-2}; SF 46.0 ± 11.5 g m^{-2}). BS also had a smaller proportion of its biomass derived from *L. latifolium* (live=10%, dead=5%) and proportionally more other live vegetation (55%) than the other sites (live *L. latifolium*=22 and 19%; dead *L. latifolium*=40 and 37%; live other=8 and 15% at OS and SF, respectively). On all burned sites, 82 to 94% of the fuel biomass was burned.

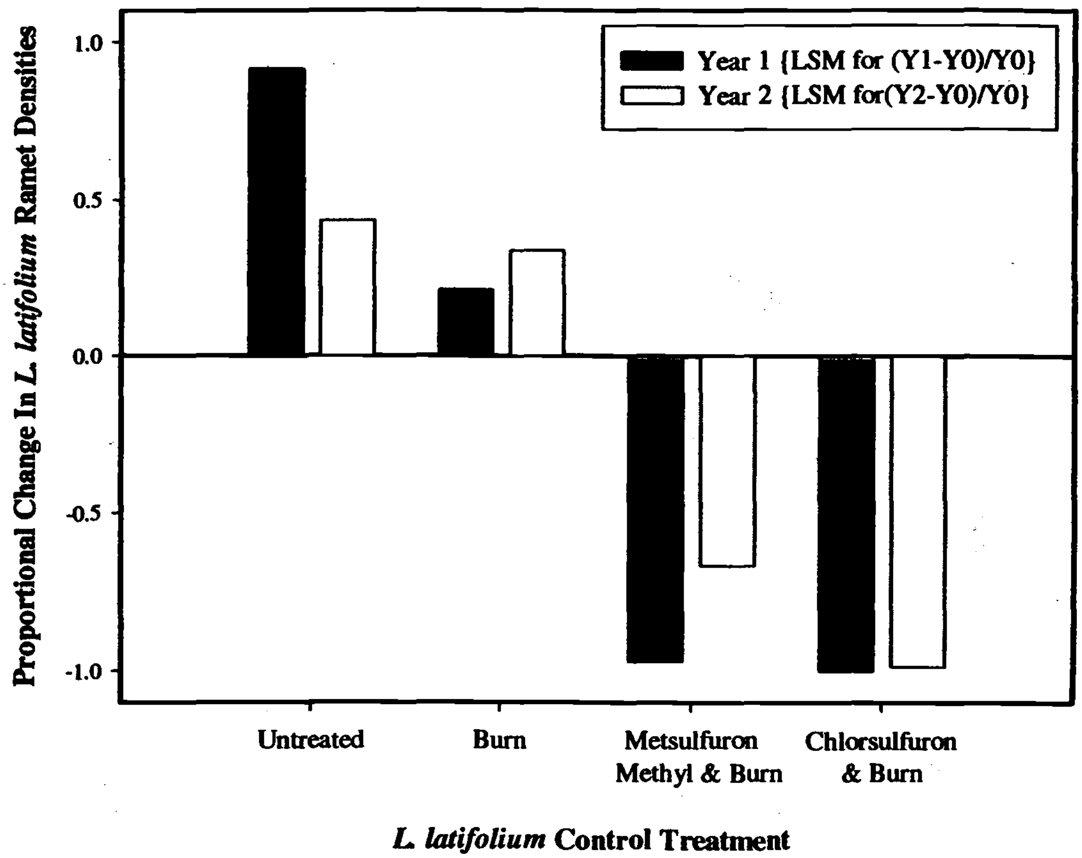

Figure 6. Proportional changes in *Lepidium latifolium* ramet densities with burn treatments from pre-treatment to one- and two-years post-treatment, using least square means (LSM) at West East Big Sagebrush (BS) Field, Malheur National Wildlife Refuge, Oregon.

Vegetative cover and species composition also changed significantly after treatments to control *L. latifolium* (Figures 7, 8, and 9). Treatments of disking and herbicide followed by disking sorted along axis 1 of the Principal Components Analysis (PCA) and were associated with increases in bare ground (r=-0.908) and decreases in residual material (r=0.867), grass (r=0.752) and sedge and rush cover

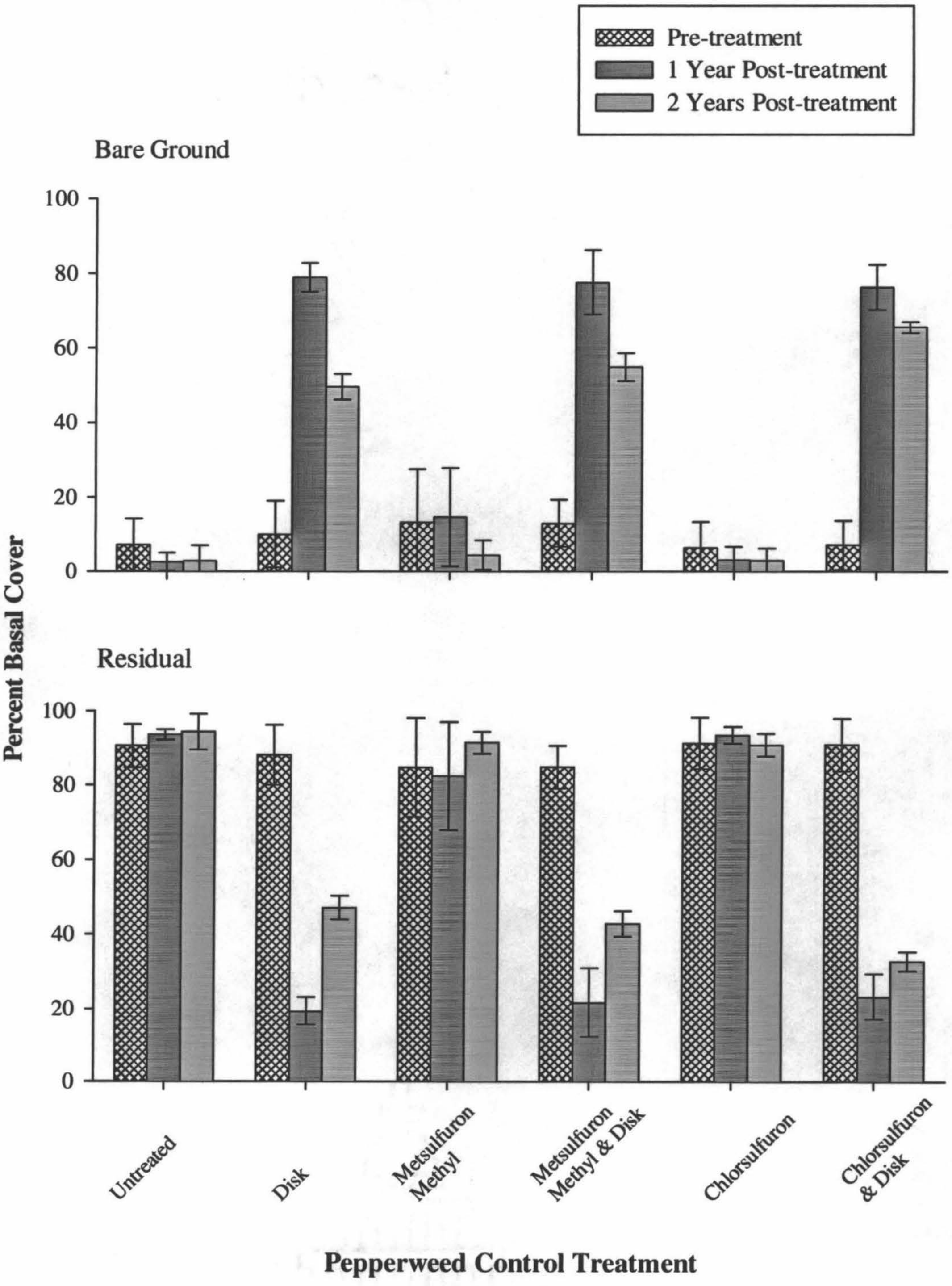

Figure 7. Percent basal cover (+/- SE) for bare ground and residual components of communities before and after *Lepidium latifolium* control treatments, averaged for three fields, at Malheur National Wildlife Refuge, Oregon.

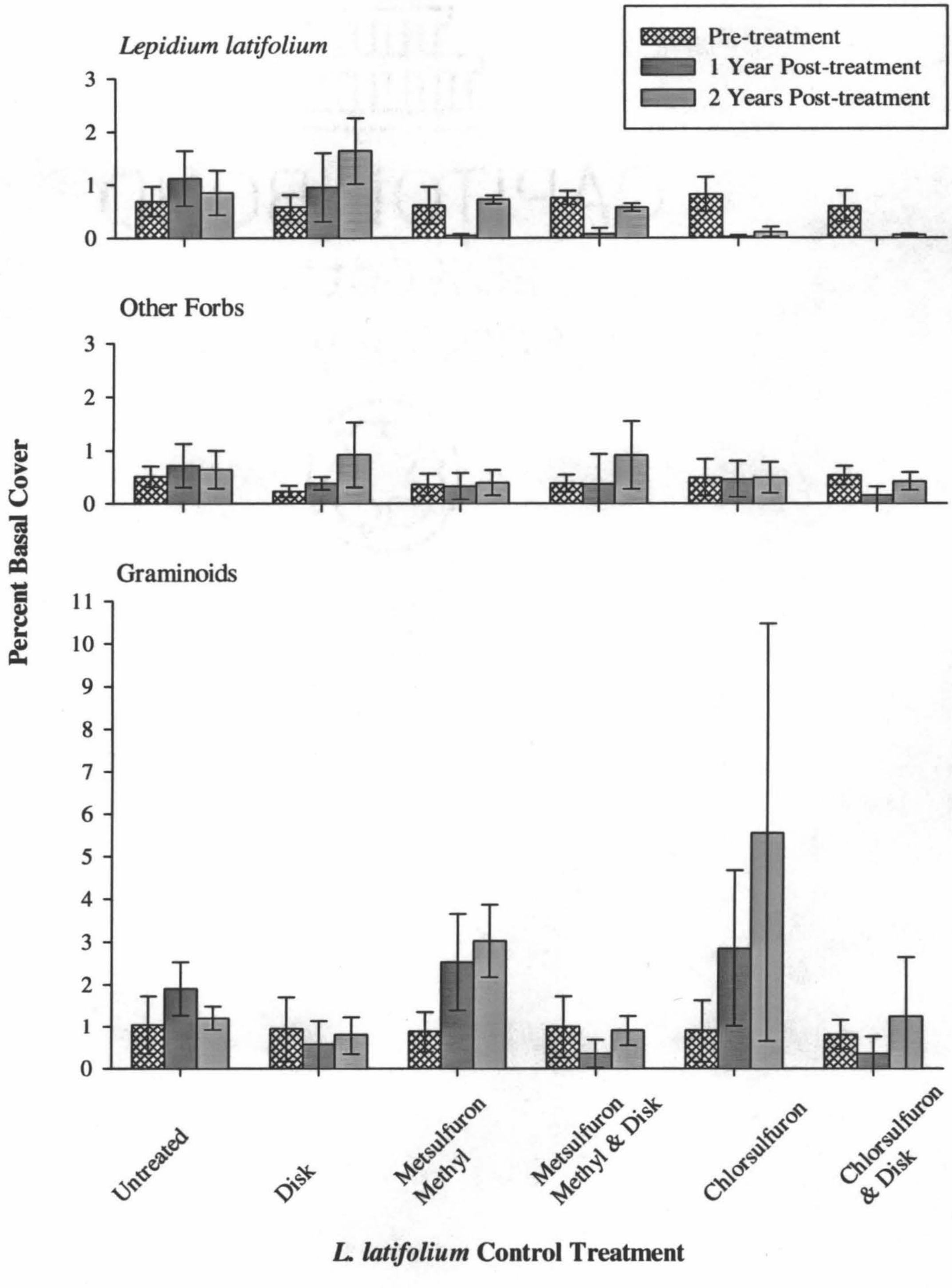

Figure 8. Percent basal cover (+/- SE) for vegetation components of communities before and after *Lepidium latifolium* control treatments, averaged for three fields, at Malheur National Wildlife Refuge, Oregon.

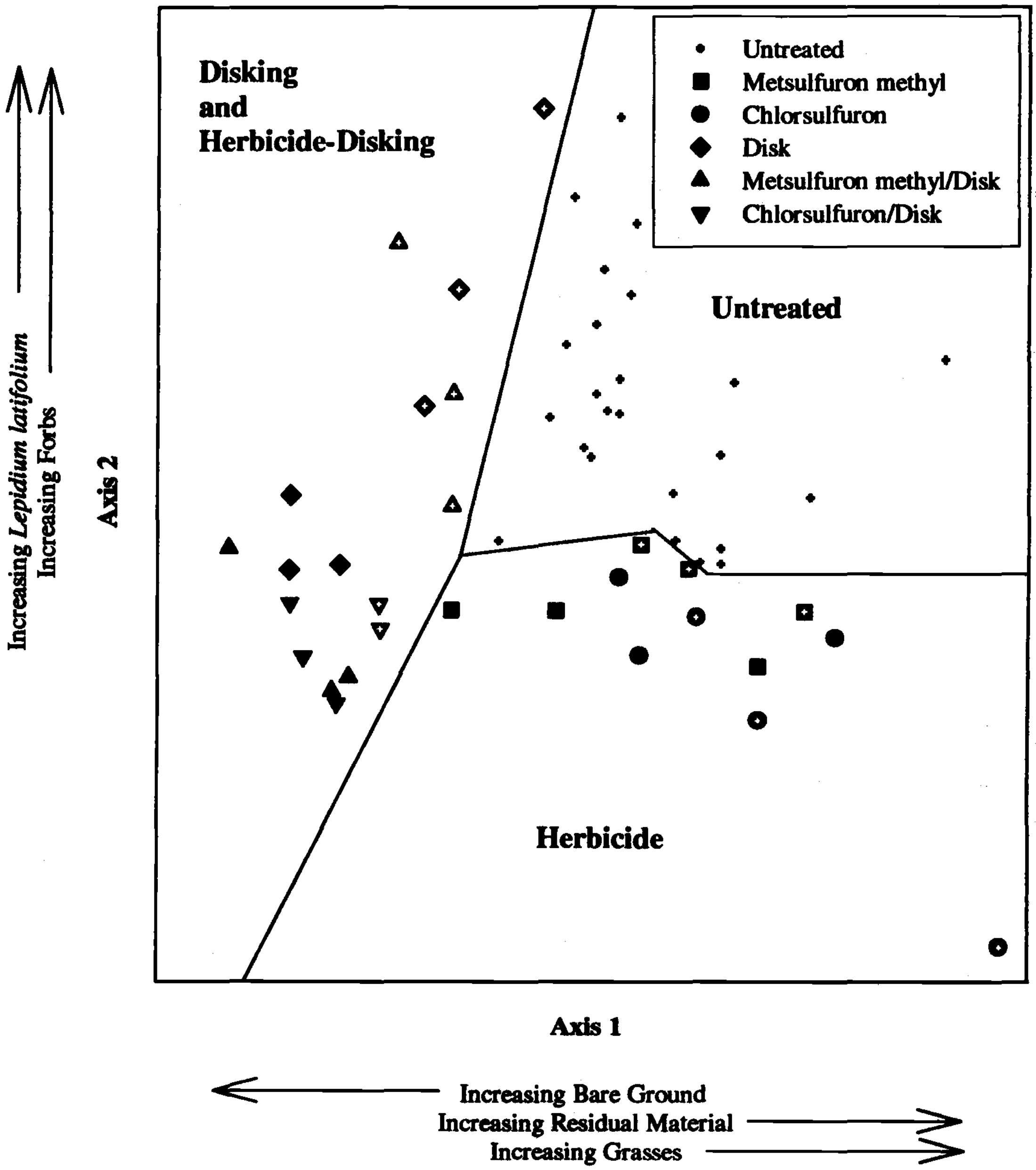

Figure 9. Results of Principal Components Analysis of community response to *Lepidium latifolium* control treatments (Untreated includes controls and all 1995 data; 1996 data are denoted by solid symbols and 1997 by cross-hairs in symbols). Variables that were significantly associated with axis 1 or 2 are listed adjacent these axes with arrows indicating direction of increase.

(r=0.659). Disking treatments were also associated with increased *L. latifolium* cover (r=0.843). Herbicide treatments sorted along axis 2 of the PCA and were associated with decreases in *L. latifolium* (r=0.843) and forb cover (r=0.701).

Grazing Treatment

After the sheep were removed, the number of flowers per *L. latifolium* ramet in grazed areas was significantly lower than those in ungrazed areas ($t=17.748$, $p<0.0001$). Grazed areas had a mean of 84 (SE=19.2) flowers per ramet *versus* 4,513 (SE=248.8) in ungrazed areas.

Revegetation Treatments

There was no significant difference in seedling establishment ($F=0.6520$, $p=0.5280$) from seeding or transplanting treatments over naturally occurring (untreated) grasses (Figures 10 and 11). There were no significant differences in seedling establishment among the pepperweed control treatments ($F=2.0945$, $p=0.1402$) or different grass species ($F=1.9197$, $p=0.1477$). The mean for establishment of emerged seedlings was 3.5%. Both local and Plant Materials Center squirreltail seed had extremely low germination and the species was dropped from consideration when emergence was insufficient for transplanting.

None of the seeded or transplanted species survived to establishment on disked plots.

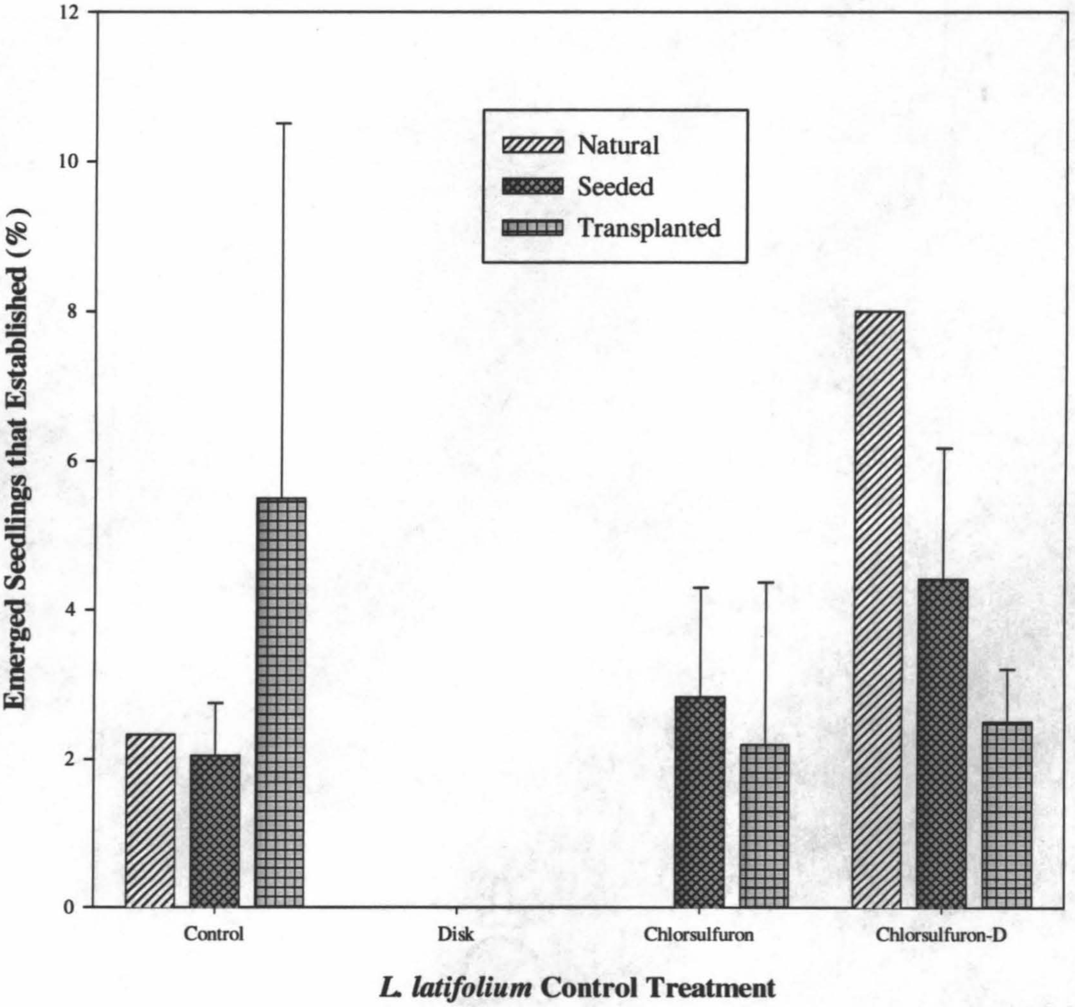

Figure 10. Proportion of emerged seedlings that survived to establishment (alive in September 1997) for each *Lepidium latifolium* control treatment at Malheur National Wildlife Refuge, Oregon.

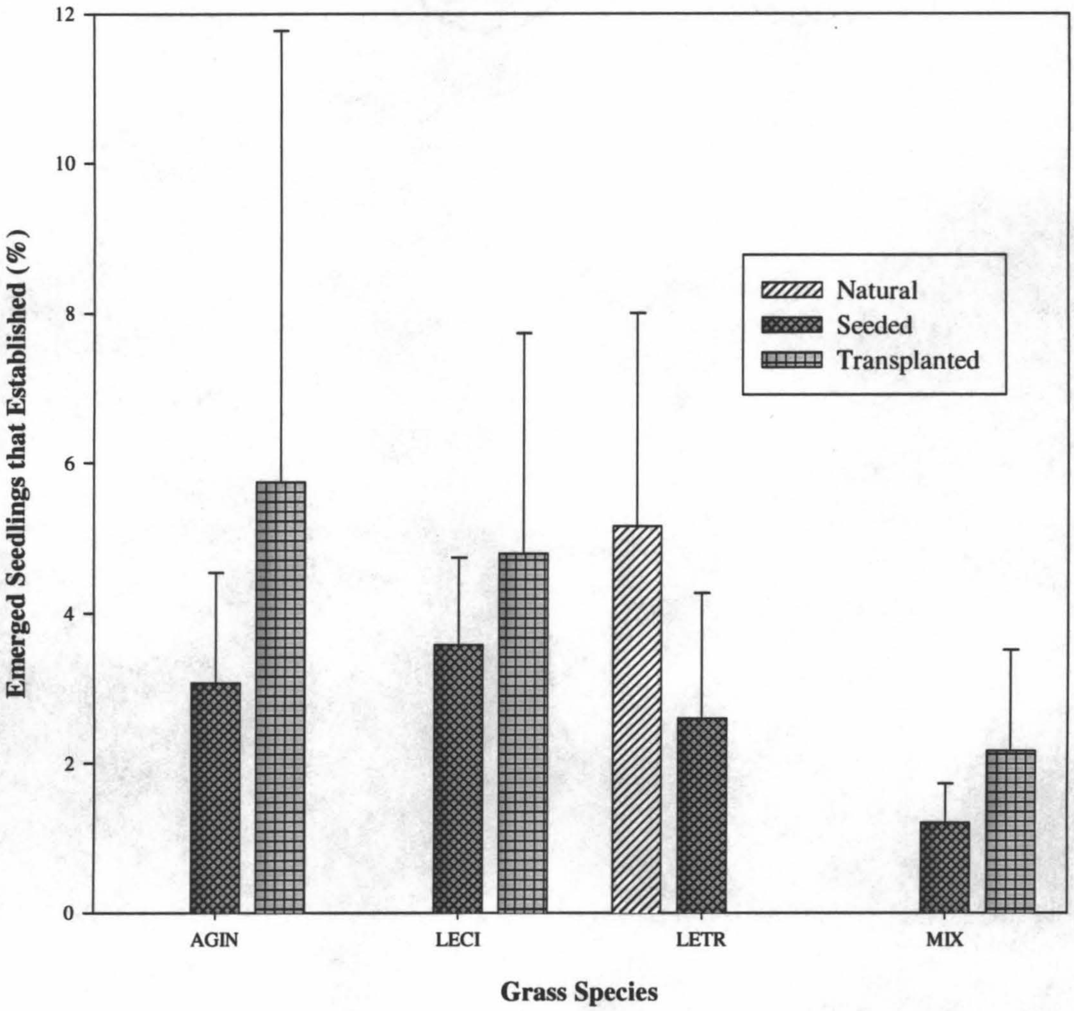

Figure 11. Proportion of emerged seedlings that survived to establishment (alive in September 1997) for each grass species at Malheur National Wildlife Refuge, Oregon.

DISCUSSION

This is the first replicated experiment to use field scale equipment and techniques to evaluate the effectiveness of various control measures on *L. latifolium*. Chlorsulfuron and metsulfuron methyl effectively controlled *L. latifolium* on small experimental plots in Nevada (Young, Palmquist, and Blank 1997) and Utah (Reid et al. 1997) and have been observed, but not quantified, to be effective controlling fields of *L. latifolium* in Wyoming (Baker 1997). Our results are similar to these findings and observations and they quantify the effectiveness of field scale techniques on the control of *L. latifolium*.

Other herbicides, such as glyphosate and 2,4-D, have been tested for *L. latifolium* control with mixed results (Cox 1997; Reid et al. 1997; Wotring et al. 1997; Young et al. 1998). The residual control of *L. latifolium* beyond the year of application with both chlorsulfuron and metsulfuron methyl provides an opportunity for native monocots to recover and dominate the site. Although 2,4-D may provide similar release for graminoids in the year of application, studies have demonstrated that it is ineffective at eliminating *L. latifolium* (Reid et al. 1997; Young et al. 1998). This herbicide may not effectively control resprouting. It may temporarily reduce the number of resprouts (Wotring et al. 1997), but *L. latifolium* is able to reach pretreatment biomass or cover in the following year (Reid et al. 1997; Young et al. 1998).

Although glyphosate provided reductions in *L. latifolium* for two years (Reid et al. 1997), its nonselective control of all species at a site would not meet management objectives for species diversity mandated by the National Wildlife Refuge System Improvement Act of 1997 (Hood 1998) and emphasized by many other public land agencies. Treatment with either chlorsulfuron or metsulfuron methyl did not denude sites of vegetation and the associated shifts in community composition to graminoid dominance allowed for maintenance of some native species diversity (Figures 7, 8, and 9).

Chlorsulfuron treatments were associated with the greatest change in community composition; composition on chlorsulfuron treatment sites continued to diverge from pretreatment *L. latifolium* dominance over time, while the shorter period of *L. latifolium* control elicited by metsulfuron methyl resulted in community similarity to untreated sites by the second year post-treatment (Figure 9). Chlorsulfuron plots were still sharply defined grass and sedge/rush communities surrounded by fields of *L. latifolium* two years after treatment, suggesting residual activity of the herbicide in the soil. Ahrens (1994) reported that in high pH soils, like those at BS, chlorsulfuron may injure susceptible crops up to 4 yr after application; it has a moderate affinity for organic matter, but low adsorption to clay, with an average field half-life of 40 d (shorter at lower pH).

While we had little success with prescribed fire, its use may be warranted to remove dead vegetation which provides protective cover to new *L. latifolium* growth and to stimulate early native plant establishment. Blank and Young (1997) suggested that shading may be important in maintaining *L. latifolium* populations; Young, Palmquist, and Wotring (1997) observed midwinter budding and early rosette growth hidden under the persistent stems from previous years. Blank and Young (1997) also speculated that a thick litter layer found in some *L. latifolium* stands, such as we encountered at BS, could be detrimental to germination and establishment of other species; more information is needed in these areas. We were successful at burning only one (BS) of three MNWR treatment sites. The most apparent difference between the replicate sites was the presence of large quantities of dead grass in the understory at BS. Burn treatments were unsuccessful at OS and SF because of a lack of sufficient fine fuels to carry the flame and high relative humidity. Burning before herbicide treatment was not tested, but might benefit control efforts by removing residual litter that protects new *L. latifolium* ramets.

At the one MNWR site that did burn successfully, *L. latifolium* ramet densities did not decrease when unaccompanied by herbicide treatments (Figure 6). The perenniating buds of *L. latifolium* are located on root stocks buried in the mineral soil which are resistant to fire (McLean 1969). At MNWR, soil pits dug at each site unearthed *L. latifolium* root stocks 2 m below the surface. Burning did appear to promote earlier spring growth (Kilbride et al. 1997), consistent with Daubenmire's (1968) findings that plants appeared on fresh burns 1 to 3 weeks earlier than on unburned areas, presumably due to increased surface light, soil surface temperature and soil nitrogen associated with removal of live vegetation and litter by fire (Hulbert 1988; Vallentine 1989). Prescribed fire as a pretreatment to herbicide application warrants additional study both for any additional control achieved on *L. latifolium* and for effects on community composition resulting from earlier growth.

Strategies for *L. latifolium* control are likely to have greater success when they emphasize halting the propagation of new infestations (Moody and Mack 1988). Some populations may be located in environments where herbicide application would not be safe, such as near water, but waterways are critical pathways for dispersal. Grazing provided an effective control for reducing seed dispersal; flower removal reduced seed production, thus reducing the potential spread of *L. latifolium* to new sites. Sheep grazing has been used successfully as a cost-effective control of other weedy species, including *Centaurea maculosa* Lam. (spotted knapweed, CENMA), *Euphorbia esula* L. (leafy spurge, EPHES), and *B. tectorum* (Lym 1998; Mosley 1996; Olson et al. 1997; Sheley et al. 1998). At MNWR, we observed *L. latifolium* plants that had flowers, leaves, and ramets grazed. Basal regrowth of large leaves was noted on many ramets within two weeks after grazing, similar to increases in basal area noted by Olson et al. (1997) on grazed *C. maculosa*. Grazing did not appear to kill *L. latifolium* plants. What effect removal of photosynthetic material had on root stock growth or stored energy reserves is unknown. Additional research is needed in these areas.

Although grazing may reduce *L. latifolium* reproduction, it may also have negative effects on other plant species. As the *L. latifolium* produced fruits, sheep appeared to forage preferentially on other plants, when available (pers. obs.). We observed trampling and grazing of native forbs, grasses, and woody riparian species. Repeated grazing might reduce the competitive ability of certain non-target species (Mosley 1996; Olson and Wallander 1997). Herding may congregate sheep on weed species and away from desirable plants, but herding was not investigated in this study. Sheep appeared to avoid certain weedy species, notably *C. arvense*, suggesting that grazing could favor growth of less palatable noxious weeds; additional study regarding this consequence is also needed.

A final caution is needed when using livestock to control reproduction of *L. latifolium*. Since *L. latifolium* seed production is asynchronous among plants in a population and individual plant's inflorescences are indeterminate, late-season grazing may allow the ingestion, transport, and passage of viable *L. latifolium* seed through sheep digestive systems or on wool. The effects of sheep digestive systems on *L. latifolium* seed viability are unknown, but seeds of *Cardaria draba* (L.) Desv. (whitetop, CADDR), another weed in the Brassicaceae, were able to survive in vitro rumen digestion from cattle (Lowry 1996).

Disking was an ineffective control treatment. Disking unearths and cuts roots and root stocks, reducing recovery by shallow-rooted plants, but it does not kill all plants that sprout from buried perenniating buds (Holechek et al. 1995;

Vallentine 1989). *L. latifolium* had deep as well as shallow root stocks on the MNWR sites and Wotring et al. (1997) has reported that at least 33% and as high as 88% of 2.5 cm root segments of *L. latifolium* sprouted. Our results confirm the visual estimates by Young et al. (1998) that *L. latifolium* cover returned to pretreatment levels within one year of disking. The disturbance of the soil and removal of most plant competitors appears to have lead to increased cover not only of *L. latifolium*, but of other weedy species, such as *C. arvense* and *B. tectorum*. Disking also buried surface growth, reducing soil cover which may lend the site to erosion. Reduced cover also allows increased evaporation, reduced snow catch, and potential for reduced soil wettability and infiltration (Daubenmire 1968; Vallentine 1989). Uncovered soils at BS formed alkaline white surface crusts. Use of disking treatments would require effective revegetation efforts with associated increased costs.

Revegetation efforts in this study were ineffective. Seedling emergence ranged from 0 to 10% in seeded plots; plant establishment ranged from 0 to 8% for those that emerged (Figures 10 and 11). This is rated as failure on the rating scale for Oregon's 254 to 305 mm mean annual precipitation zone (Hyder and Sneva 1954; Vallentine 1989). When treated with chlorsulfuron or metsulfuron methyl alone, wet meadow sites invaded by *L. latifolium* were capable of natural recovery by grasses, sedges, and rushes. Where these herbicides were applied, creeping wildrye, rushes, and other grass and grasslike species reoccupied the sites within one year. Natural restoration of plants is preferred because it is less expensive than artificial means (Vallentine 1989), less intrusive upon the ecosystem and, in this case, was highly successful. Only on the chlorsulfuron/disked sites did low plant density approach the less than one desirable bunchgrass per 0.9 m^2 recommended for artificial seeding by Plummer et al. (1955).

Revegetation efforts aimed at reestablishing native forbs may be warranted since these herbicides tend to eliminate forbs. Future studies should examine potential forb species as well as the appropriate timing of restoration after herbicide application, since these herbicides have residual effects that may last for years. Summer and autumn herbicide application has been suggested by representatives of the herbicide manufacturers and may enhance native forb viability by allowing completion of their growth cycle prior to application.

Transplanting was unsuccessful, expensive, time-consuming and unnecessary. Vagaries of local climate resulted in one field (replicate) of transplants killed by an hour-long hailstorm in July. Such stochastic events should be considered in any revegetation effort; the success of efforts restricted to one growing season will always depend on climatic luck. If revegetation was deemed necessary, a reasonable approach would not restrict efforts to one year. Vallentine (1989) suggests that multi-year response is probable when dealing with perennial plants.

Possible reasons for failure of seeding and transplanting included poor-quality seed from local sites, *L. latifolium* litter layer interference with germination and establishment, late-season transplanting, insufficient soil moisture and dessication, shading by *L. latifolium*, wind erosion and frost heaving at herbicide/disked locations, high soil alkalinity and poor soil drainage at BS, predation by herbivores--including rodents and insects (many of the transplants disappeared entirely)--or competition from other species (Blank and Young 1997; Hyder et al. 1955; Vallentine 1989; Welch et al. 1962; Young, Palmquist, and Wotring 1997).

SUMMARY AND RECOMMENDATIONS

Herbicide application was the most effective method of those tested to reduce infestations of *L. latifolium*. Herbicide use is dependent on available equipment, staffing, budget, time, and restrictions on application. Single application costs in 1995 averaged \$49.34 per ha (\$121.93 per acre) using chlorsulfuron (Telar®) and \$25.47 per ha (\$62.93 per acre) using metsulfuron methyl (Escort®). Application of chlorsulfuron at the maximum application rate of 63 g ai ha^{-1} (3 oz per acre) provided the best control over the longest period tested and had the least negative impacts on native vegetation. Others have found it effective at lesser rates, as low as 21 g ha^{-1} (1 oz per acre) (Baker 1997), which could reduce the cost of application. Collocated species, terrain, weather, and drift potential should be considered in any decision to use herbicides. Soil pH should be checked to identify potential residual soil activity (Ahrens 1994). Use in ungrazed areas only, consistent with label restrictions (Du Pont 1992), is recommended. Chlorsulfuron's grazing restrictions for livestock lead to questions about use where wildlife graze. Further research into the effects of residual herbicide activity on wildlife grazing would be useful. The use of metsulfuron methyl is recommended if the area is to be grazed. If the same duration of control as chlorsulfuron is desired, reapplication of metsulfuron methyl may be necessary, requiring additional herbicide and surfactant purchases, personnel, equipment, and time.

In 1995, the reapplication cost two years later would have resulted in total costs of $50.94 per ha ($125.86 per acre) for treatment with metsulfuron methyl.

Neither disking nor prescribed fire are recommended to control *L. latifolium*. Use of fire to remove protective cover from young *L. latifolium* plants prior to herbicide application should be investigated as a method for increasing herbicide effectiveness.

While chlorsulfuron provided longer *L. latifolium* control and more change in community composition than metsulfuron methyl, if repeated applications are needed for long-term control then a rotation of herbicide treatments should be explored. Varying application over time between sulfonylurea compounds and other chemical families of herbicides could potentially extend control of *L. latifolium*, encourage graminoid diversity, and avoid natural selection by weeds for herbicide resistance that may occur with repeated treatments of one family of herbicide (Wotring et al. 1997). A number of weeds have developed resistant biotypes following repeated use of sulfonylurea herbicides, including *Lactuca serriola* L. (prickly lettuce, LACSE) and *Salsola iberica* Sennen & Pau (Russian thistle, SASKR) (Mallory-Smith et al. 1990; Stallings et al. 1994). Chlorsulfuron and metsulfuron methyl may be effective over a wide geographic range and in a variety of site conditions; however, these reports suggest that alternating applications of these herbicides with other herbicides that have different modes of action may provide better long-term control options. The influence of repeated treatments of *L. latifolium* with sulfonylurea herbicides warrants additional study and concern.

Grazing should be considered when determining an integrated weed management strategy to control *L. latifolium*. Grazing may reduce *L. latifolium* seed production. It may retard plant growth, extending the period when herbicides can be applied effectively and, when followed by herbicide spraying of *L. latifolium* regrowth, may provide greater control than either treatment alone. Grazing may also be used where herbicide application is restricted: sheep are able to graze *L. latifolium* on slopes or rough ground where equipment cannot be operated and next to waterways where herbicide application is prohibited. Sheep grazing may be used to control a variety of weedy species and may enhance grass seedling establishment if revegetation is appropriate (Miller et al. 1998). Use of grazing permits assists the refuge with weed control efforts while providing the permit holders with forage for their livestock. A decision to incorporate grazing as part of a *L. latifolium* control strategy should consider methods that reduce potential collateral damage and avoid transporting seed away from the grazed site. Sheep grazing poses some risk of trampling nests and young of ground-nesting bird species during nesting season which coincides with plant bolting growth. Unaesthetic aspects include the presence of sheep and herders in public view at a wildlife refuge and sheep feces on and adjacent to roads.

Revegetation efforts were expensive, time-consuming, and ineffective. Native vegetation recovered naturally on sites treated with herbicides alone: either chlorsulfuron or metsulfuron methyl could be used successfully to control *L. latifolium* without necessitating revegetation efforts. Undesirable species such as *C. arvense* and *B. tectorum* increased on sites treated with herbicides followed by disking. Disking alone reduced native vegetation cover. Burning appeared to stimulate earlier, more vigorous regrowth, but was possible at only one field due to insufficient residual fine fuels to carry the fire at other locations. Given the apparent resiliency of native wet meadow vegetation, revegetation efforts with native grasses were unnecessary.

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APPENDICES

APPENDIX A

Photographs of Treatments and Results

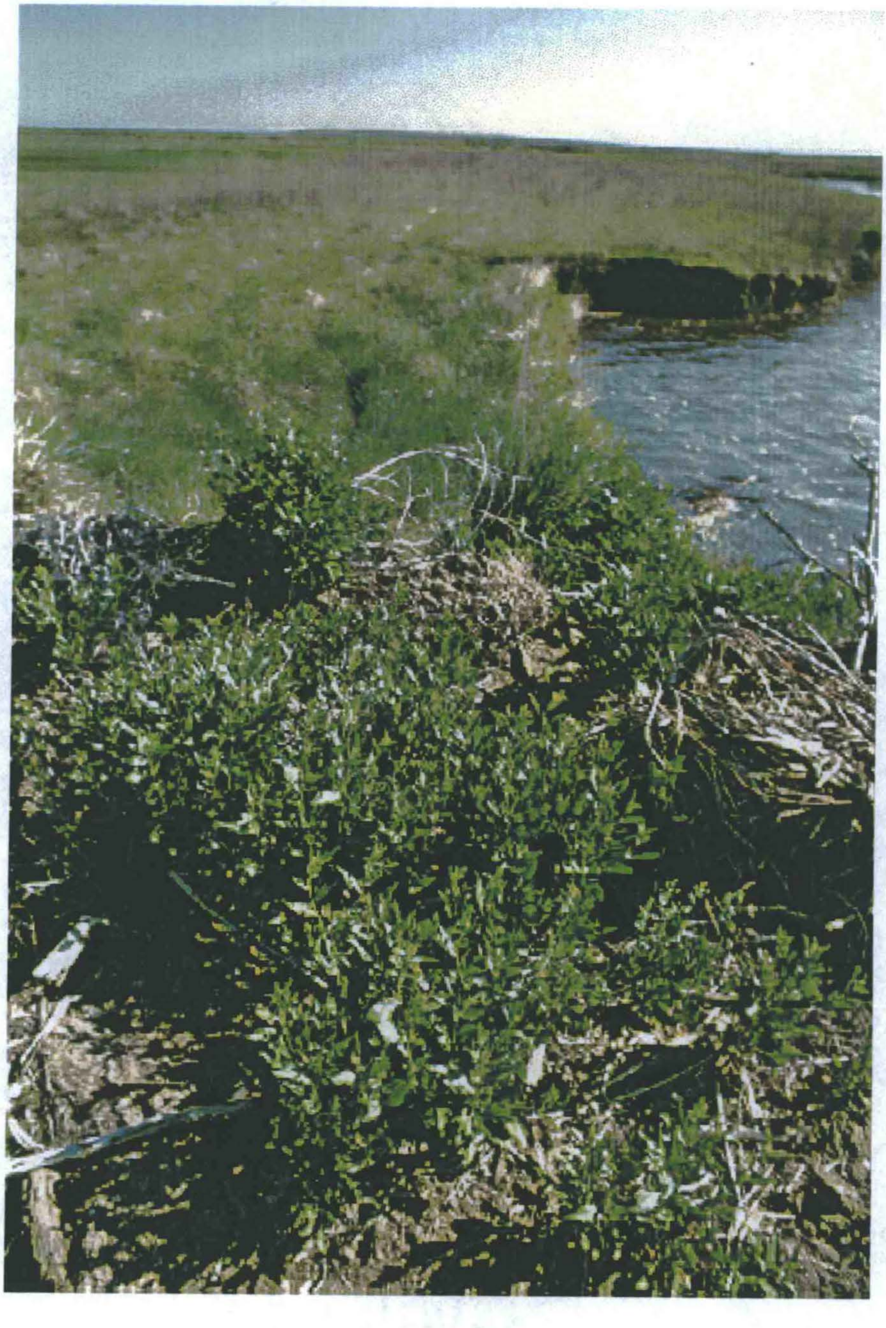

Figure A1. *Lepidium latifolium* L. (perennial pepperweed) invades disturbed sites along waterways and roadsides.

Figure A2. Spreading both by seed and rhizomes, *Lepidium latifolium* dominates sites that it invades.

Figure A3. *Lepidium latifolium* averages over 4,500 flowers (>9,000 seeds) per stem.

Figure A4. Malheur National Wildlife Refuge in southeast Oregon where treatments were applied.

Figure A5. Density and basal cover data were collected along transects using two rectangular 25-point sampling frames.

Figure A6. Herbicides were applied in 1995 during bud development by tractor-mounted broadcast sprayer.

Figure A7. Chlorsulfuron reduced *Lepidium latifolium* stem densities >97% two years after treatment.

Figure A8. Disking was used to cut, unearth and dry rhizomes in 1995 using a 4.3 m wide disk.

Figure A9. Native plant cover decreased and *Lepidium latifolium* continued to dominate on disked sites.

Figure A10. Application of herbicide followed by disking reduced all plant cover.

Figure A11. First year results, provided to the public in 1996, included a field tour.

Figure A12. Burn treatments were mowed one week prior to burning and ignited by drip torches.

Figure A13. Burning appeared to enable earlier green-up and promote more vigorous growth.

Figure A14. Sheep grazed *Lepidium latifolium* from green-up through flowering during 1997.

Figure A15. Sheep grazing reduced *Lepidium latifolium* flower, thus seed, production by over 98%.

Figure A16. Seeding treatments were applied in October 1996, using an experimental size rangeland drill.

Figure A17. *Elymus elymoides* (Raf.) Swezey (bottlebrush squirreltail) was a native species used in revegetation treatments.

Figure A18. *Leymus cinereus* (Scribn. & Merr.) A. Löve (basin wildrye) was one of three native species used in revegetation treatments.

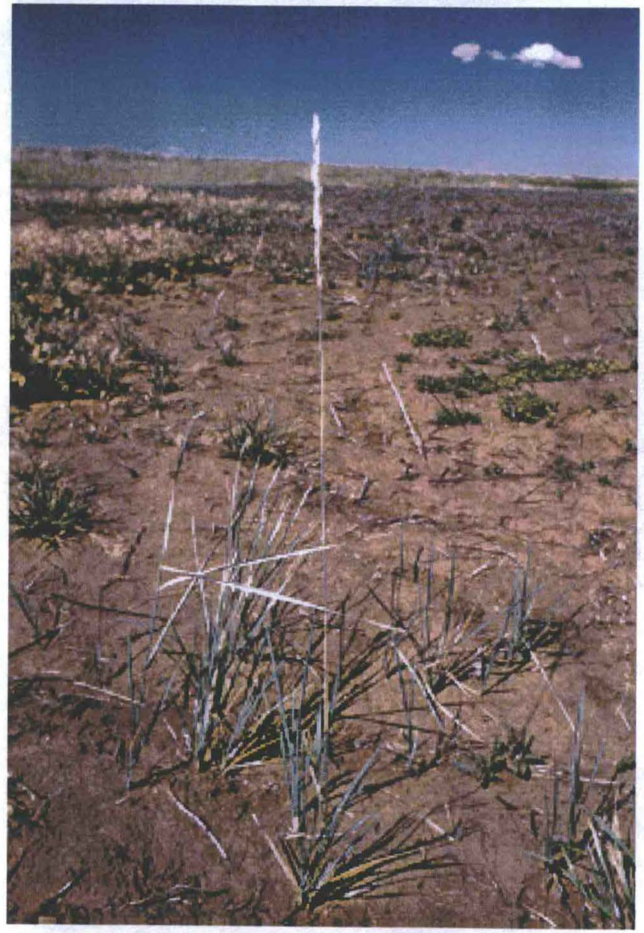

Figure A19. *Leymus triticoides* (Buckl.) Pilger (creeping wildrye) was another one of the native species used in revegetation treatments.

Figure A20. Transplants for restoration treatments in 1997 were grown in styrofoam containers.

Figure A21. Holes were drilled along transects to receive transplants.

Figure A22. One of the few grass seedlings to emerge was overshadowed by *Lepidium latifolium* and subsequently died. Revegetation treatments were ineffective and proved unnecessary where *L. latifolium* control treatments were effective.

APPENDIX B

Plants Identified on *Lepidium latifolium* Research Sites at Malheur National Wildlife Refuge, Oregon

Broadleaf Plants:

CODE	SPECIES	COMMON NAME	DURATION	ORIGIN *
AGGL	*Agoseris glauca* (Pursh) Raf.	Pale agoseris	Perennial	Native
ALLIU	*Allium* L. *sp.*	Wild onion species		
ARAN7	*Argentina anserina* (L.) Rydb.	Silverweed cinquefoil	Perennial	Native
ARCA12	*Artemisia campestris* L.	Field sagewort	Perennial	Native
ARTR2	*Artemisia tridentata* Nutt. *Wyomingensis*	Wyoming big sagebrush	Perennial	Native
ATMI2	*Atriplex micrantha* Ledeb.	Twoscale saltbush	Annual	Introduced
CADR	*Cardaria draba* (L.) Desv.	Whitetop (hoary cress)	Perennial	Introduced
CHAL7	*Chenopodium album* L.	Common lambsquarters	Annual	Introduced
CHLE4	*Chenopodium leptophyllum* (Moq.) Nutt.	Narrowleaf goosefoot	Annual	Native
CIAR4	*Cirsium arvense* (L.) Scop.	Canada thistle	Perennial	Introduced
CRSE2	*Crepis setosa* Haller f.	Bristly hawksbeard	Annual	Introduced
DESO2	*Descurainia sophia* (L.) Webb ex Prantl	Flixweed	Annual	Introduced
EPPA	*Epilobium palustre* L.	Marsh willowherb	Perennial	Native
GNPA	*Gnaphalium palustre* Nutt.	Western marsh cudweed	Annual	Native

CODE	SPECIES	COMMON NAME	DURATION	ORIGIN *
HEVIV	*Heterotheca villosa* (Pursh) Shinners	Hairy false goldenaster	Perennial	Native
IVAX	*Iva axillaris* Pursh	Povertyweed	Perennial	Native
LATAP	*Lactuca tatarica* (L.) C.A. Mey.	Blue lettuce	Perennial	Native
LASE	*Lactuca serriola* L.	Prickly lettuce	Annual	Introduced
LEMI3	*Lemna minor* L.	Common duckweed	Perennial	Native
LELA2	*Lepidium latifolium* L.	Perennial pepperweed	Perennial	Introduced
MENTH	*Mentha* L. *sp.*	Mint species		
MYAR	*Myosotis arvensis* (L.) Hill	Field forget-me-not	Annual	Introduced
PHGR16	*Phlox gracilis* (Hook.) Greene	Slender phlox	Annual	Native
RANUN	*Ranunculus* L. *sp.*	Buttercup species		
ROCU	*Rorippa curvisiliqua* (Hook.) Bess. ex	Western yellowcress	Annual	Native
ROSI2	*Rorippa sinuata* (Nutt.) A.S. Hitchc.	Spreading yellowcress	Perennial	Native
RUCR	*Rumex crispus* L.	Curly dock	Perennial	Introduced
SIAL2	*Sisymbrium altissimum* L.	Tumble mustard	Annual	Introduced
SIAN3	*Sisyrinchium angustifolium* P. Mill.	Blue-eyed grass	Perennial	Native
TAOF	*Taraxacum officinale* G.H. Weber ex	Common dandelion	Perennial	Introduced
TRDU	*Tragopogon dubius* Scop.	Yellow salsify	Annual	Introduced
TRIFO	*Trifolium* L. *sp.*	Clover species		
THAR5	*Thlaspi arvense* L.	Field pennycress	Annual	Introduced

CODE	SPECIES	COMMON NAME	DURATION	ORIGIN *
VAHI2	*Vaccaria hispanica* (P. Mill.) Rauschert	Cow soapwort (cowcockle)	Annual	Introduced
VETH	*Verbascum thapsus* L.	Common mullein	Biennial	Introduced
VEHA2	*Verbena hastata* L.	Swamp verbena (blue vervain)	Perennial	Native
VISA	*Vicia sativa* L.	Common vetch	Annual	Introduced

Sedges, Rushes, and Associated Species:

CODE	SPECIES	COMMON NAME	DURATION	ORIGIN *
CAREX	*Carex* L. *sp.*	Sedge species		
ELPA3	*Eleocharis palustris* (L.) Roemer & J.A.	Common spikerush	Perennial	Native
ELEOC	*Eleocharis* R. Br. *sp.*	Spikerush species		
JUNCU	*Juncus* L. *sp.*	Rush species		
SPARG	*Sparganium* L. *sp.*	Bur-reed species		
TYLA	*Typha latifolia* L.	Common cattail	Perennial	Native

Grasses:

CODE	SPECIES	COMMON NAME	DURATION	ORIGIN *
AGCR	*Agropyron cristatum* (L.) Gaertn.	Crested wheatgrass	Perennial	Introduced
AGROP	*Agropyron* Gaertn. *sp.*	Wheatgrass species		
BRTE	*Bromus tectorum* L.	Cheatgrass (downy brome)	Annual	Introduced

CODE	SPECIES	COMMON NAME	DURATION	ORIGIN *
DISP	*Distichlis spicata* (L.) Greene	Inland saltgrass	Perennial	Native
ELELE	*Elymus elymoides* (Raf.) Swezey	Bottlebrush squirreltail	Perennial	Native
ELMA7	*Elymus macrourus* (Turcz.) Tzvelev	Thickspike wheatgrass	Perennial	Native
HOLA	*Holcus lanatus* L.	Common velvetgrass	Perennial	Introduced
HOJU	*Hordeum jubatum* L.	Foxtail barley	Perennial	Native
LECI4	*Leymus cinereus* (Scribn.& Merr.) A. Löve	Basin wildrye (giant wildrye)	Perennial	Native
LETR5	*Leymus triticoides* (Buckl.) Pilger	Creeping wildrye (beardless wildrye)	Perennial	Native
PADI	*Panicum dichotomiflorum* Michx.	Fall panicgrass (western witchgrass)	Annual	Native
PHAR3	*Phalaris arundinacea* L.	Reed canarygrass	Perennial	Native
PHPR3	*Phleum pratense* L.	Common timothy	Perennial	Introduced
POAR3	*Poa arida* Vasey	Plains bluegrass	Perennial	Native
POPR	*Poa pratensis* L.	Kentucky bluegrass	Perennial	Introduced
POSE	*Poa secunda* J. Presl	Sandberg (Nevada) bluegrass	Perennial	Native
POSP	*Poa* L. *sp.*	Bluegrass species		
POMO5	*Polypogon monspeliensis* (L.) Desf.	Rabbitsfoot beardgrass	Annual	Introduced

* Plants identified as native or introduced to the United States according to the PLANTS database (USDA NRCS 1999).

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APPENDIX C

Effects of Pepperweed Control Treatments on Ground Cover (Percent Cover by Type)

Treatment Averages

1995

Treatment	Bare Ground	Residual	Vegetation
Untreated	7.2%	90.5%	2.2%
Disk	10.1%	88.2%	1.7%
Metsulfuron methyl	13.3%	84.8%	1.9%
Metsulfuron methyl/Disk	13.0%	84.9%	2.1%
Chlorsulfuron	6.5%	91.3%	2.2%
Chlorsulfuron/Disk	7.2%	90.9%	1.9%

1996

Treatment	Bare Ground	Residual	Vegetation
Untreated	2.6%	93.6%	3.8%
Disk	78.9%	19.2%	1.9%
Metsulfuron methyl	14.6%	82.5%	2.9%
Metsulfuron methyl/Disk	77.5%	21.7%	0.8%
Chlorsulfuron	3.2%	93.5%	3.3%
Chlorsulfuron/Disk	76.3%	23.2%	0.5%

1997

Treatment	Bare Ground	Residual	Vegetation
Untreated	2.9%	94.4%	2.7%
Disk	49.6%	47.1%	3.3%
Metsulfuron methyl	4.5%	91.4%	4.1%
Metsulfuron methyl/Disk	54.8%	42.8%	2.4%
Chlorsulfuron	3.0%	90.8%	6.2%
Chlorsulfuron/Disk	65.5%	32.8%	1.7%

Effects of Pepperweed Control Treatments on Ground Cover
(Percent Cover by Type)

Location Averages: W. E. Big Sagebrush Field

1995

Treatment	Bare Ground	Residual	Vegetation
Untreated	0.0%	96.6%	3.4%
Disk	1.2%	95.9%	2.8%
Metsulfuron methyl	0.3%	96.9%	2.9%
Metsulfuron methyl/Disk	7.9%	89.2%	3.0%
Metsulfuron methyl/Fire	0.0%	96.1%	3.9%
Mow/Fire	2.5%	95.1%	2.5%
Chlorsulfuron	0.1%	97.2%	2.7%
Chlorsulfuron/Disk	2.4%	95.8%	1.8%
Chlorsulfuron/Fire	0.3%	95.6%	4.0%

1996

Treatment	Bare Ground	Residual	Vegetation
Untreated	0.1%	94.8%	5.1%
Disk	74.4%	23.7%	2.0%
Metsulfuron methyl	0.5%	96.2%	3.3%
Metsulfuron methyl/Disk	70.1%	29.8%	0.2%
Metsulfuron methyl/Fire	86.4%	8.2%	5.4%
Mow/Fire	24.5%	72.5%	3.0%
Chlorsulfuron	0.1%	94.1%	5.8%
Chlorsulfuron/Disk	78.7%	21.2%	0.1%
Chlorsulfuron/Fire	36.7%	57.9%	5.4%

1997

Treatment	Bare Ground	Residual	Vegetation
Untreated	0.0%	97.0%	3.0%
Disk	48.4%	47.1%	4.5%
Metsulfuron methyl	0.0%	94.6%	5.4%
Metsulfuron methyl/Disk	56.6%	41.7%	1.6%
Metsulfuron methyl/Fire	1.8%	92.7%	5.6%
Mow/Fire	10.0%	85.0%	4.9%
Chlorsulfuron	0.1%	88.3%	11.6%
Chlorsulfuron/Disk	63.8%	35.7%	0.5%
Chlorsulfuron/Fire	6.1%	85.1%	8.8%

Effects of Pepperweed Control Treatments on Ground Cover
(Percent Cover by Type)

Location Averages: Oliver Springs Field

1995

Treatment	Bare Ground	Residual	Vegetation
Untreated	13.9%	84.8%	1.3%
Disk	19.0%	79.7%	1.3%
Metsulfuron methyl	28.5%	70.5%	1.0%
Metsulfuron methyl/Disk	20.0%	78.3%	1.7%
Chlorsulfuron	5.6%	92.9%	1.4%
Chlorsulfuron/Disk	4.4%	94.2%	1.4%

1996

Treatment	Bare Ground	Residual	Vegetation
Untreated	3.0%	93.9%	3.2%
Disk	81.6%	16.8%	1.6%
Metsulfuron methyl	29.0%	67.2%	3.8%
Metsulfuron methyl/Disk	87.0%	11.4%	1.7%
Chlorsulfuron	2.4%	95.5%	2.1%
Chlorsulfuron/Disk	69.5%	30.3%	0.2%

1997

Treatment	Bare Ground	Residual	Vegetation
Untreated	1.0%	97.3%	1.7%
Disk	53.4%	43.9%	2.8%
Metsulfuron methyl	5.8%	90.4%	3.7%
Metsulfuron methyl/Disk	50.4%	46.6%	3.0%
Chlorsulfuron	2.6%	94.1%	3.3%
Chlorsulfuron/Disk	66.6%	32.1%	1.3%

Effects of Pepperweed Control Treatments on Ground Cover
(Percent Cover by Type)

Location Averages: Skunk Farm Field

1995

Treatment	Bare Ground	Residual	Vegetation
Untreated	7.7%	90.3%	2.0%
Disk	9.9%	89.0%	1.1%
Metsulfuron methyl	11.2%	87.0%	1.7%
Metsulfuron methyl/Disk	11.2%	87.1%	1.7%
Chlorsulfuron	13.7%	83.8%	2.5%
Chlorsulfuron/Disk	14.6%	82.8%	2.6%

1996

Treatment	Bare Ground	Residual	Vegetation
Untreated	4.8%	92.2%	3.0%
Disk	80.8%	17.1%	2.1%
Metsulfuron methyl	14.4%	84.0%	1.6%
Metsulfuron methyl/Disk	75.6%	23.9%	0.5%
Chlorsulfuron	7.1%	90.9%	2.0%
Chlorsulfuron/Disk	80.7%	18.2%	1.1%

1997

Treatment	Bare Ground	Residual	Vegetation
Untreated	7.7%	88.9%	3.4%
Disk	47.0%	50.3%	2.7%
Metsulfuron methyl	7.6%	89.1%	3.3%
Metsulfuron methyl/Disk	57.4%	40.1%	2.5%
Chlorsulfuron	6.3%	90.1%	3.6%
Chlorsulfuron/Disk	66.1%	30.6%	3.3%

APPENDIX D

Effects of Pepperweed Control Treatments on Vegetation (Percent Vegetation by Type)

Treatment Averages

1995

Treatment	LELA	Forbs	CIAR	Grasses	BRTE	Sedge/Rush	Other*
Untreated	31.4%	11.8%	7.2%	16.8%	17.6%	10.1%	5.1%
Disk	34.9%	16.8%	0.0%	18.9%	20.1%	9.3%	0.0%
Metsulfuron methyl	32.1%	13.4%	5.9%	17.1%	23.4%	8.1%	0.0%
Metsulfuron methyl/Disk	37.1%	15.2%	5.1%	25.5%	10.4%	6.8%	0.0%
Chlorsulfuron	37.2%	11.8%	12.0%	13.6%	9.0%	16.5%	0.0%
Chlorsulfuron/Disk	30.3%	15.3%	13.4%	25.0%	12.1%	3.8%	0.0%

1996

Treatment	LELA	Forbs	CIAR	Grasses	BRTE	Sedge/Rush	Other*
Untreated	28.7%	7.0%	8.9%	15.9%	21.6%	14.1%	3.7%
Disk	50.3%	14.6%	5.5%	0.0%	29.6%	0.0%	0.0%
Metsulfuron methyl	1.3%	5.6%	5.3%	32.2%	42.2%	12.1%	1.3%
Metsulfuron methyl/Disk	33.9%	5.3%	21.0%	5.4%	21.0%	13.4%	0.0%
Chlorsulfuron	0.3%	12.5%	1.3%	41.1%	23.7%	21.1%	0.0%
Chlorsulfuron/Disk	0.0%	43.1%	0.0%	16.6%	40.3%	0.0%	0.0%

1997

Treatment	LELA	Forbs	CIAR	Grasses	BRTE	Sedge/Rush	Other*
Untreated	30.4%	9.8%	9.8%	16.5%	12.1%	17.0%	4.4%
Disk	48.9%	19.3%	6.4%	6.9%	18.5%	0.0%	0.0%
Metsulfuron methyl	17.8%	5.3%	3.8%	39.7%	18.6%	14.8%	0.0%
Metsulfuron methyl/Disk	26.3%	21.7%	14.3%	15.5%	15.9%	6.4%	0.0%
Chlorsulfuron	3.1%	4.8%	6.6%	55.1%	5.4%	25.0%	0.0%
Chlorsulfuron/Disk	3.5%	21.5%	14.7%	32.1%	28.1%	0.0%	0.0%

*Other: Category includes shrubs, mosses, and aquatics (cattails and duckweed)

Effects of Pepperweed Control Treatments on Vegetation
(Percent Vegetation by Type)

Location Averages: W. E. Big Sagebrush Field

1995

Treatment	LELA	Forbs	CIAR	Grasses	BRTE	Sedge/Rush	Other*
Untreated	29.0%	6.8%	0.0%	25.8%	0.0%	28.1%	10.2%
Disk	29.7%	6.2%	0.0%	37.3%	0.0%	26.8%	0.0%
Metsulfuron methyl	33.2%	9.2%	7.4%	26.0%	0.0%	24.2%	0.0%
Metsulfuron methyl/Disk	30.2%	8.0%	0.0%	50.1%	0.0%	11.8%	0.0%
Metsulfuron methyl/Fire	36.2%	8.1%	3.8%	14.0%	0.0%	30.2%	7.6%
Mow/Fire	20.3%	13.3%	4.5%	48.4%	0.0%	13.5%	0.0%
Chlorsulfuron	28.5%	6.7%	0.0%	17.9%	0.0%	46.9%	0.0%
Chlorsulfuron/Disk	23.0%	18.9%	0.0%	49.8%	0.0%	8.3%	0.0%
Chlorsulfuron/Fire	25.7%	5.0%	3.0%	21.4%	0.0%	45.0%	0.0%

1996

Treatment	LELA	Forbs	CIAR	Grasses	BRTE	Sedge/Rush	Other*
Untreated	33.8%	6.2%	0.0%	18.9%	0.0%	29.9%	11.2%
Disk	87.1%	12.9%	0.0%	0.0%	0.0%	0.0%	0.0%
Metsulfuron methyl	2.5%	4.9%	9.9%	42.6%	0.0%	36.2%	3.9%
Metsulfuron methyl/Disk	100%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Metsulfuron methyl/Fire	1.4%	6.3%	2.9%	34.6%	0.0%	51.9%	2.9%
Mow/Fire	21.4%	11.0%	4.0%	46.3%	0.0%	17.3%	0.0%
Chlorsulfuron	1.0%	14.1%	0.0%	40.5%	0.0%	44.5%	0.0%
Chlorsulfuron/Disk	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Chlorsulfuron/Fire	0.0%	19.6%	0.0%	27.2%	0.0%	53.2%	0.0%

1997

Treatment	LELA	Forbs	CIAR	Grasses	BRTE	Sedge/Rush	Other*
Untreated	39.7%	13.7%	0.0%	17.6%	0.0%	28.9%	0.0%
Disk	50.6%	35.5%	0.0%	13.9%	0.0%	0.0%	0.0%
Metsulfuron methyl	14.9%	4.2%	7.8%	28.8%	0.0%	44.3%	0.0%
Metsulfuron methyl/Disk	39.3%	26.7%	0.0%	26.7%	0.0%	7.3%	0.0%
Metsulfuron methyl/Fire	4.3%	5.9%	3.2%	20.9%	0.0%	61.5%	4.3%
Mow/Fire	18.3%	13.5%	5.1%	35.2%	0.0%	27.9%	0.0%
Chlorsulfuron	0.0%	3.2%	0.0%	37.4%	0.0%	59.4%	0.0%
Chlorsulfuron/Disk	2.9%	51.4%	0.0%	45.7%	0.0%	0.0%	0.0%
Chlorsulfuron/Fire	0.0%	2.5%	0.0%	33.5%	0.0%	64.0%	0.0%

Effects of Pepperweed Control Treatments on Vegetation (Percent Vegetation by Type)

Location Averages: Oliver Springs Field

1995

Treatment	LELA	Forbs	CIAR	Grasses	BRTE	Sedge/Rush	Other*
Untreated	33.2%	12.9%	5.1%	13.5%	29.6%	0.6%	5.1%
Disk	33.8%	29.3%	0.0%	5.8%	31.2%	0.0%	0.0%
Metsulfuron methyl	25.3%	13.0%	0.0%	13.6%	48.2%	0.0%	0.0%
Metsulfuron methyl/Disk	37.4%	17.0%	15.2%	13.0%	17.4%	0.0%	0.0%
Chlorsulfuron	35.9%	8.3%	20.9%	14.4%	17.9%	2.5%	0.0%
Chlorsulfuron/Disk	32.2%	11.4%	29.0%	17.5%	6.7%	3.2%	0.0%

1996

Treatment	LELA	Forbs	CIAR	Grasses	BRTE	Sedge/Rush	Other*
Untreated	27.1%	5.6%	2.6%	14.7%	47.5%	2.6%	0.0%
Disk	39.9%	8.2%	16.4%	0.0%	35.5%	0.0%	0.0%
Metsulfuron methyl	0.0%	4.4%	0.0%	19.9%	75.6%	0.0%	0.0%
Metsulfuron methyl/Disk	0.7%	5.3%	55.0%	0.0%	39.0%	0.0%	0.0%
Chlorsulfuron	0.0%	3.8%	3.8%	34.9%	38.7%	18.9%	0.0%
Chlorsulfuron/Disk	0.0%	0.0%	0.0%	40.0%	60.0%	0.0%	0.0%

1997

Treatment	LELA	Forbs	CIAR	Grasses	BRTE	Sedge/Rush	Other*
Untreated	22.4%	9.4%	4.4%	23.8%	22.6%	4.4%	13.1%
Disk	58.4%	6.7%	19.3%	6.7%	8.8%	0.0%	0.0%
Metsulfuron methyl	18.6%	4.7%	0.0%	36.8%	40.0%	0.0%	0.0%
Metsulfuron methyl/Disk	16.1%	12.0%	43.0%	5.7%	23.2%	0.0%	0.0%
Chlorsulfuron	5.1%	3.2%	5.3%	64.4%	6.3%	15.8%	0.0%
Chlorsulfuron/Disk	5.8%	9.9%	35.2%	35.9%	13.2%	0.0%	0.0%

*Other: Category includes shrubs, mosses, and aquatics (cattails and duckweed)

Effects of Pepperweed Control Treatments on Vegetation
(Percent Vegetation by Type)

Location Averages: Skunk Farm Field

1995

Treatment	LELA	Forbs	CIAR	Grasses	BRTE	Sedge/Rush	Other*
Untreated	32.1%	15.7%	16.5%	11.0%	23.2%	1.5%	0.0%
Disk	41.3%	14.9%	0.0%	13.5%	29.1%	1.2%	0.0%
Metsulfuron methyl	37.7%	18.1%	10.3%	11.8%	22.0%	0.0%	0.0%
Metsulfuron methyl/Disk	43.7%	20.7%	0.0%	13.3%	13.7%	8.6%	0.0%
Chlorsulfuron	47.2%	20.3%	15.0%	8.5%	9.0%	0.0%	0.0%
Chlorsulfuron/Disk	35.9%	15.5%	11.3%	7.8%	29.6%	0.0%	0.0%

1996

Treatment	LELA	Forbs	CIAR	Grasses	BRTE	Sedge/Rush	Other*
Untreated	25.3%	9.1%	24.2%	14.2%	17.3%	9.9%	0.0%
Disk	23.9%	22.6%	0.0%	0.0%	53.4%	0.0%	0.0%
Metsulfuron methyl	1.5%	7.3%	6.1%	34.2%	50.9%	0.0%	0.0%
Metsulfuron methyl/Disk	1.0%	10.7%	8.0%	16.1%	24.1%	40.1%	0.0%
Chlorsulfuron	0.0%	19.5%	0.0%	47.9%	32.6%	0.0%	0.0%
Chlorsulfuron/Disk	0.0%	29.3%	0.0%	9.8%	61.0%	0.0%	0.0%

1997

Treatment	LELA	Forbs	CIAR	Grasses	BRTE	Sedge/Rush	Other*
Untreated	29.2%	6.2%	25.2%	8.1%	13.7%	17.6%	0.0%
Disk	37.6%	15.7%	0.0%	0.0%	46.7%	0.0%	0.0%
Metsulfuron methyl	20.1%	7.1%	3.6%	53.5%	15.8%	0.0%	0.0%
Metsulfuron methyl/Disk	23.3%	26.3%	0.0%	14.2%	24.4%	11.9%	0.0%
Chlorsulfuron	4.1%	8.1%	14.7%	63.4%	9.8%	0.0%	0.0%
Chlorsulfuron/Disk	2.0%	3.2%	8.9%	14.7%	71.2%	0.0%	0.0%

*Other: Category includes shrubs, mosses, and aquatics (cattails and duckweed)

APPENDIX E

Results of Principal Components Analysis Using PC-ORD

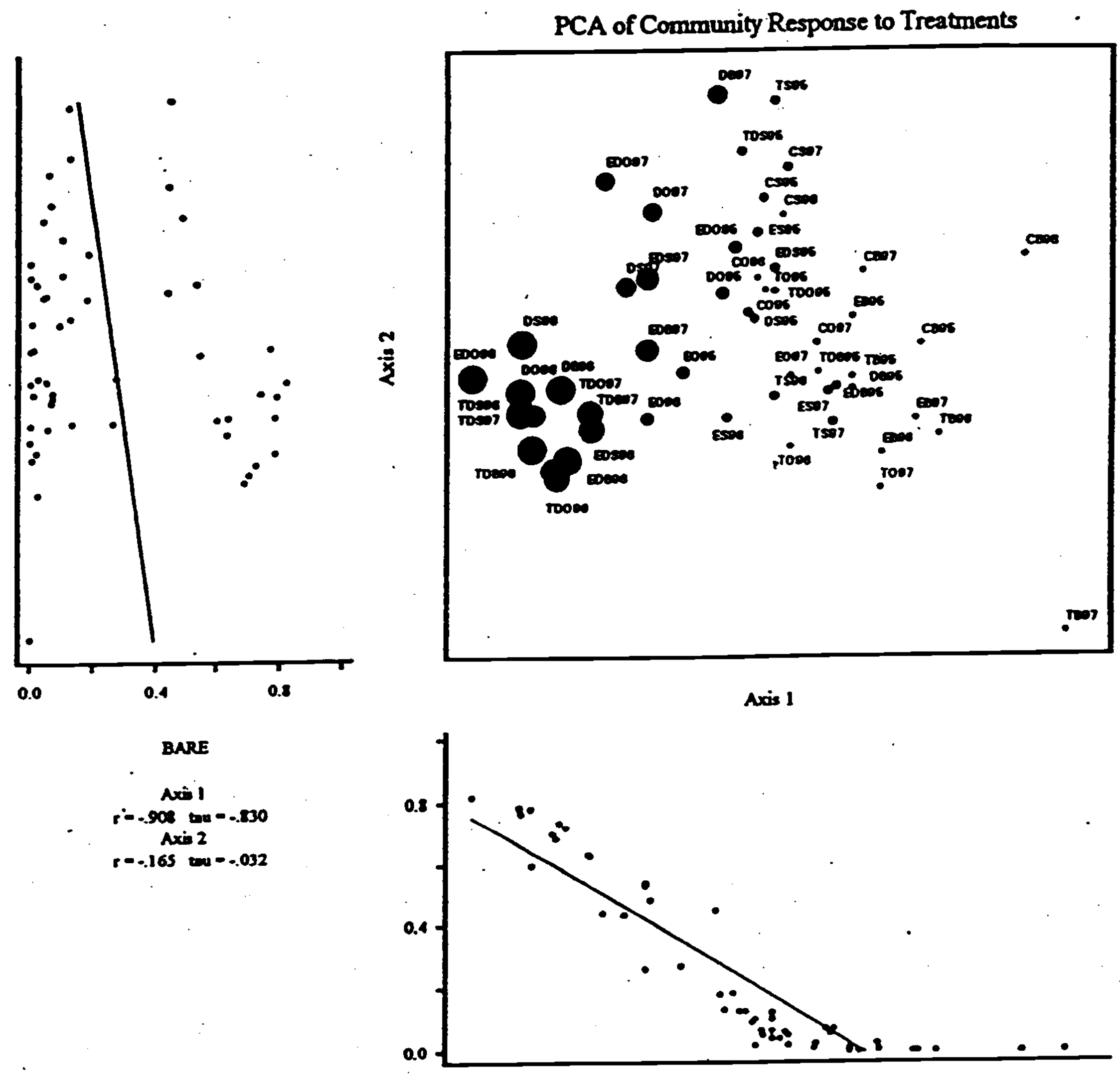

Figure E1. Effects of bare soil (BARE) cover in community response to *Lepidium latifolium* control treatments at Malheur National Wildlife Refuge, Oregon.

Results of Principal Components Analysis Using PC-ORD

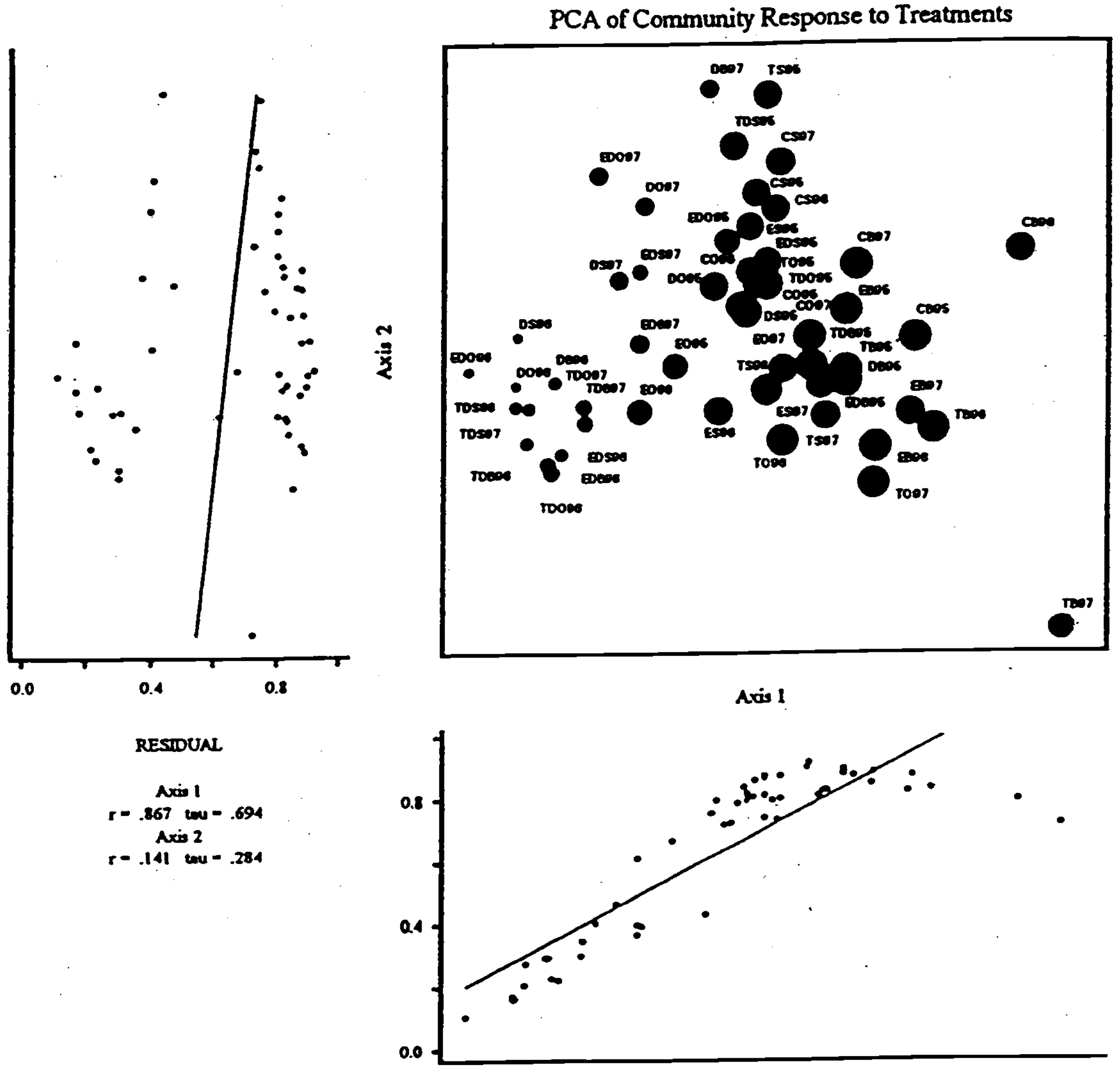

Figure E2. Effects of litter (RESIDUAL) cover in community response to *Lepidium latifolium* control treatments at Malheur National Wildlife Refuge, Oregon.

Results of Principal Components Analysis Using PC-ORD

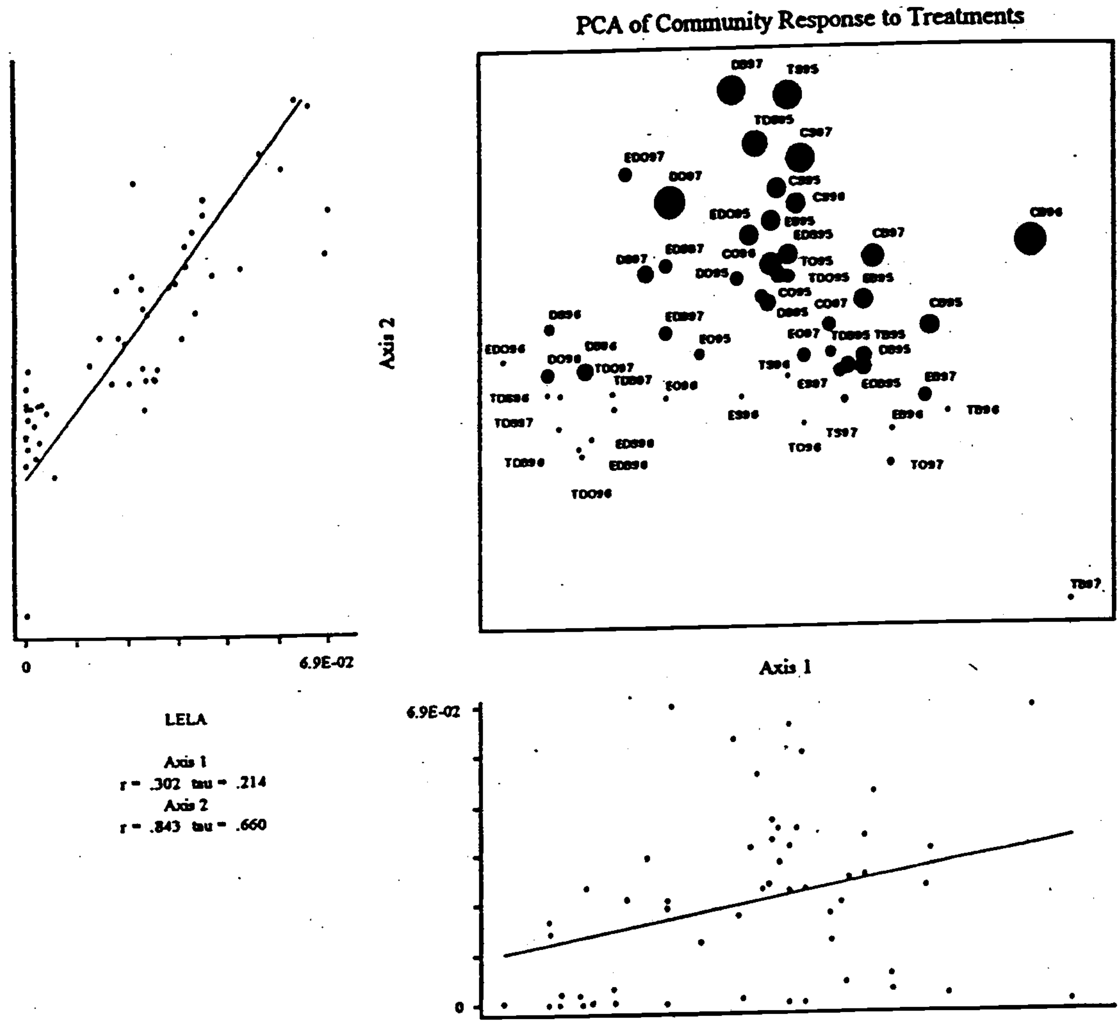

Figure E3. Effects of *Lepidium latifolium* (LELA) cover in community response to *L. latifolium* control treatments at Malheur National Wildlife Refuge, Oregon.

Results of Principal Components Analysis Using PC-ORD

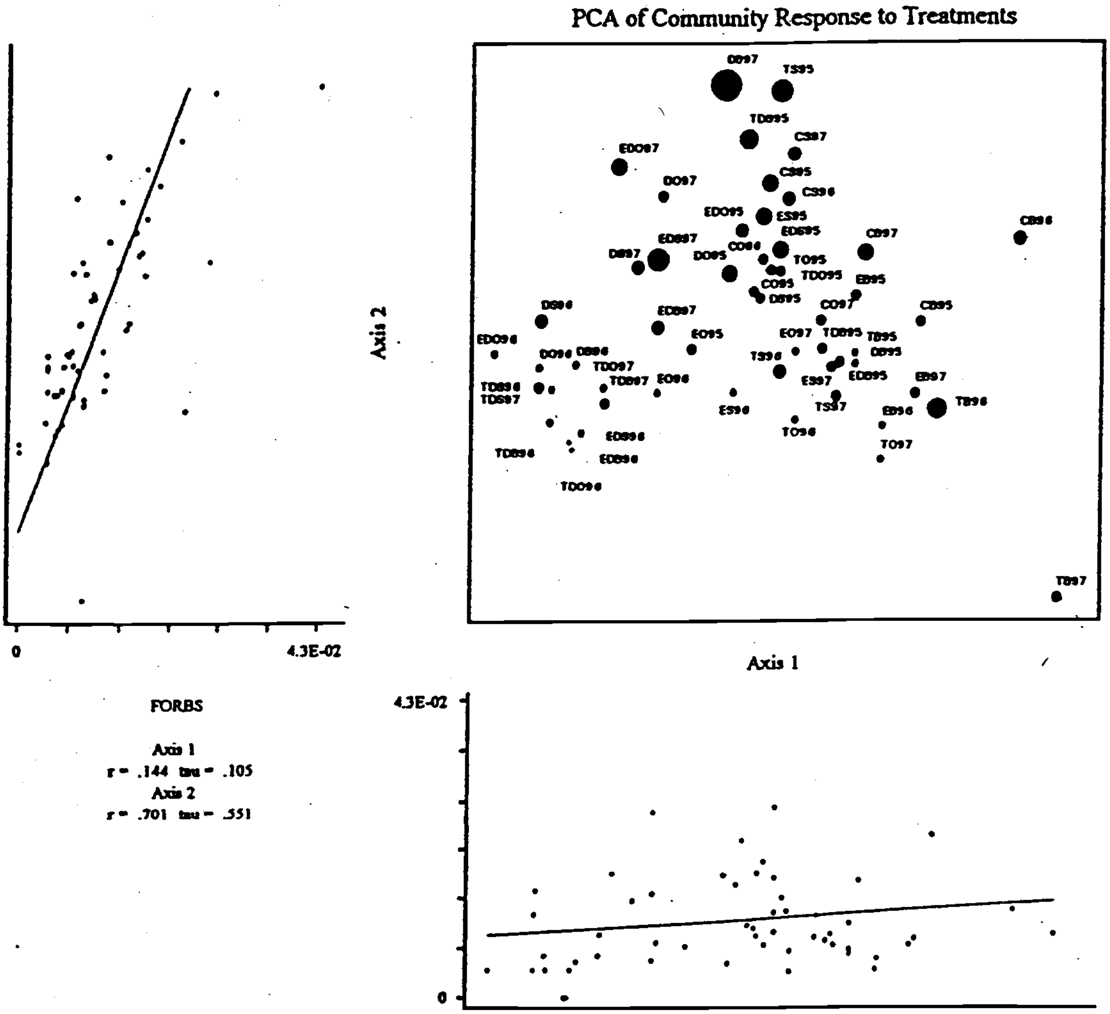

Figure E4. Effects of forb (FORBS) cover in community response to *Lepidium latifolium* control treatments at Malheur National Wildlife Refuge, Oregon.

Results of Principal Components Analysis Using PC-ORD

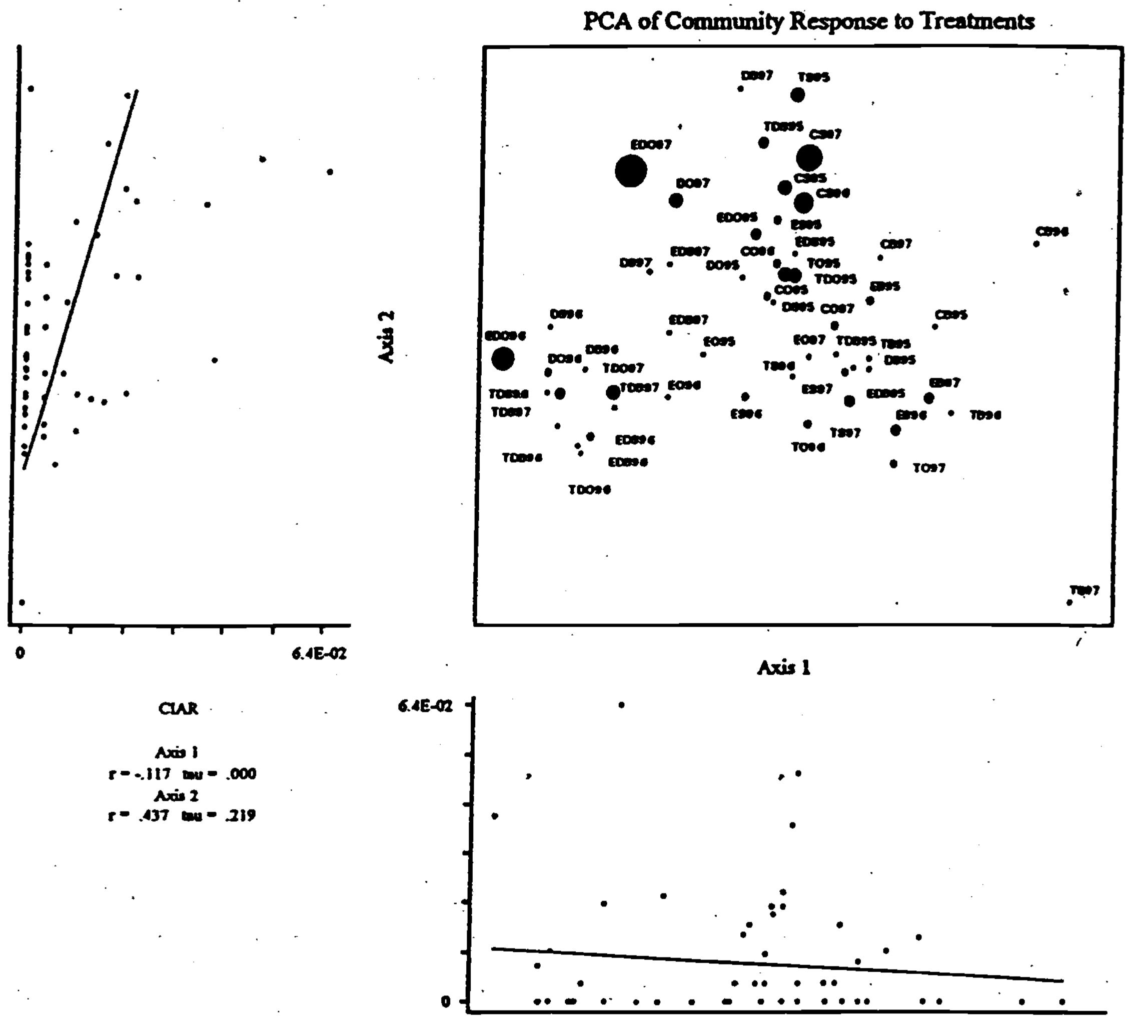

Figure E5. Effects of *Cirsium arvense* (CIAR) cover in community response to *Lepidium latifolium* control treatments at Malheur National Wildlife Refuge, Oregon.

Results of Principal Components Analysis Using PC-ORD

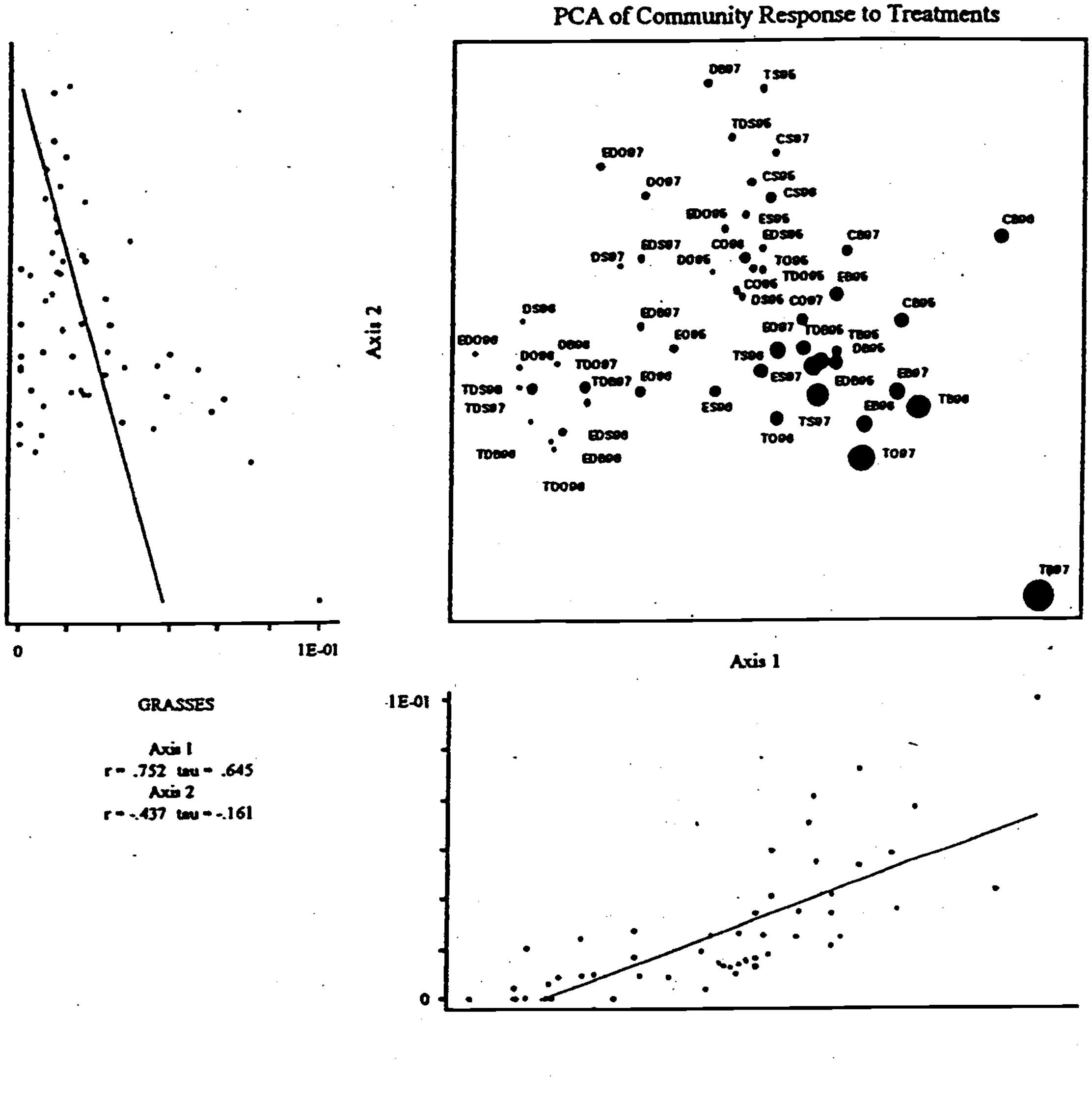

Figure E6. Effects of grass (GRASSES) cover in community response to *Lepidium latifolium* control treatments at Malheur National Wildlife Refuge, Oregon.

Results of Principal Components Analysis Using PC-ORD

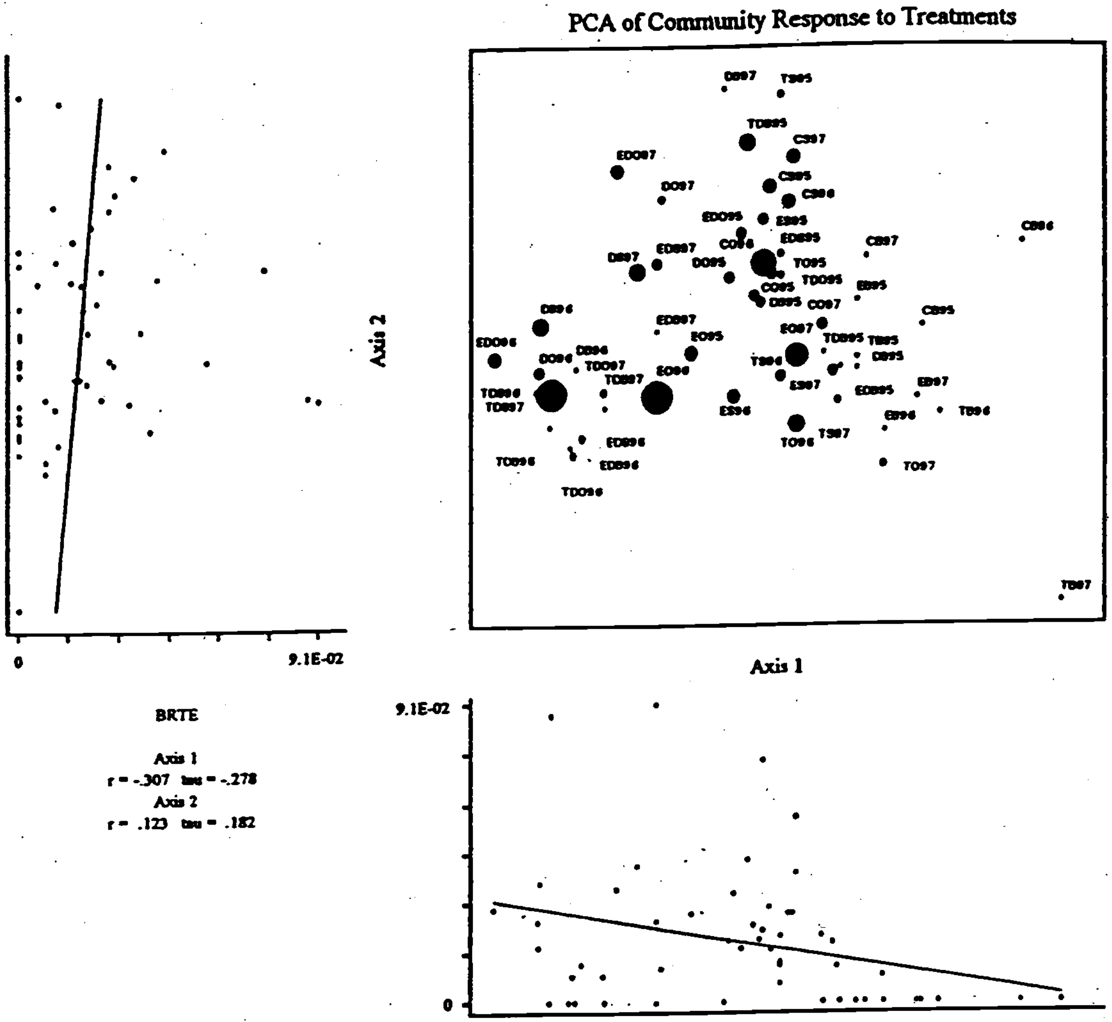

Figure E7. Effects of ***Bromus tectorum*** (BRTE) cover in community response to ***Lepidium latifolium*** control treatments at Malheur National Wildlife Refuge, Oregon.

Results of Principal Components Analysis Using PC-ORD

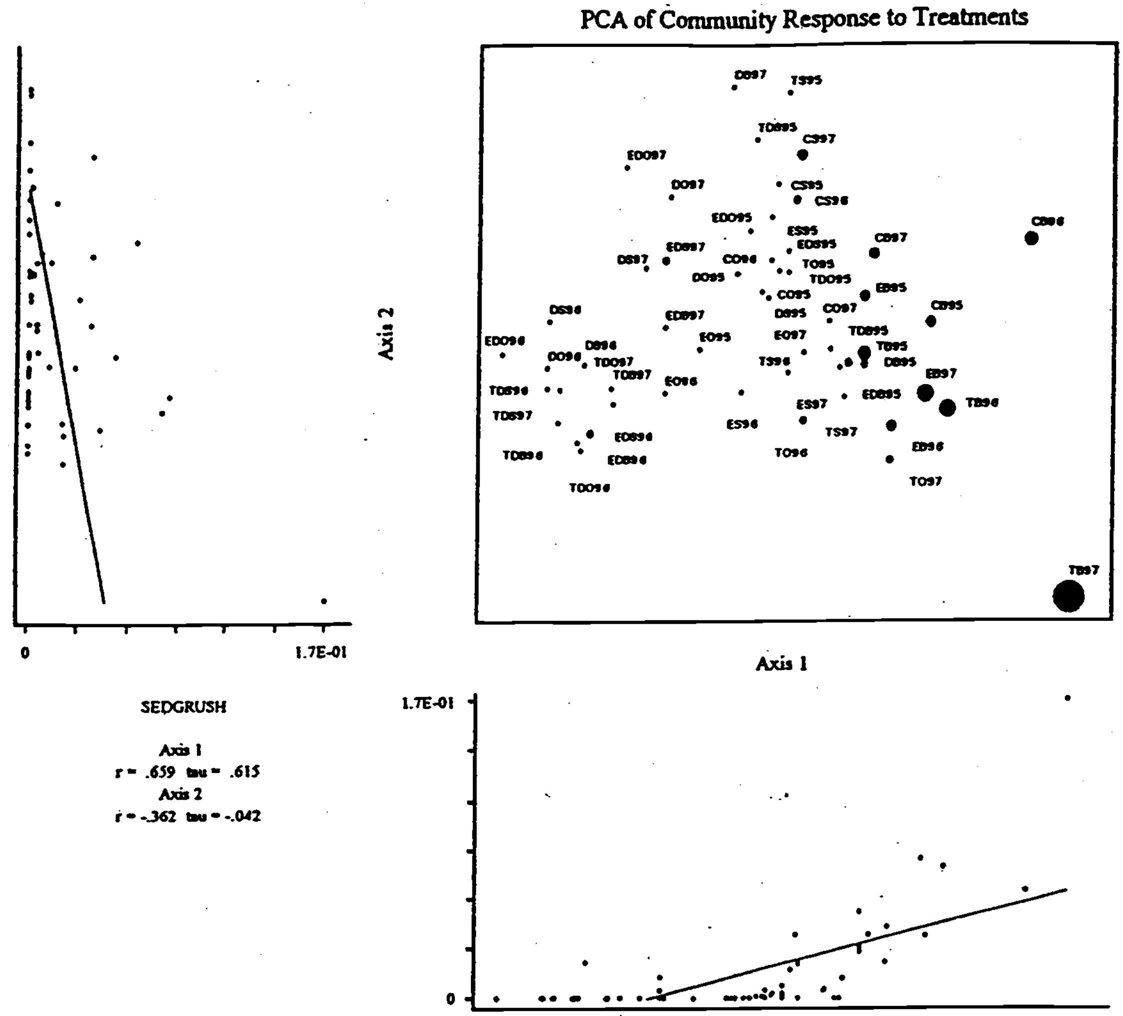

Figure E8. Effects of sedge and rush (SEDGRUSH) cover in community response to *Lepidium latifolium* control treatments at Malheur National Wildlife Refuge, Oregon.

Results of Principal Components Analysis Using PC-ORD

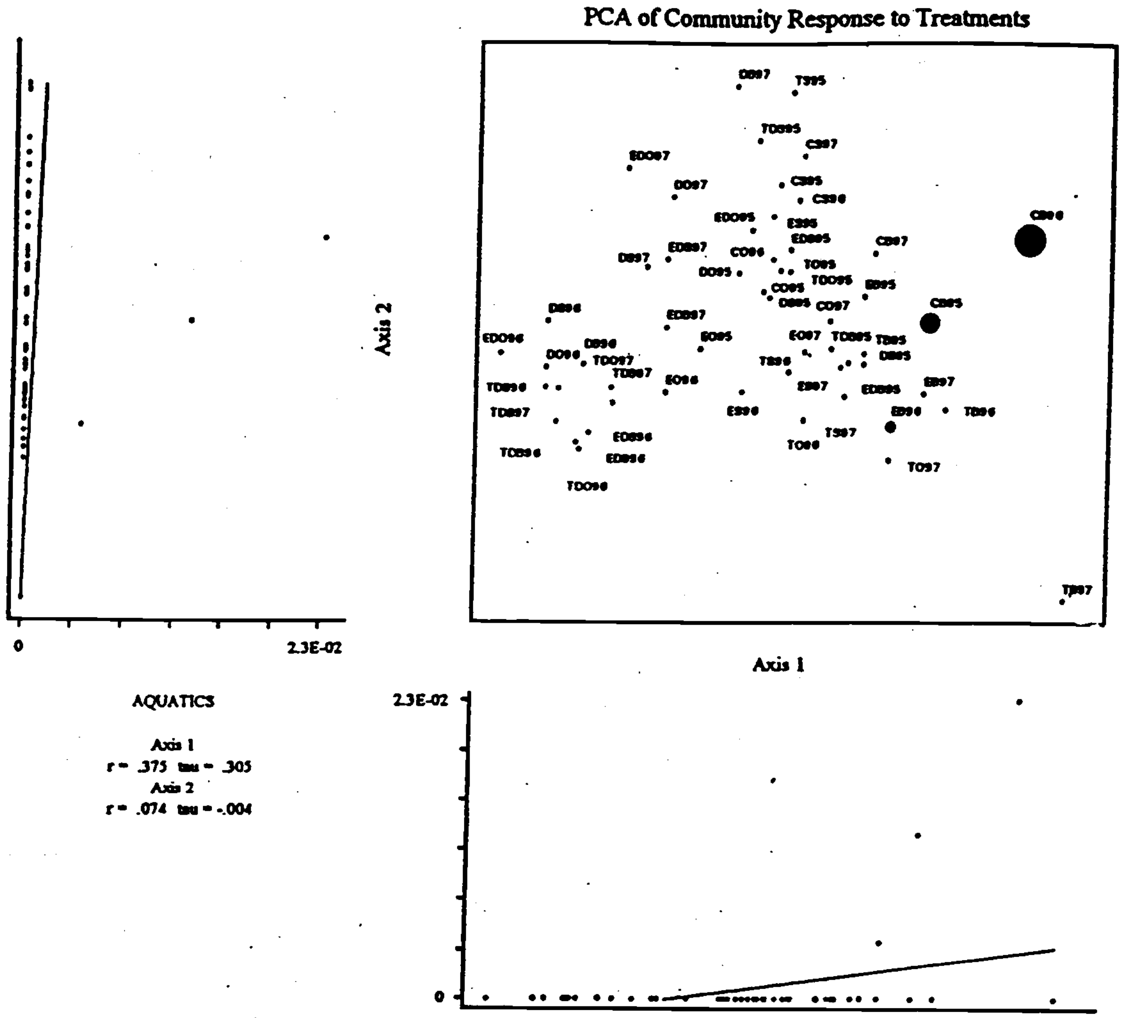

Figure E9. Effects of aquatic plant (AQUATICS) cover in community response to *Lepidium latifolium* control treatments at Malheur National Wildlife Refuge, Oregon.

Results of Principal Components Analysis Using PC-ORD

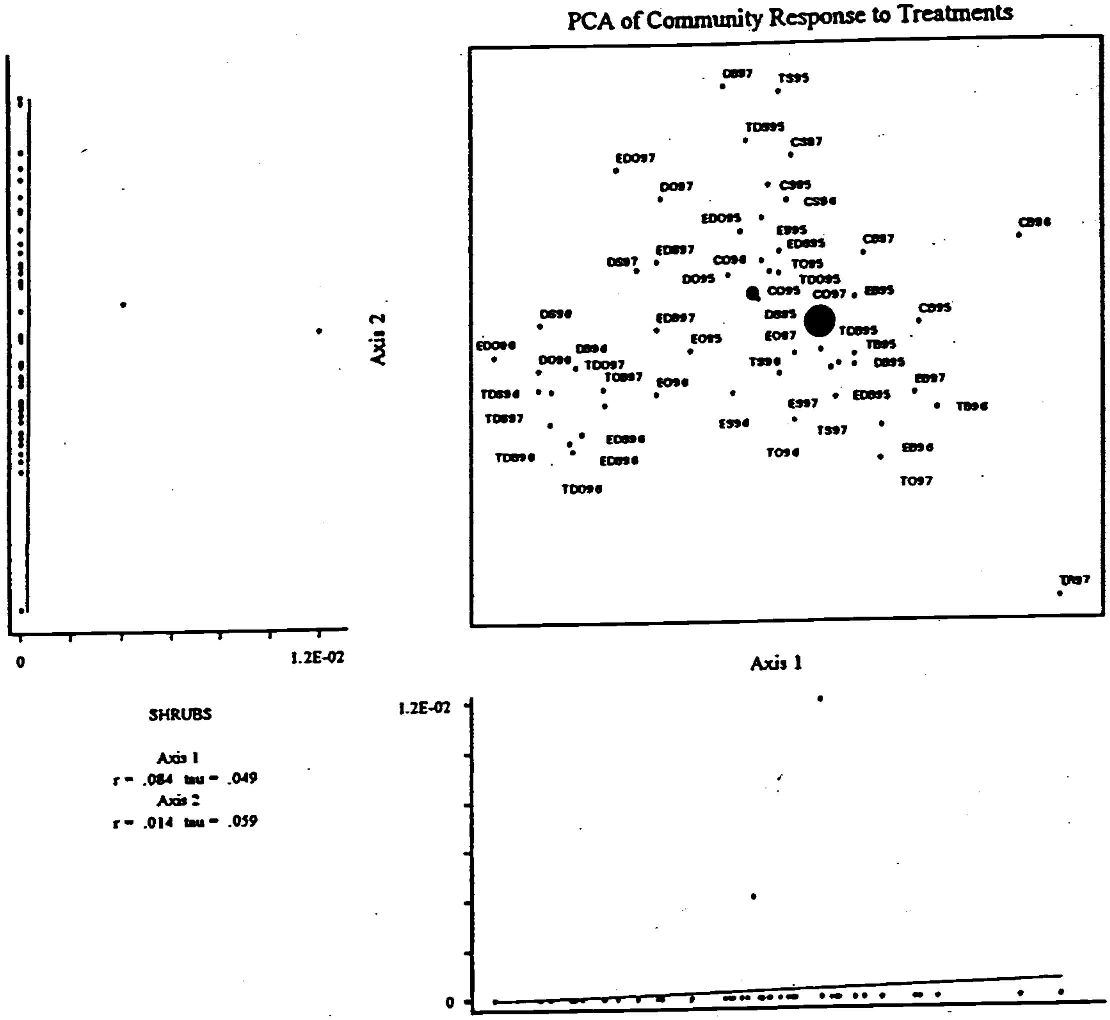

Figure E10. Effects of shrub (SHRUBS) cover in community response to *Lepidium latifolium* control treatments at Malheur National Wildlife Refuge, Oregon.

Results of Principal Components Analysis Using PC-ORD

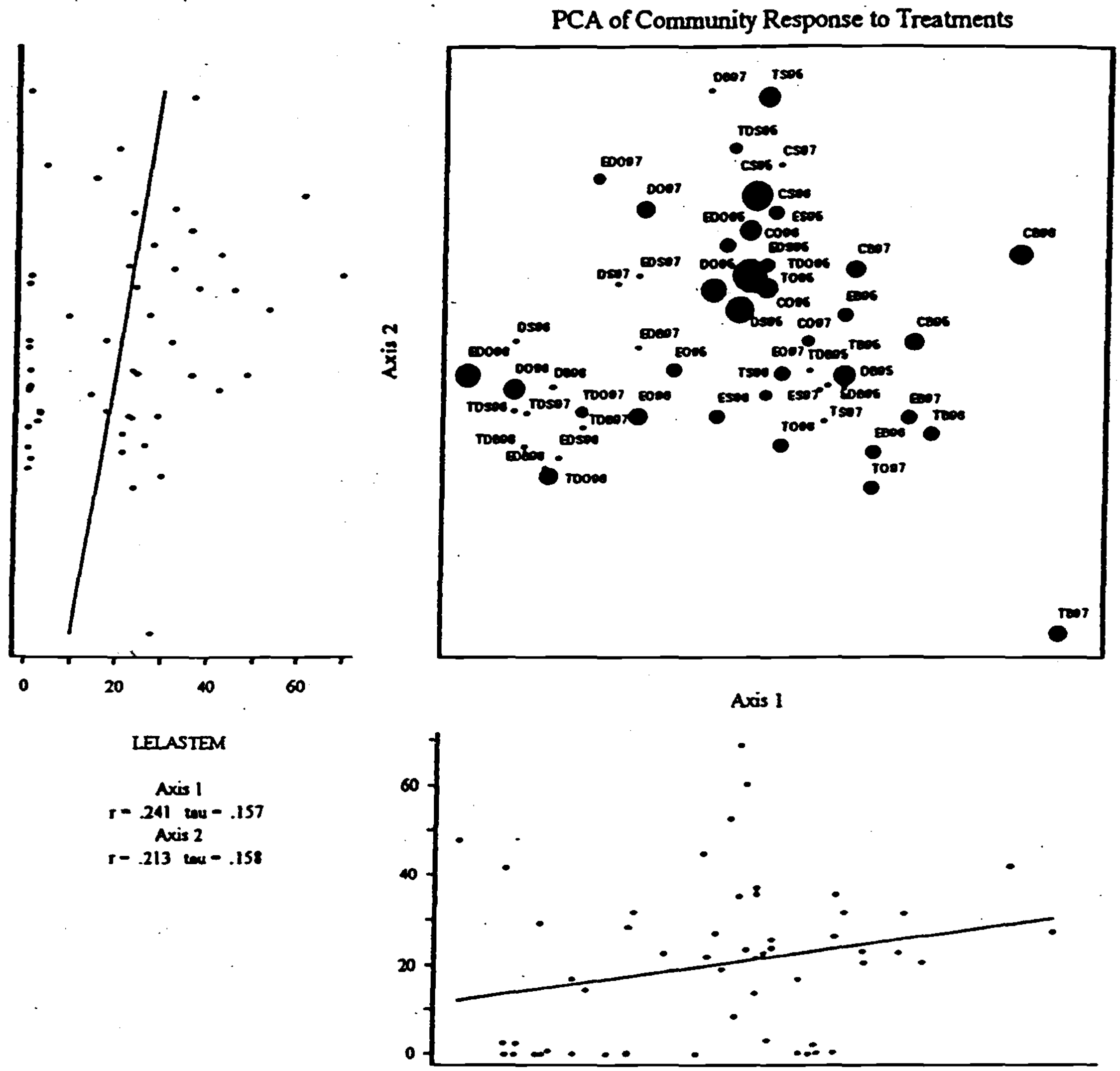

Figure E11. Effects of *Lepidium latifolium* stem densities (LELASTEM) on community response to *Lepidium latifolium* control treatments at Malheur National Wildlife Refuge, Oregon.

APPENDIX F

1995 Cost Comparison of Herbicide Applications at Malheur National Wildlife Refuge

Chemical Costs

chemical	price	unit	application rate	cost/acre	minimum purchase	minimum price	minimum area
Telar herbicide	$28.00	per oz	3 oz/acre	$84.00	8 oz	$224.00	2.67 acres
Escort herbicide	$25.00	per oz	1 oz/acre	$25.00	8 oz	$200.00	8 acres
Sylgard surfactant	$10.00	per pint	2 pints/acre	$20.00	0.5 gal	$40.00	2 acres

Operator and Equipment Costs

application type	applicator costs	price	unit	cost/acre	minimum area	minimum price
Ground Application						
1. truck with boom sprayer	application	$45.00	per hour	$17.93	None	$860.00
2. big rig with 1500 gal tank	application	$5.00	per acre	$5.00	200 acres	$1,000.00
and 55 ft boom	travel	$2.50	per mile			
	lodging/per diem	$65.00	per day			
Aerial Application						
1. Fixed wing	application	$8.00	per acre	$8.00	400 acres	$3,200.00
	travel	N/A				
	per diem	N/A				

1995 Cost Comparison of Herbicide Applications at Malheur National Wildlife Refuge

Estimated Cost per Acre

	Year 1		Year 2		Year 3	
	TELAR	ESCORT	TELAR	ESCORT	TELAR	ESCORT*
Herbicide	$84.00	$25.00	$0.00	$0.00	$0.00	$25.00
Surfactant	$20.00	$20.00	$0.00	$0.00	$0.00	$20.00
Total for Chemicals	$104.00	$45.00	$0.00	$0.00	$0.00	$45.00
Operator/Equipment						
Ground: truck	$17.93	$17.93	$0.00	$0.00	$0.00	$17.93
Ground: big rig	$5.00	$5.00	$0.00	$0.00	$0.00	$5.00
Aerial: fixed wing	$8.00	$8.00	$0.00	$0.00	$0.00	$8.00
MINIMUM PRICE						
Ground (truck) & chemicals	$1,124.00	$1,100.00				$1,100.00

	Three Year Total	
	TELAR	ESCORT
Herbicide	$84.00	$50.00
Surfactant	$20.00	$40.00
Total for Chemicals	$104.00	$90.00
MINIMUM PRICE		
Ground (truck) & chemicals	**$1,124.00**	**$2,200.00**

	Three Year Total	
	TELAR	ESCORT
Ground: truck	$17.93	$35.86
Ground: big rig	$5.00	$10.00
Aerial: fixed wing	$8.00	$16.00

* Expect 60-100% of area to require retreatment on 3rd year of Escort application.

APPENDIX G

Results of Revegetation Treatments

Revegetation was attempted at three sites (BS, OS, SF) where four *Lepidium latifolium* control treatments (untreated, disked, chlorsulfuron, chlorsulfuron then disked) had been tried. Three revegetation treatments (untreated, seeded, transplanted), using three grass species (AGIN, LECI, LETR) plus a mix of those species were applied with the following results:

Pepperweed Treatment	Growth Stage	Untreated		Seeded					Transplanted					*Grand*
		LETR	*Total*	AGIN	LECI	LETR	MIX	*Total*	AGIN	LECI	LETR	MIX	*Total*	*Total*
Untreated	Germinated			5520	3810	3330	2478	*15138*						*15138*
	Emerged	43	*43*	145	119	181	140	*585*	300	300	300	300	*1200*	*1828*
	Established*	1	*1*	1	2	3	3	*9*	20	15	0	9	*44*	*54*
Disked	Germinated			5520	3810	3330	2478	*15138*						*15138*
	Emerged			86	10	95	17	*208*	300	300	300	300	*1200*	*1408*
	Established*			0	0	0	0	*0*	0	0	0	0	*0*	*0*
Chlorsulfuron	Germinated			5520	3810	3330	2478	*15138*						*15138*
	Emerged			80	84	83	111	*358*	300	300	300	300	*1200*	*1558*
	Established*			0	3	1	1	*5*	3	6	0	2	*11*	*16*
Chlorsulfuron then Disked	Germinated			5520	3810	3330	2478	*15138*						*15138*
	Emerged	25	*25*	59	120	96	69	*344*	300	300	300	300	*1200*	*1569*
	Established*	2	*2*	1	5	2	0	*8*	0	3	0	2	*5*	*15*
Total Germinated				**22080**	**15240**	**13320**	**9912**	***60552***						***60552***
Total Emerged		***68***	***68***	**370**	**333**	**455**	**337**	***1495***	**1200**	**1200**	**1200**	**1200**	***4800***	***6363***
Total Established		**3**	**3**	**2**	**10**	**6**	**4**	***22***	**23**	**24**	**0**	**13**	***60***	***85***

* Established indicates that individual plants were still alive in September 1997.

Grass Species used: AGIN = *Agropyron intermedium* LECI = *Leymus cinereus* LETR = *Leymus triticoides*